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Effects of Socio-Economic and Demographic Factors on Meat Consumption Pattern in Iran: A Demand System Approach

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Abstract

Meat as one of the most important resources of protein has a special role in human nutrition. Understanding the meat consumption structure of households is essential for planning and policymaking in this regard. In this research, we studied consumption patterns of meat products including chicken, veal, lamb, and fish for households in Iran (Mashhad city) using demand system estimation. The hypothesis of this study is that chicken is a necessary goods and other types of meat are luxury goods. Given the cross-sectional nature of the data and presence of zero expenditure for some households, we used the censored demand model based on a consistent two-step approach. For this purpose, at first, four Probit models were estimated to determine the factors affecting the probability of purchasing each selected meat product. After that, the probability density function (PDF) and the cumulative distribution function (CDF) were calculated for each selected meat product, and the Almost Ideal Demand System (AIDS) considering PDF and CDF was estimated for all types of meat using a non-linear seemingly unrelated regression. Also, the effect of demographic variables on meat consumption pattern was considered in demand system. The results of expenditure elasticities confirmed the hypothesis. The highest own-price elasticity was related to veal. Based on compensated price elasticities, all types of meat were net substitutes for chicken and chicken was also a net complement for all types of meat. On the other hand, the only substitute for lamb and chicken was veal, but with compensating income effect fish also became a substitute for them. So, in the event of an increase of the price of lamb and chicken, we recommend subsidizing the consumers with low purchasing power in order to increase the diversity of consumption of protein products. This can increase the consumption of fish.

Keywords

Censored demand system, demographic variables, meat, Iran, Probit model.

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Introduction

Although food consumption behavior has changed over time, meat is still an essential meal component for consumers (Grunert, 2006). Animal protein products incorporate numerous amino acids and fats, which needed for body health and growth. Due to increasing population and awareness about health and nutrition, demand for animal protein products such as red meat, fish, and chicken has increased (Al-Shuaibi, 2011). According to the Statistical Center of Iran (2023), total expenditure on all types of meat had the largest share of gross expenditure (21 %) among the food, beverage and tobacco products. Consumption of red meat in Iran, particularly in rural areas and in low-income groups compared to developed countries, is undesirable (Rahimi et al., 2014). The average global per capita consumption of red meat is about 30 to 45 kg (FAO, 2015), while the per capita consumption of red meat in Iran is about 11.1 kg (Iran Ministry of Agriculture Jihad, 2022). In recent years, the sharp rise in the price of red meat in Iran has caused a major part of the vulnerable people of the society to reduce their consumption of this type of meat

and to consume other meat products (including chicken) as a substitute for it (Cheraghi and Gholipoor, 2010); so that, per capita consumption of chicken in Iran is about 33.1 kg, which is almost twice the global average (Iran Ministry of Agriculture Jihad, 2022). Despite this, fish consumption in Iran is also less than the global standard. So that, per capita consumption of fish in Iran is 10 kg, which is less than half of the global average (Sharifi Tehrani and Mahdavi Damghani, 2021). Changes in the pattern of meat consumption, in addition to the effects on the health of people, have a significant effect on other food market and the involved supply chain participants through demand for inputs (Phuong et al., 2014). Hence, investigating meat consumption pattern and consumer behavior in response to changes in price, income, and demographic variables can provide better insights for policymakers.

Household consumption expenditure analysis is one of the most important areas of economic research and the results of the estimation of the demand system can be used to forecast demand and welfare policy analysis (Wang and Bessler, 2003). The meat demand elasticity analysis shows how consumption varies when prices and income for each type of meat change (Bouyssou et al., 2024). Valid estimates of the demand elasticities are essential for public sector policy and strategic intentions at the industry level; for instance, the results of the estimation of demand elasticity can be helpful to prioritize research and development costs, predict future market conditions and evaluate tax proposals (Ulubasoglu et al., 2016). Producer decision makers in the agricultural sector and other sectors of the economy can use information obtained from these elasticities (Hupkova and Bielik, 2010). Studies elsewhere have used system analysis to investigate the demand for meat. In particular, the Almost Ideal Demand System (AIDS) has been applied in studies that targeted on demand elasticity (Zhang et al., 2018).

Lazaridis (2003) investigated meat demand system of Greek households using linear AIDS model. Their results revealed that all types of meat, including poultry, beef, lamb, and pork were normal goods, while beef and poultry were gross complements. Taljaard et al. (2004) estimated linear AIDS model for meat in South Africa. Results showed that beef and mutton were luxury goods and chicken and pork were normal goods. Jabarin (2005) estimated linear censored AIDS model for meat in Jordan and concluded that the demand for mutton and poultry was elastic whereas the demand for beef and fish was inelastic. Falsafian and Ghahramanzadeh (2012) estimated different meat demand systems in Iran and concluded that AIDS model was more consistent with the consumption behavior of Iranian households. Delport et al. (2017) investigated the demand for meat in South Africa using a linear AIDS model and concluded that chicken could be considered a luxury good. Zhang et al. (2018) studied the factors affecting meat demand in China using a linear AIDS model. Results revealed that pork had the largest price elasticity among all types of meat. Widarjono and Mumpuni Ruchba (2021) estimated meat demand system for Indonesian urban household using non-linear AIDS model and concluded that broiler chicken was most elastic to price changes and goat meat was the least elastic to price changes. Additionally, they showed that all types of meat were normal good based on the income elasticities. Also Roosen et al (2022) calculated demand elasticities for meat in Germany based on AIDS model and showed that beef and veal were luxury meat. Also, mixtures were substitutes for all other types of meat.

Due to the unfavorable amount of meat consumption in Iran, especially red meat and fish, the study of factors affecting the pattern of meat consumption, which was the main subject of the present study, could be useful in decision making and planning to improve the nutritional status of households. A review of previous studies showed that in the most of them researchers have applied a linear price index to estimate the demand system. Furthermore, in the literature on meat demand system fewer studies have considered the zero expenditure. Most of these studies have not documented the impacts of demographic factors. So, in this study, we used Translog price index which was nonlinear and provided consistent parameter estimation. Also, we accommodated observed zero expenditure values to obtain consistent parameter and elasticity estimates by using censoring approach. Another novelty of this research was that we considered the impact of demographic variables on meat consumption pattern. So the research questions of this study are: (1) what are the effects of socio-economic variables on consumer demand for various types of meat in Mashhad? (2) what are the substitution relationships between various types of meat in Mashhad? (3) how much is the expenditure elasticitiy of demand for various types of meat in Mashhad?

Materials and methods

Non-linear Almost Ideal Demand System

The AIDS model is commonly utilized in studies of household demand. A few benefits of this model include: it is obtained from a particular cost function; thus, it corresponds with the explicit preference structure, it provides a first-order approximation to each arbitrary demand system, it satisfies the principles of choice, it aggregates across individuals while the Engel curve can remain non-linear and it is consistent with recognized household expenditure data (Sulgham et al., 2006; Aung, 2022). The AIDS model proposed by Deaton and Muellbauer (1980) for a set of n goods can be shown as Equation 1:

$$w_i = \alpha_i + \sum_{j=1}^{n} \gamma_{ij} \ln p_j + \beta_i \ln(\frac{x}{P_t}). \quad (1)$$

Where w_i indicates the expenditure share of good i for each household. p_j are the prices of goods j and x is per capita expenditure on all goods included in the system (Gustavsen and Rickertsen, 2014). Also α_i, γ_{ij} and β_i are parameters to be estimated. P_t denotes the Translog price index, which is described by Equation 2 (Delport et al., 2017):

$$\ln P_t = \alpha_0 + \sum_{j=1}^{n} \alpha_j \ln p_j + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} \ln p_i \ln p_j \quad (2)$$

Due to the non-linearity of this index and the difficulty in the estimation of non-linear demand system, in most empirical studies, a linear version of the AIDS model has been applied by replacing Stone price index. However, using Stone price index in demand system leads to hard econometric and theoretical problems (Henningsen, 2017). One of these problems is the measurement error. The use of Stone price index leads to inconsistent parameter estimation (Mizobuchi and Tanizaki, 2014). Another problem is theoretical inconsistency; the symmetry restriction in AIDS model is violated if all prices are not identical (Henningsen, 2017). By inserting the Stone price index in AIDS model, the expenditure share appears on both sides of the share equation. Consequently, the correlation between the explanatory variable $\ln(\frac{x}{P_t})$ and the error term leads to a simultaneity bias (Henningsen, 2017). Thus, researchers have proposed various approaches to deal with these problems. However, the inconsistency of using Stone price index has not been completely resolved. In order to avoid these inconsistencies, in this research, we estimated the non-linear AIDS model using the Translog price index.

Demographic variables

Demographic changes of households lead to change consumption patterns of goods (Mejia and Peel, 2012). So, it is essential to consider demographic variables in demand system to estimate correct expenditure and price elasticities. If we do not consider these effects, in fact, we have assumed that households have the same demographic composition which is not true. Therefore, we have to estimate the effects of changes in price and income on demand separately for each household type. It is not possible due to scarcity of data. Also, when there is some relationship across household types, not pooling the data leads to inefficient estimates (Blow, 2003). According to Golan et al. (2001) and Dong et al. (2004), demographic variables change the intercept term in demand system. In this study, demographic variables were incorporated into demand system by Translating approach (Senia and Dharmasena, 2017):

$$\alpha_i = \rho_{i0} + \sum_{k=1}^{m} \rho_{ik} Z_k; \; k = 1, ..., m \quad (3)$$

Where, ρ_{i0} and ρ_{ik} are the parameters which should be estimated and Z_k represents the demographic factors.

Some researchers considered *household size* and *age* and *education of the household head* as demographic variables in the meat demand analysis (Phuong et al., 2014; Caro et al., 2017; Zhang et al., 2018). Moreover, *sex of the household head* (Lazaridis, 2003; Caro et al., 2017; Zhang et al., 2018), *residential location of the household* (Dhraief et al., 2012), *having kids in the household* (Caro et al., 2017; Zhang et al., 2018) and *per capita income* (Phuong et al., 2014; Zhang et al., 2018) can affect the meat consumption pattern.

In this study, we considered demographic factors such as *household size, education, age* and *sex of the household head, having kids, residential location of the household* (urban or rural) and *total expenditure on meat in household* (as a proxy of household income) in the meat demand system. We utilized these variables in two different stages of household demand analysis. First, we used *household size, education, age* and *sex of the household head* and *total expenditure on meat* in the Probit models as factors affecting the probability of purchasing each type of meat. Then, we applied *education of the household head, having kids* and *residential location of the household* along with the price variables to demand system as factors affecting each expenditure share equation.

Correction for zero expenditure

Data collected from Household Income Expenditure Survey (HIES) can consist of zero consumption for some households. The reasons for this would be the lack of accessibility of goods, lack of consumer preferences, non-affordability and low consumption (Caro et al., 2017). Using this type of data without considering censoring of the dependent variables leads to inconsistent estimation (Mhurchu et al., 2013). There are several techniques for considering censoring in a system of equations. One of the most common techniques is a two-step procedure developed by Heien and Wessels (1990) which named HW approach. The process involves estimating the Probit model to determine purchasing behavior of consumers, calculating the inverse Mills ratio (ratio of the PDF to the CDF) and its application to demand system as an added explanatory variable (Alviola et al., 2010). Shonkwiler and Yen (1999) noted that HW estimator was inherently missing the specified conditional mean function and could not be interpreted with respect of the conditional mean. Also, it has a poor performance in the Monte Carlo simulation (Tauchmann, 2010). They suggested an alternative unbiased two-step approach to deal with this problem (Coelho et al., 2010). On the basis of this approach, first, a Probit model is estimated to specify the probability that a household would purchase the related goods, and applied this model to derive the cumulative distribution function (Φ) and probability density function (ϕ) for any households. Then, these functions are used in the next step as instruments that correct for zero expenditure values in estimating demand system. The new expenditure shares after applying the information derived from the Probit model is presented as Equation 4 (Caro et al., 2017):

$$w_i^* = \hat{\Phi}_i(Z_i'\Psi_i)w_i + \delta_i\hat{\phi}_i(Z_i'\Psi_i) \quad (4)$$

Where, w_i^* shows the new expenditure share of good i for each household and w_i is the previous expenditure share as defined in the Equation 1. Also, $\Phi(Z_i'\Psi_i)$ is cumulative density function, $\hat{\phi}_i(Z_i'\Psi_i)$ is probability density function for each household and is parameter to be estimated. By inserting Equations 3 and 4 into Equation 1 and adding a stochastic disturbance term, we could obtain the censored AIDS model with demographic variables in the form of Equation 5 (Gustavsen and Rickertsen, 2014):

$$\begin{aligned} w_i &= \rho_{i0}\Phi(Z_i'\Psi_i) + \sum_{j=1}^{n}\gamma_{ij}\Phi(Z_i'\Psi_i)\ln p_j + \\ &+ \beta_i\Phi(Z_i'\Psi_i)\ln(\frac{x}{P_t}) + \sum_{k=1}^{m}\rho_{ik}\Phi(Z_i'\Psi_i)Z_k + \\ &+ \delta_i\hat{\phi}_i(Z_i'\Psi_i) + \varepsilon_i \end{aligned} \quad (5)$$

Where, w_i, p_i and x are defined in Equation 1; ρ_{i0} and $\sum_{k=1}^{m}\rho_{ik}Z_k$ are specified in Equation 3 and ε_i is disturbance term. The restrictions related to the demand theory that need to be imposed on Equation 5 include adding up, homogeneity and symmetry. These restrictions are imposed on the system as follows (Zheng and Henneberry, 2010; Gustavsen and Rickertsen, 2014):

$$\sum_{i}^{n}\rho_{i0} = 1,\ \sum_{k=1}^{m}\rho_{ik} = 0,\ \sum_{j=1}^{n}\gamma_{ij} = 0,\ \sum_{i}^{n}\beta_i = 0,$$
$$\sum_{i}^{n}\delta_i = 0. \quad (6)$$

$$\sum_{j}^{n}\gamma_{ij} = 0 \ \textit{for any } j. \quad (7)$$

$$\gamma_{ij} = \gamma_{ji} \ \ \textit{for any } i \textit{ and } j. \quad (8)$$

Omitting one of the n equations from the system provides these situations. Moreover, homogeneity and adding up restrictions can recover the parameters of the eliminated equation (Maganga et al., 2014). It should be noted that the meat demand system in this study was estimated in STATA software version 15.1 by using command NLSUR and selecting Iterated Feasible Generalized Non-linear Least Squares (IFGNLS) Approach[1].

Elasticities

We can calculated the expenditure elasticity (η_i), uncompensated own-price elasticity (e^u_{ii}) and uncompensated cross-price elasticity (e^u_{ij}) as Equations 9 to 11 (Golan et al., 2001; Maganga et al., 2014):

$$\eta_i = \Phi(Z_i'\Psi_i).\frac{\beta_i}{w_i} + 1 \quad (9)$$

$$e^u_{ii} = -1 + w_i^{-1}\left[\Phi(Z_i'\Psi_i)\left(\gamma_{ii} - \beta_i\left(\alpha_i + \gamma_{ii}\ln p_i\right)\right)\right] \quad (10)$$

$$e^u_{ij} = w_i^{-1}\left[\Phi(Z_i'\Psi_i)\left(\gamma_{ij} - \beta_i(\alpha_j + \sum_{j}^{n}\gamma_{ij}\ln p_i)\right)\right] \quad (11)$$

Where γ_{ii}, γ_{ij}, α_i, α_j and β_i are parameters.

[1] For more information about this method, refer to Poi (2008).

Additionally, we can compute compensated own-price elasticity (e^c_{ii}) and compensated cross-price elasticity (e^c_{ij}) as equations 12 and 13 (Jonas and Roosen, 2008):

$$e^c_{ii} = e^u_{ii} + \eta_i w_i \quad (12)$$

$$e^c_{ij} = e^u_{ij} + \eta_i w_j \quad (13)$$

Data

Mashhad is the second largest Iranian metropolis in Khorasan Razavi province with a population of 3 027 692 people (Statistics of Mashhad city, 2015). During the period of 2011-2015, Khorasan Razavi province had the largest share of the red meat production (6.22 %) after Fars province and East Azerbaijan province. Moreover, it had the largest share of chicken production (6 %) after Mazandaran province and Isfahan province (Majlis, 2016). This study was based on primary data came from Iran's Household Income Expenditure Survey in 2020. The HIES is a nationally representative household survey accomplished by Statistical Center of Iran (SCI) annually to provide information on income and expenditure for urban and rural households at regional and country level (Statistical Center of Iran, 2023). We extracted and used data for Mashhad city from this primary data which included information on 445 rural and urban households.

Results and discussion

Among all types of meat, lamb had the highest price with an average price of 9.16 USD per kg. Also, chicken had the lowest price with an average price of 2.08 USD per kg. Each household, on average, has consumed 4.85 kg chicken, 0.9 kg veal, 1.60 kg lamb and 0.74 kg fish per month. Chicken had the largest expenditure share of total expenditure on meat (40 %) and fish had the lowest expenditure share (7 %). About demographic variables, on average, 87 % of household heads were male and 86 % of households lived in urban areas. On average, 65 % of households had kids under the age of 16. The education of the household head was based on the number of grades (from 1 - elementary to 8 - graduates or higher). On average, 3.37 people lived in each household (Table 1).

Variable	Description	Mean	S.D.	Min	Max
p_1	Price of chicken (USD per kg)	2.08	0.01	1.76	2.83
p_2	Price of veal (USD per kg)	8.02	0.04	5	12
p_3	Price of lamb (USD per kg)	9.16	0.04	6	12
p_4	Price of fish (USD per kg)	4.57	0.02	2.33	6.66
q_1	Chicken consumption (kg per month)	4.85	0.14	0	16
q2	Veal consumption (kg per month)	0.90	0.07	0	11
q_3	Lamb consumption (kg per month)	1.60	0.08	0	12
q_4	Fish consumption (kg per month)	0.74	0.06	0	7
w_1	Chicken expenditure share	0.40	0.01	0	1
w_2	Veal expenditure share	0.18	0.01	0	1
w_3	Lamb expenditure share	0.35	0.01	0	1
w_4	Fish expenditure share	0.07	0.01	0	1
size	Household size (person)	3.37	0.06	1	8
sex	Sex of the household head (male=1; 0 otherwise)	0.87	0.01	0	1
res	Residence (urban=1; 0 otherwise)	0.86	0.02	0	1
kids	Kids under the age of 16 (have=1; 0 otherwise)	0.65	0.02	0	1
edu	Education of the household head (grade)	3.23	0.09	1	8
age	Age of the household head (year)	48.95	0.68	18	86
w	Total expenditure on meat (USD per month)	35.18	1.19	3.17	157.77
m	Per capita expenditure on meat (USD per month)	11.79	0.44	0.95	66.92

Source: Author's calculation

Table 1: Variables descriptive statistics for values in the sample.

Household size had a positive and significant effect on the probability of purchasing veal, and chicken. It means that increasing household size leads to increase in the probability of purchasing veal, and chicken. On the contrary, size had a negative and significant effect on the probability of purchasing lamb and fish (Table 2). The education of the household head had a positive effect on the probability of purchasing lamb, veal and fish and had a negative and significant effect on the probability of purchasing chicken. Therefore, an increase in education of the household head could influence his or her awareness of the nutritional value of red meat and fish.

Sex of the household head affected the probability of purchasing distinct types of meat. When the household head was male, the probability of purchasing veal was reduced and the probability of purchasing other types of meat was increased. Total expenditure on meat (Log transformed - lnw) had a positive and significant effect on the probability of purchasing all types of meat (Table 2). Therefore, it could be concluded that an increase in household income led to increase the probability of purchasing all types of meat. The age of the household head had a negative effect on the probability of purchasing fish and chicken and had a positive effect on the probability of purchasing veal and lamb. So, the higher was the age of the household head, the lower was the probability of purchasing fish and chicken and the higher was the probability of purchasing veal and lamb. Percentage of corrected classified and R2 indicated the goodness of fit of the models (Table 2).

After estimating Probit models, we obtained the cumulative distribution function (Φ) and probability density function (ϕ). We used the cumulative distribution function (Φ) to multiply the covariates, and probability density function (ϕ) as an independent variable in demand system.

In the second step, we estimated the AIDS model using non-linear seemingly unrelated regression (NLSUR) considering the adding up, homogeneity and symmetry restrictions. Dropping fish equation provided adding up restriction. So, we estimated the three remaining equations by Iterated Feasible Generalized Non-linear Least Squares (IFGNLS) approach. The results were presented in Table 3.

The coefficient estimates of the variable (ϕ) were significant for lamb, fish and chicken equations. Consequently, ignoring censoring led to biased parameter estimates. This revealed the importance of censoring data and using the two-step approach. As shown in Table 3, the residential location of the household had a positive effect on the expenditure share of lamb and fish and had a negative effect on the expenditure share of veal and chicken. When the household lived in urban area, the expenditure share of lamb and fish was increased and the expenditure share of veal and chicken was reduced.

However, only the effect of it on the expenditure share of lamb was significant. So, we can conclude that urban households tended to eat more lamb. The urban households paid more attention to nutrition value of meat whereas rural households tended to consume cheaper meat. These results corroborated the findings of Yıldırım and Ceylan (2008) for chicken and lamb and Sacli and Ozer (2017) for veal and lamb. Having kids in the household under the age of 16 had a positive effect on the expenditure share of lamb and veal

Variable	Veal		Lamb		Chicken		Fish	
	Coefficient	ME¶	Coefficient	ME¶	Coefficient	ME¶	Coefficient	ME¶
const†	-9.81[a]	-	-16.77[a]	-	-1.67	-	-11.33[a]	-
lnedu¤	0.07	0.03	0.14	0.05	-0.17	-0.04	0.56[a]	0.19[a]
lnsize¶	1.14[a]	0.45[a]	-1.08[a]	-0.36[a]	0.67[a]	0.17[a]	-0.38[b]	-0.13[b]
lnage§	0.18	0.07	0.33	0.11	-0.30	-0.08	-0.25	-0.08
sex	-0.45[c]	-0.18[b]	0.16	0.05	0.26	0.07	0.04	0.01
lnw††	0.71[a]	0.28[a]	1.50[a]	0.50[a]	0.26[a]	0.07[a]	1.02[a]	0.34[a]
R^2	0.33		0.56		0.17		0.38	
PCC¤¤	72.58		85.62		80.22		75.28	

Note: [a,b,c] mean error probabilities of $p \leq 0.01$, $p \leq 0.05$ and $p \leq 0.10$, respectively; †const = constant, ¤lnedu = Log transformed edu , ¶lnsize = Log transformed size, §lnage = Log transformed age, ††lnw = Log transformed w, ¤¤PCC = Percentage of Corrected Classified and ¶¶ME = Marginal effects.
Source: Author's calculation

Table 2: Parameter estimates of the Probit model.

Variable	Veal		Lamb		Chicken		Fish	
	Coefficient	S.D.	Coefficient	S.D.	Coefficient	S.D.	Coefficient	S.D.
const† $\hat{\Phi}_i(Z_i'\Psi_i)$	0.60[a]	0.18	0.91[a]	0.19	-1.06[a]	0.18	0.549[a]	0.16
lnp1▫ $\hat{\Phi}_i(Z_i'\Psi_i)$	0.17[c]	0.10	-0.21[a]	0.07	0.18	0.13	-0.143	0.09
lnp2¶ $\hat{\Phi}_i(Z_i'\Psi_i)$	-0.45[a]	0.14	0.13	0.09	0.17[c]	0.10	0.15[b]	0.08
lnp3§ $\hat{\Phi}_i(Z_i'\Psi_i)$	0.13	0.09	0.01[a]	0.01	-0.21[a]	0.07	0.07	0.07
lnp4†† $\hat{\Phi}_i(Z_i'\Psi_i)$	0.15[b]	0.08	0.07	0.07	-0.14	0.09	-0.08	-
lnedu▫▫ $\hat{\Phi}_i(Z_i'\Psi_i)$	0.04	0.03	-0.01	0.02	-0.10[a]	0.02	0.07[a]	0.02
res $\hat{\Phi}_i(Z_i'\Psi_i)$	-0.07	0.05	0.09[b]	0.04	-0.03	0.03	0.02	0.03
kids $\hat{\Phi}_i(Z_i'\Psi_i)$	0.03	0.04	0.06[b]	0.03	-0.01	0.03	-0.07[a]	0.02
lnm¶¶ $\hat{\Phi}_i(Z_i'\Psi_i)$	0.01	0.03	0.15[a]	0.03	-0.25[a]	0.02	0.10[a]	0.03
φ§§	0.05	0.05	0.35[a]	0.08	1.16[a]	0.06	-1.56[a]	0.09
R^2	0.39		0.73		0.76		-	
Observations	445		445		445		445	

Note: [a,b,c] mean error probabilities of $p \leq 0.01$, $p \leq 0.05$ and $p \leq 0.10$, respectively; †const = constant, ▫lnp1 = Log transformed p1, ¶lnp2 = Log transformed p2, §lnp3 = Log transformed p3, ††lnp4 = Log transformed p4, ▫▫lnedu = Log transformed edu, ¶¶lnm = Log transformed m and = probability density function. †††Fish equation parameters were derived from the adding up, homogeneity, and symmetry conditions.

Source: Author's calculation

Table 3: Parameter estimates of the Almost Ideal Demand System (AIDS) model.

and had a negative effect on the expenditure share of fish and chicken. However, only the effect of it on the expenditure share of lamb and fish was significant. Therefore, households with kids under the age of 16, tended to consume more lamb and less fish. These results were consistent with Ezedinma et al. (2006) finding for veal, chicken and fish and Zhang et al. (2018) finding for veal, chicken and lamb. Red meat is an essential source of iron which is highly bioavailable. So, it is a core food in the young child's diet (Wyness, 2016). This is one of the reasons that households with kids under the age of 16 consume more veal and lamb. The education of the household head had a positive effect on the expenditure share of fish and veal and had a negative effect on the expenditure share of chicken and lamb. Although only the effect of it on the expenditure share of chicken and fish was significant. It appears that higher education of the household head leads to increase the consumption of fish and veal and reduces the consumption of chicken and lamb; these findings were in line with the results of the studies by Lazaridis (2003) and Zhang et al. (2018) for veal and chicken. Normally, consumers with high educational level are more concerned about health than others with low educational level. The positive effect of education of household head on fish expenditure share confirmed this reality.

Uncompensated and compensated own-price elasticity and cross-price elasticity along with the expenditure elasticity were reported in Table 4. We calculated these elasticities at the means of the independent variables based on estimated parameters of the AIDS model. As the results showed, the expenditure elasticity of chicken was less than one while the expenditure elasticities of lamb, veal, and fish were greater than one. So, for 1 % increase in the total expenditure on meat, the demand for veal, lamb, fish, and chicken would increase by 1.01, 1.27, 2.40 and 0.50 percent, respectively. Consequently, chicken was a normal good and veal, lamb and fish were luxury goods. So, the demand for luxury goods is highly sensitive to income changes. Among these luxury goods, fish had the highest expenditure elasticity. So, we found that consumers decided to spend the extra budget on fish than other types of meat, by increasing their income. Also, the quantity demanded of chicken (4.85 kg per month) was higher than the total demand of other meat products (3.24 kg per month) (Table 1). So, despite the fact that the expenditure on chicken increases at a lower rate with increasing income compared with the increasing rates of other types of meat, the absolute quantity of chicken demand will increase at more rapid rate compared with the quantity demanded of other types of meat. Hence, if consumer expenditure on meat increased by 10 %, the monthly average household consumption of chicken, veal, lamb and fish would be increased by 0.24 kg (4.85 × 5 %), 0.09 kg

(0.9 × 10.01 %), 0.2 kg (1.6 × 12.7 %) and 0.17 kg (0.74 × 24 %). Most veal and lamb estimated by low income region were identified as luxury goods; as income increases, the quantity demanded also increases, but at more rapid rate than the normal goods. For instance, we can mention the findings of studies conducted by Taljaard et al. (2004), Ezedinma et al. (2006), Falsafian and Ghahramanzadeh (2012) for Southern Africa, Nigeria and Iran. In contrast, in high income region veal and lamb were normal goods. In this context, we could refer to the results of the studies accomplished by Tonsor et al. (2010) and Okrent and Alston (2012) for the United States, Sheng et al. (2010) for Malaysia, Cranfield (2012) for Canada and Basarir (2013) for UAE. Also fish was a luxury good in Mashhad, this finding is consistent with the results of a previous studies by Agbola et al. (2002), Osho and Uwakonye (2003) and Falsafian and Ghahramanzadeh (2012) for Southern Africa, Nigeria and Iran. Whereas the results of the other research studies showed that fish was a normal good including Tonsor et al. (2010) and Okrent, Alston (2012) for the United States, Basarir (2013) for UAE and Nakakeeto and Chidmi (2016) for Texas.

The quantity consumed for normal goods will increase with income, but at a slower rate than the luxury goods. For the reason that, by increasing income, consumers are likely to use their increased income to purchase more luxury goods rather than buying more normal goods. Chicken was a normal good, this result is logical due to the fact that chicken was a net complement for all types of meat (Table 4) and it is an important source of protein in Iranian diet. The results of the most studies in low income and high income region have shown that chicken was a normal good including Taljaard et al. (2004), Sheng et al. (2010), Falsafian and Ghahramanzadeh (2012), Okrent and Alston (2012), Cranfield (2012), and Basarir (2013).

Each compensated and uncompensated own-price elasticity had proper negative sign. However, compensated and uncompensated own-price elasticities were only meaningful for veal and lamb. Veal had the largest uncompensated own-price elasticity (-2.19) which indicated that the demand for veal was very sensitive to price changes. Also, chicken had the lowest own-price elasticity (-0.37) which showed that it was a necessary good for households. The results

	Veal	Lamb	Chicken	Fish¤
Uncompensated price elasticities				
Veal	-2.19[a] (0.48)[†]	0.32 (0.42)	0.45 (0.43)	0.37[c] (0.2)
Lamb	0.05 (0.17)	-1.25[a] (0.1)	-0.13 (0.1)	0.01 (0.14)
Chicken	-0.1 (0.75)	-0.73[a] (0.09)	-0.37 (0.9)	-0.81 (0.71)
Fish¤	0.07 (0.39)	-0.43 (0.43)	-0.55 (0.39)	-1.27
Compensated price elasticities				
Veal	-2.02[a] (0.48)	0.67 (0.42)	0.84[b] (0.43)	0.44[b] (0.201)
Lamb	0.28 (0.17)	-0.78[a] (0.1)	0.38[a] (0.1)	0.1 (0.14)
Chicken	-0.01 (0.75)	-0.55[a] (0.09)	-0.16 (0.9)	-0.77 (0.71)
Fish¤	0.49 (0.39)	0.42 (0.43)	0.4 (0.39)	-1.09
Expenditure elasticities				
Expenditure	1.01[a] (0.08)	1.27[a] (0.06)	0.50[a] (0.03)	2.40[a] (0.28)

Note: [a,b,c] mean error probabilities of $p \leq 0.01$, $p \leq 0.05$ and $p \leq 0.10$, respectively; [†]Numbers in parentheses are standard errors. [¤]Fish elasticities were derived from the adding up, homogeneity, and symmetry conditions of demand parameters.
Source: Author's calculation

Table 4: Uncompensated and compensated price elasticities, and expenditure elasticities of Almost Ideal Demand System (AIDS) model.

of the own price elasticities were similar to those reported by Jabarin (2005) and Taljaard et al. (2004) for chicken, veal and lamb, Ezedinma et al. (2006) for veal, lamb and fish, Basarir (2013) for chicken and lamb and Zhang et al. (2018) for veal and lamb. Based on uncompensated elasticities, when the price of veal rose, the demand for lamb and fish increased and the demand for chicken decreased. Therefore, lamb and fish were substitutes for veal, while chicken was a complement. As well as, Falsafian and Ghahramanzadeh (2012) and Dhraief et al. (2012) found that lamb was a substitute for veal, Ezedinma et al. (2006) showed that chicken was a complement for veal and Dhraief et al. (2012) and Basarir (2013) showed that fish was a substitute for veal. As lamb price rose, the demand for veal increased and the demand for other types of meat decreased. So, veal was a substitute for lamb and other types of meat were complements. Similar results to those reported by Falsafian and Ghahramanzadeh (2012). Basarir (2013) concluded that fish was a complement for lamb, Ezedinma et al. (2006) showed that chicken and fish were complements for lamb. Also, veal was a substitute for chicken while other types of meat were complements for chicken. This result was consistent with previous studies; Basarir (2013) found that fish was a complement for chicken, Falsafian and Ghahramanzadeh (2012) showed that lamb was a complement for chicken, Ezedinma (2006) showed that lamb and fish were complements for chicken. Falsafian and Ghahramanzadeh (2012) and Dhraief et al. (2012) concluded that veal was a substitute for chicken. Based on results of this study veal and lamb were substitutes for fish while chicken was a complement for fish. This is similar to the result of the earlier research; Falsafian and Ghahramanzadeh (2012) and Basarir (2013) pointed out that lamb was a substitute for fish. Also, Dhraief et al. (2012) showed that veal and lamb were substitutes for fish.

We can determine substitution and complementary relationships between all types of meat; since the income effect was not present in uncompensated cross-price elasticities. Based on uncompensated cross-price elasticities, veal, lamb and fish were net substitutes for chicken. Veal and fish were net substitutes for lamb and chicken was a net complement for lamb. On the other hand, lamb and fish were net substitutes for veal while chicken was a net complement for veal. Also, veal and lamb were net substitutes for fish while chicken was a net complement for fish.

Thus, we can notice that by compensating the income effect, with the increase in chicken price, households increased the consumption of lamb and fish. Also, with the increase in lamb price, they increased the consumption of veal and fish. Since chicken was a net complement for other types of meat (based on compensated and uncompensated cross-price elasticities), it was a necessary good in consumer basket of the households.

Conclusion

In order to deal with zero expenditure values, we proposed the censored demand system for the market of meat in Mashhad. Also, we calculated the expenditure and price elasticities based on estimated parameters of the AIDS model. The expenditure elasticities suggested that the absolute quantity of chicken demand would increase at a lower rate with meat expenditure increased compared with the quantity of any other types of meat. The implication was that chicken was a normal good while veal, lamb and fish were luxury goods for consumers in this city. Based on the results of the expenditure elasticities and comparing them with previous studies, we concluded that in most of the low income regions, veal, lamb and fish were luxury goods. However, in most of the high income regions, they were normal goods. The results highlighted that the only substitute for lamb and chicken was veal (based on uncompensated cross-price elasticity), while with compensating income effect (based on compensated cross-price elasticity) fish became a substitute for them too. Thus, we concluded that income policies could affect the meat consumption pattern in this region. The low consumption of fish and low expenditure share on this good (7 %) and the high nutritional value of this type of meat, we recommend to subsidize consumers with low purchasing power to increase the diversity of consumption of protein products, in the event of an increase in the price of lamb and chicken; this can increase the consumption of fish somewhat.

Regarding the fact that demographic variables have significant effect on meat consumption pattern in this city, policymakers and planners can identify the tastes and consumption pattern of urban and rural households based on the demographic composition of the households. They can use this information in decision-making and designing marketing strategies for meat products.

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Impact of Agricultural Ontologies Evolution on the Alignment Preservative Adaptation

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Abstract

Ontology matching techniques are a solution to surmount the problem of interoperability on the fly between ontologies. However, both alignments and ontologies are likely to be evolved throughout their life cycle, which frequently degrades their qualities. One of the main features of an alignment is its conservativity, so that it should never generate new knowledge compared to those generated by reasoning solely on ontologies. We focus in this paper on the issue of adapting the fresh alignment between evolved OWL-2 ontologies while respecting the conservativity principle. We also propose several patterns to deal with the problem of detection and repair of conservativity breaches during such evolution depending on the type of change in the related OWL-2 ontologies. We use famous ontologies from the field of agriculture to validate our experimentation. At the end we present a set of open research issues.

Keywords

Agricultural ontologies, matching adaptation, breaches identifying, breaches remedying, OWL-2 ontologies evolution, ontology matching, semantic web.

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Introduction

Several web applications seen in the last few years are essentially based on the Ontology Alignment task (Euzenat and Shvaiko, 2013). As not exhaustively, we can cite: Semantic web, communication in MAS (Multi-Agent System), data warehouse, integrating schema/ontologies, etc. Ontology is defined as the conceptualization of objects recognized as existing in a domain, with their properties and linking relationships. The problem is that given the same domain or related domains, it is possible that several ontologies are available (developed simultaneously by several different communities). The comparison of two ontologies, passing the one to the other or integrating them becomes therefore necessary. This necessity does not make alignment perfect and faultless, since mappings can lead to many undesirable logical consequences in the aligned ontologies and therefore the domain covered by these ontologies. Alignment conservativity is one of three principles proposed in [Jiménez-Ruiz, 2011) to minimize the number of potentially unintended consequences. It intend to avoid introducing new semantic relationships between concepts from one of the input ontologies. Thereby, the alignment must allows interaction between ontologies, rather than providing a new description of the domain. Moreover, even if the alignment conservativity is well cared for during the calculation phase, or as a revision task just before its deployment, alignments such as ontologies are likely to be evolved throughout their life cycle (Stojanovic, 2004), and this evolution frequently degrades their qualities. As a result, alignments must be evolved and maintained in order to keep up with the change in ontology or to meet the demands of applications and users. In this work, we focus on the adaptation of the fresh alignment between evolved OWL-2 ontologies while respecting the conservativity principle, and make the following contributions:

- We formally define and illustrate the conservativity principle problem, highlighting the complexity of the problem. In addition, to present our problematic, we propose a concrete example of a non-conservative alignment evolution following the evolution of one of its input ontologies.
- We systematically review the literature on two main topics for our problematic which

are: the Conservativity Principle problem and Ontologies Alignment Evolution, offering a brief state-of-the-art by presenting and discussing the existing approaches.

- We propose a set of patterns, to adapt the fresh alignment (according to a conservative evolution) depending on the type of change applied to one of the input OWL-2 ontologies.
- Experimentation
- Discussion and open issues.

We structure the remainder of this paper as follows: Section 2 summarizes the basics concepts and definitions we will rely on along the paper. In Section 3, we introduce the Conservative Alignment Evolution which constitutes the background of our framework. Section 4 presents the (24*2) proposed patterns concerning the detection and repair process, following the source of the change. Section 5 discusses our findings. Section 6 is an examination of the conservativity principle problem studied in other related works. Finally, Section 7 examines challenges of different nature, representing open research issues and wraps up with concluding remarks and outlines future works.

Materials and methods

Preliminaries and notations. An ontology seen as logical theory is a pair (S, A), where S is a signature to designate a vocabulary and A is a set of axioms to specify the intended interpretation of this vocabulary in a domain of discourse. The signature of an ontology is the set $S = C \cup P \cup R \cup In$, where, C represents the set of vocabulary to designate concepts, P is the set of vocabulary to designate objects properties, R is the set of vocabulary to designate data properties and In is the set of vocabulary to designate individuals. We distinguish between the origins axioms A and their logical consequences A^* (also called closure). Theory (S, A) is called the presentation of (S, A^*). In this work, we take into account all parts of S, such as: $S = C \cup P \cup R \cup In$ and we designate by ontological entity: a concept, a property or an individual.

Axioms act as constraints for interpretations of this vocabulary. An interpretation which satisfies all axioms of an ontology constitutes a model of that ontology.

Definition 1 (Ontology Model). An interpretation I is a model of an ontology O if and only if I satisfies every axiom δ in that ontology ($\forall \delta \in O, I \vDash \delta$).

Ontologies are expressed in logical languages such as RDF[1], RDFS[2] and OWL[3]. These languages provide a consequence relation between axioms of the language and ontologies. The W3C[4] proposes a finite set of OWL-2 axiom, subdivided into three subsets, to represent the different situations of expressivity that an ontology OWL2 can be found opposite, concretely :

- Class Expression Axioms: {SubClassOf, EquivalentClasses, DisjointClasses, DisjointUnion}.
- Object Property Axioms: {SubObjectPropertyOf, EquivalentObjectProperties, DisjointObjectProperties, InverseObjectProperties, ObjectPropertyDomain/Range, FunctionalObjectProperty, InverseFunctionalObjectProperty, Reflexive/IrreflexiveObjectProperty, Symmetric/AsymmetricObjectProperty, TransitiveObjectProperty}.
- Data Property Axioms: {SubDataPropertyOf, EquivalentDataProperties, DisjointDataProperties, DataPropertyDomain/Range, FunctionalDataProperty}.

Ontology alignment is the task to detect links between elements from two ontologies. These links are referred as correspondences and express semantic relations. According to Euzenat and Shvaiko (2013) we define a correspondence as follows and introduce an alignment as set of correspondences.

Definition 2 (Correspondence and Alignment). Given two ontologies O_1 and O_2, let Q a function that defines sets of matchable elements $Q(O_1)$ and $Q(O_2)$. A correspondence between O_1 and O_2 is a 5-tuple (id, e_1, e_2, r, n) such that, id a unique identifier, $e_1 \in Q(O_1)$, $e_2 \in Q(O_2)$, r is a semantic relation, and $n \in [0; 1]$ is a confidence value. An alignment M between O_1 and O_2 is a set of correspondences between O_1 and O_2. We restrict r to be one of the semantic relations from the set $\{\sqsubseteq, \sqsupseteq, \equiv, \perp\}$.

The literature does not contain a standard for alignment semantics. Borgida and Serafini (2003) propose a distributed description logics semantics. The called reductionist semantics is

[1] https://www.w3.org/RDF/
[2] https://www.w3.org/wiki/RDFS
[3] https://www.w3.org/OWL/
[4] https://www.w3.org/TR/owl2-syntax/

a second approach which interprets correspondences of the alignment as axioms in some merged ontology Meilicke and Stuckenschmidt (2009) called aligned ontology. In this work, we use an example of this semantic called natural semantic. It involves building a merged ontology through the union of the two ontologies to align and axioms obtained by translating relations of the alignment. We introduce this semantic through its aligned ontology.

Definition 3 (Natural Semantics). Given an alignment M between two ontologies O_1 and O_2 and trans: M→A, a function that transforms a correspondence to an axiom. The natural semantics of M is defined by the following aligned ontology:

$O_1 \cup_M O_2 = O_1 \cup O_2 \cup trans(M)$.

Alignment consequence according to natural semantics is introduced as follows.

Definition 4 (Alignment Consequence). An axiom δ is an alignment consequence of an alignment M between two ontologies O_1 and O_2 if and only if δ is a logical consequence of the aligned ontology $O_1 \cup M\, O_2$.

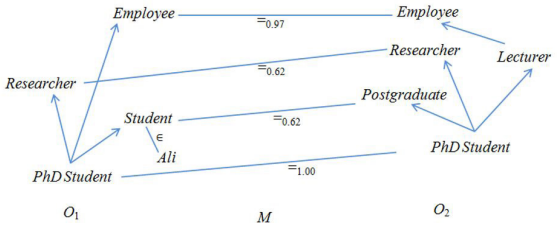
An axiom which is an alignment consequence either represents an ontological axiom or the image of a correspondence by the transformation function of the alignment.

Definition 5 (Ontology Signature Isomorphism). Given tow ontologies $O_1 = (S_1, A_1)$ and $O_2 = (S_2, A_2)$, an ontology signature isomorphism is a particular alignment M:$S_1 \rightarrow S_2$ such that $A_2 \vDash M(A_1)$ and $A_1 \vDash M^{-}(A_2)$, i.e., all models of A_2 are models of the image of A_1 by M and vice versa. The image of an axiom is obtained by systematically replacing signature elements of this axiom by their correspondents, according to the signature isomorphism M.

Problem Statement. We consider the conservativity principle as an alignment that allows interaction between ontologies, rather than providing a new description of the domain. However, two successive challenges are considered to overcome the problem of alignment conservativity violation Atig (2022). However, before detailing these challenges, let's start first by formally defining the conservative alignment.

Definition 6 (Conservative Alignment). An alignment M between two ontologies O_1 and O_2 is conservative if and only if for every ontological axiom δ that is not an image of any alignment correspondence, $(O_1 \cup_M O_2) \vDash \delta \rightarrow \exists i \in \{1, 2\} / O_i \vDash \delta$, i.e. any reasoning on the set $\{O_1 \cup M\, O_2\}$ that leads to logical consequences δ must not surpassed the set of entailments generated by reasoning on $\{O_1, O_2\}$ separately.

The concrete example in Figure 1 represents a scenario of non-conservative evolution, which is caused by a change affecting one of the input ontologies of an alignment. This scenario will allow us to reveal the problem of violating the conservativity principle in the case of evolving one related ontology.



Source: Authors

Figure 1: An example of alignment M between two educational domain ontologies O_1 and O_2.

Example 1: Considering the alignment M of Figure 1. We use Description Logic like syntax to describe both ontologies. Also, we use the index number in ontologies notation as name space to designate entities. Table 1 shows the set of axioms within the input ontologies O_1 and O_2. Whereas, Table 2 presents the set of correspondences of the alignment M between these two ontologies.

Ontology O_1	**Ontology** O_2
α_1 PhD Student ⊆ Researcher	β_1 PhD Student ⊆ Lecturer
α_2 PhD Student ⊆ Student	β_2 Lecturer ⊆ Employee
α_3 Lecturer ⊆ Employee	β_3 PhD Student ⊆ Researcher
α_4 Student (Ali)	β_4 PhD Student ⊆ Postgraduate

Source: Authors

Table 1: Example of two educational domain ontologies

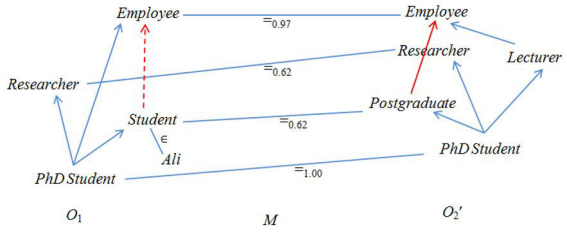
We use in Table 1, the α_i notification for ontology O_1 and the β_i notification for ontology O_2 to uniquely identify each axiom within these two ontologies.

Alignment M				
id	e_1	e_2	n	ρ
m_1	1 : *PhD Student*	2 : *PhD Student*	1.00	=
m_2	1 : *Researcher*	2 : *Researcher*	0.62	=
m_3	1 : *Employee*	2 : *Employee*	0.97	=
m_4	1 : *Student*	2 : *Postgraduate*	0.62	=

Source: Authors

Table 2: Correspondences for alignment M between ontologies O_1 and O_2.

Consider the set of correspondences m_i of the conservative alignment M of Table 2 between O_1 and O_2 generated by a generic ontology alignment system.



Source: Authors

Figure 2: Impact of evolving ontology O_2 into O_2'.

Assuming that one of the two input ontologies of the conservative alignment M has evolved. For example, and as illustrated in Figure 2, the ontology O_2 has evolved into O_2', and adds a new axiom $\beta_5 = \{2 : Postgraduate \subseteq 2 : Employee\}$, shown by the red solid arrow.

δ	Entailment:	follows from:	Violation?
δ_1	1 : *Student* $\subseteq$ 1 : *Employee*	m_3 , m_4 , β_5	YES
δ_2	1: *Employee* (Ali)	δ_1, α_4	YES

Source: Authors

Table 3: Violations of the conservativity principle following the evolution of ontology O_2.

According to Table 3, after evolving the ontology O_2 towards O_2' (adding the axiom β_5 = {2 : *Postgraduate* $\subseteq$ 2 : *Employee*}), the alignment M represented by the set of correspondences m_i violates the principle of conservativity according to the definition of conservative alignment (see definition 6), and introduces two new undesirable logical consequences (δ_1 shown by the red dashed arrow and δ_2) in the input ontology O_1. which represents an excess of the inferences generated by the reasoning on O_1 in isolation, and consequently an involuntary extension of the domain covered by this ontology. Therefore, the alignment M must be revised to restore its lost conservativity following the evolution of one of its input ontologies.

The alignment adaptation under ontology change problem aims to correct the alignment so that it fulfills its role in the interaction between ontologies, rather than generating new relationships within them, which provides a new description of the covered domains. However, this problem can be refined to include two sub-problems, namely: conservativity violations *detection* problem and *repair* problem.

Identifying Violations of Conservativity. The conservativity violations detection problem intends to designate the set of axioms causing violations of alignment conservativity upon evolving input ontologies. In fact, we are not interested here by the process of detecting ontological changes but by the impact of these changes on the alignment w.r.t conservativity principle. Despite, we must first identify the possible ontological changes to study this impact.

According to the W3C[5] definition, an OWL-2 ontology is a formal description of a domain of interest. The following three different syntactic categories composite the OWL-2 ontologies:

- Entities, represent the primitive terms that form the basic elements of an ontology. They are identified by IRIs, and composed by the set of *classes, properties*, and *individuals* which express the knowledge conveyed in a domain being described. For example, a class *O1:Child* can be used to represent the set of all childs. Similarly, the object property O_1*:hasBrother* can be used to represent the brotherhood relationship. Finally, the individual O_1*:Mohamed* can be used to represent a particular child called "Mohamed".
- Expressions, represent complex notions in the domain being described. For example, a *class expression* describes a set of individuals in terms of the restrictions on the individuals characteristics.
- Axioms are statements that are asserted to be true in the domain being described. For example, using a subclass axiom, one can state that the class O_1*:Boy* is a subclass of the class O_1*:Child*.

To analyze the possible changes that an OWL-2 ontology can undergo, Table 4 shows in the first column three sets of these changes: Class expression axiom set expresses the changes on ontology classes. Object property axioms and data property axioms sets express respectively the changes on the object properties and data-type properties of an OWL-2 ontology. The second column in Table 4 presents the change label. The third column shows the expression of each change jointly with a concrete example. While the last column is an interpretation of the change and the related example.

[5] https://www.w3.org/TR/2012/REC-owl2-syntax-20121211/

Change Class	Change Type	Change Expression	Interpretation
Class Expression Axiom	SubClassOf	SubClassOf(O'_2:c'_2 O'_2:c_2)	Each c'_2 is an c_2.
		SubClassOf(*a:Baby a:Child*) SubClassOf(*a:Child a:Person*) ClassAssertion(*a:Baby a:Sara*) => SubClassOf(*a:Baby a:Person*)	Each baby is a child. Each child is a person. Sara is a baby. => Each baby is a person.
	EquivalentClasses	EquivalentClasses(O'_2:c_2) ObjectIntersectionOf(O'_2:c'_2 O'_2:c''_2)	The instances of c_2 are exactly those instances that are both an instance of c'_2 and an instance of c''_2.
		EquivalentClasses(*a:Boy ObjectIntersectionOf(a:Child a:Man)*) ClassAssertion(*a:Child a: Younes*) ClassAssertion(*a:Man a: Younes*) ClassAssertion(*a:Boy a: Mohamed*)	A boy is a male child. Younes is a child. Younes is a man. Mohamed is a boy.
	DisjointClasses	DisjointClasses(O'_2:c_2 O'_2:c'_2)	Nothing can be both an c_2 and an c'_2.
		DisjointClasses(*a:Boy a:Girl*) ClassAssertion(*a:Girl a:Sara*)	Nothing can be both a boy and a girl. Sara is a girl.
	DisjointUnion	DisjointUnion(O'_2:c_2 O'_2:c'_2 O'_2:c''_2)	Each c_2 is either an c'_2 or an c''_2, each c'_2 is an c_2, each c''_2 is an c_2, and nothing can be both an c_2 and an c''_2.
		DisjointUnion(*a:Child a:Boy a:Girl*) ClassAssertion(*a:Child a: Mohamed*) ClassAssertion(. ObjectComplementOf(*a:Girl a: Mohamed*)	Each child is either a boy or a girl, each boy is a child, each girl is a child, and nothing can be both a boy and a girl. Mohamed is a child. Mohamed is not a girl.
Object Property Axioms	SubObjectPropertyOf	SubObjectPropertyOf(O'_2:p'_2 O'_2:p_2)	Having the property p'_2 implies having the property p_2.
		SubObjectPropertyOf(*a:hasDog a:hasPet*) ObjectPropertyAssertion(*a:hasDog a:Yahia a:Brian*)	Having a dog implies having a pet. Brian is a dog of Yahia.
	EquivalentObjectProperties	EquivalentObjectProperties(O'_2:p_2 O'_2:p'_2)	Having the property p_2 is the same as having the property p'_2.
		EquivalentObjectProperties(*a:hasBrother a:hasMaleSibling*) ObjectPropertyAssertion(*a:hasBrother a:Younes a:Mohamed*) ObjectPropertyAssertion(*a:hasMaleSibling a:Mohamed a:Younes*)	Having a brother is the same as having a male sibling. Mohamed is a brother of Younes. Younes is a male sibling of Mohamed.
	DisjointObjectProperties	DisjointObjectProperties(O'_2:p_2 O'_2:p'_2)	Nothing can be both an p_2 and an p'_2.
		DisjointObjectProperties(*a:hasFather a:hasMother*) ObjectPropertyAssertion(*a:hasFather a: Mohamed a:Yahia*) ObjectPropertyAssertion(*a:hasMother a: Mohamed a:Fatima*)	Fatherhood is disjoint with motherhood. Yahia is Mohamed's father. Fatima is the mother of Mohamed.
	InverseObjectProperties	InverseObjectProperties(O'_2:p_2 O'_2:p'_2)	Having the property p_2 is the opposite of having the property p'_2.
		InverseObjectProperties(*a:hasFather a:fatherOf*) ObjectPropertyAssertion(*a:hasFather a: Mohamed a:Yahia*) ObjectPropertyAssertion(*a:fatherOf a:Yahia a:Younes*)	Having a father is the opposite of being a father of someone. Yahia is Mohamed's father. Yahia is Younes's father.
	ObjectPropertyDomain	ObjectPropertyDomain(O'_2:p_2 O'_2:c_2)	Each individual that has an outgoing p_2 connection must be an instance of c_2.
		ObjectPropertyDomain(*a:hasDog a:Person*) ObjectPropertyAssertion(*a:hasDog a:Yahia a:Brian*)	Only people can own dogs. Brian is a dog of Yahia.
	ObjectPropertyRange	ObjectPropertyRange(O'_2:p_2 O'_2:c_2)	Each individual that has an incoming p_2 connection must be an instance of O'_2:c_2.
		ObjectPropertyRange(*a:hasDog a:Dog*) ObjectPropertyAssertion(*a:hasDog a:Yahia a:Brian*)	The range of the *a:hasDog* property is the class *a:Dog*. Brian is a dog of Yahia.
	FunctionalObjectProperty	FunctionalObjectProperty(O'_2:p_2)	Each individual that has the property p_2 can point to at most one distinct individual.
		FunctionalObjectProperty(*a:hasFather*)	Each object can have at most one father.
		ObjectPropertyAssertion(*a:hasFather a:Mohamed a:Yahia*)	Yahia is Mohamed's father.
	InverseFunctionalObjectProperty	InverseFunctionalObjectProperty(O'_2:p_2)	Each individual that has the property p_2 can point to at most one distinct individual.
		InverseFunctionalObjectProperty*(a:fatherOf*)	Each object can have at most one father.
		ObjectPropertyAssertion(*a:fatherOf a:Yahia a:Mohamed*)	Yahia is Mohamed's father.
	ReflexiveObjectProperty	ReflexiveObjectProperty(O'_2:p_2)	Each individual that has the property p_2 must be connected to itself.
		ReflexiveObjectProperty(*a:knows*) ClassAssertion(*a:Person a:Yahia*) =>ObjectPropertyAssertion(*a:knows a: Yahia a: Yahia*)	Everybody knows themselves. Yahia is a person. Yahia knows himself.

Source: Author

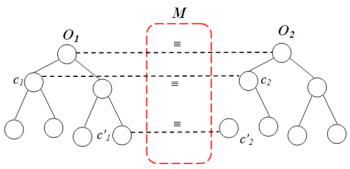
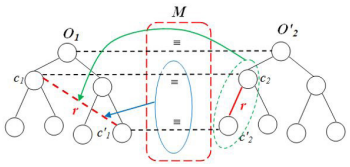
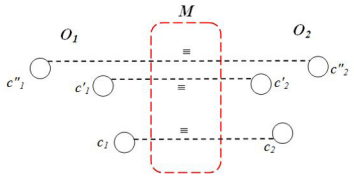
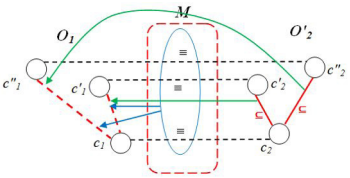
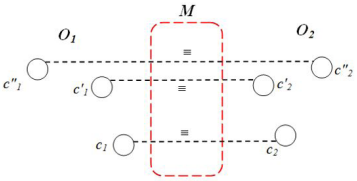
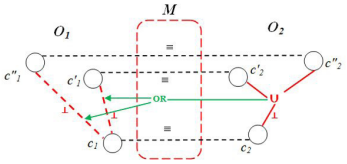
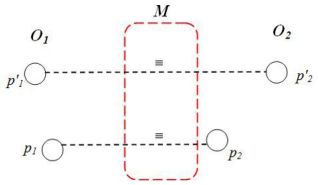
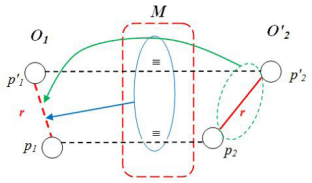
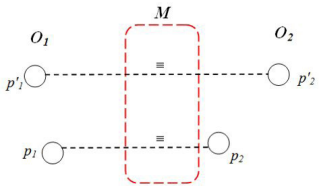
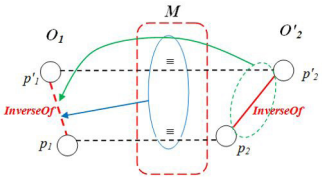
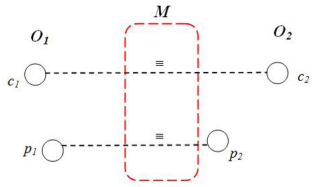
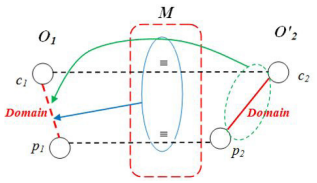
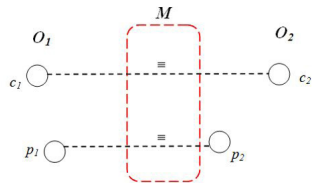
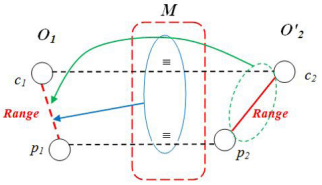
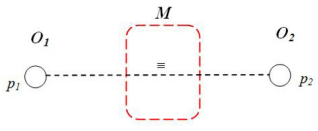
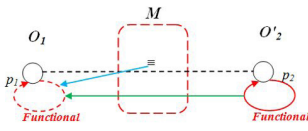
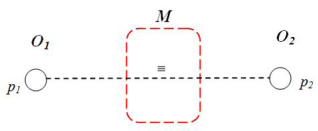
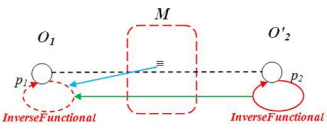
Table 4: OWL-2 Ontological changes (To be continued).

Change Class	Change Type	Change Expression	Interpretation
Object Property Axioms (Continuation)	IrreflexiveObjectProperty	IrreflexiveObjectProperty(O'_2:p_2)	Each individual that has the property p_2 cannot be connected to itself.
		IrreflexiveObjectProperty(*a:marriedTo*)	Nobody can be married to themselves.
	SymmetricObjectProperty	SymmetricObjectProperty(O'_2:p_2)	If an individual x is connected by p_2 to an individual y, then y is also connected by p_2 to x.
		SymmetricObjectProperty(*a:friend*) ObjectPropertyAssertion(*a:friend a:Yahia a:Brian*)	If x is a friend of y, then y is a friend of x. Brian is a friend of Yahia.
	AsymmetricObjectProperty	AsymmetricObjectProperty(O'_2:p_2)	If an individual x is connected by p_2 to an individual y, then y cannot be connected by p_2 to x.
		AsymmetricObjectProperty(*a:parentOf*) ObjectPropertyAssertion(*a:parentOf a: Yahia a: Mohamed*)	If x is a parent of y, then y is not a parent of x. Yahia is a parent of Mohamed.
	TransitiveObjectProperty	TransitiveObjectProperty(O'_2:p_2)	If an individual x is connected by p_2 to an individual y that is connected by p_2 to an individual z, then x is also connected by p_2 to z.
		TransitiveObjectProperty(*a:ancestorOf*) ObjectPropertyAssertion(*a:ancestorOf a:Djilali a:Yahia*) ObjectPropertyAssertion(*a:ancestorOf a:Yahia a:Sara*) =>ObjectPropertyAssertion(*a:ancestorOf a:Djilali a:Sara*)	If x is an ancestor of y and y is an ancestor of z, then x is an ancestor of z. Djilali is an ancestor of Yahia. Yahia is an ancestor of Sara. Djilali is an ancestor of Sara.
Data Property Axioms	SubDataPropertyOf	SubDataPropertyOf(O'_2:p'_2 O'_2:p_2)	If an individual x is connected by p'_2 to a literal y, then x is connected by p_2 to y as well.
		SubDataPropertyOf(*a:hasLastName a:hasName*) DataPropertyAssertion(*a:hasLastName a:Yahia "Atig"*) => DataPropertyAssertion(*a:hasName a:Yahia "Atig"*)	A last name of someone is his/her name as well. Yahia's last name is "Atig". Yahia's name is "Atig".
	EquivalentDataProperties	EquivalentDataProperties(O'_2:p_2 O'_2:p'_2)	In any expression in O'_2 containing such an axiom, p can be replaced with p' without affecting the meaning of O'_2.
		EquivalentDataProperties(*a:hasName a:Nom*) DataPropertyAssertion(*a:hasName a:Sara "Sara Atig"*) DataPropertyAssertion(*a:estNommé a:Sara "Atig Sara"*) => DataPropertyAssertion(*a:estNommé a:Sara "Sara Atig"*)	*a:hasName and a:estNommé* (in French) are synonyms. Sara's name is " Sara Atig". Sara's name is " Atig Sara".
	DisjointDataProperties	DisjointDataProperties(O'_2:p_2 O'_2:p'_2)	No individual x can be connected to a literal y by both p_2 and p'_2.
		DisjointDataProperties(*a:hasName a:hasAddress*) DataPropertyAssertion(*a:hasName a:Yahia "Yahia Atig"*) DataPropertyAssertion(*a:hasAddress a:Yahia "Saida, Algeria"*)	Someone's name must be different from his address. Yahia's name is "Yahia Atig". Yahia's address is "Saida, Algeria".
	DataPropertyDomain	DataPropertyDomain(O'_2:p_2 O'_2:c_2)	If an individual x is connected by p_2 with some literal, then x is an instance of c_2.
		DataPropertyDomain(*a:hasName a:Person*) DataPropertyAssertion(*a:hasName a:Yahia "Yahia Atig"*)	Only people can have names. Yahia's name is "Yahia Atig".
	DataPropertyRange	DataPropertyRange(O'_2:p_2 *DR*)	If some individual is connected by p_2 with a literal x, then x is in DR.
		DataPropertyRange(*a:hasName xsd:string*) DataPropertyAssertion(*a:hasName a:Yahia "Yahia Atig"*)	The range of the *a:hasName* property is *xsd:string.* Yahia's name is "Atig".
	FunctionalDataProperty	FunctionalDataProperty(O'_2:p_2)	For each individual x, there can be at most one distinct literal y such that x is connected by p_2 with y.
		FunctionalDataProperty(*a:hasAge*) DataPropertyAssertion(*a:hasAge a:Younes "17"^^xsd:integer*)	Each object can have at most one age. Younes is seventeen years old.

Source: Author

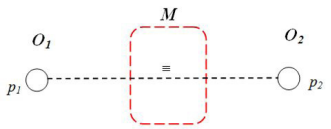
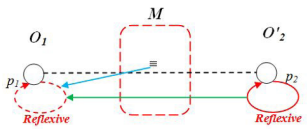
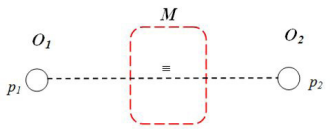
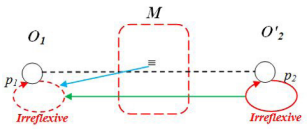
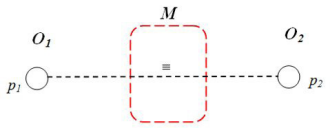
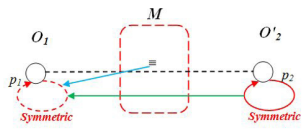
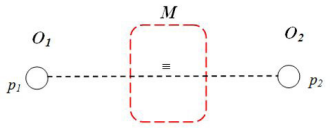
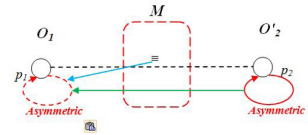
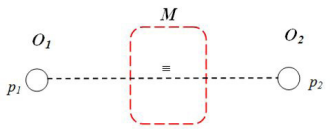
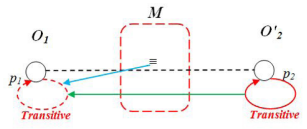
Table 4: OWL-2 Ontological changes (Continuation).

Based on the OWL-2 ontological changes and the ontology signature isomorphism (see definition 5), we propose in what follows a set of patterns to detect the violations of alignment conservativity following each change. Table 5 expresses in the first column the ontological change label. The second column shows the aligned ontology $O_1 \cup_M O_2$ before change application. While the third column shows the impact of the ontological change on the aligned ontology and the related conservativity violation detection pattern. For example, consider the first change type "SubClassOf". Upon evolving O_2 into O'_2 through the addition of the axiom $\{2{:}\ c'_2 \subseteq 2{:}\ c_2\}$, the related detection pattern requires that the image $M(2{:}\ c'_2 \subseteq 2{:}\ c_2) = \{1{:}\ c'_1 \subseteq 1{:}\ c_1\}$ be a logical consequence after reasoning on the ontology O_1 in isolation. Otherwise, this axiom is considered as a conservativity violation.

Change Type	Aligned Ontology	Conservativity Violation Detection Pattern
SubClassOf		
EquivalentClass (specific case)		
DisjointClasses		
SubObjectPropertyOf **EquivalentObjectProperties** **DisjointObjectProperties** **SubDataPropertyOf** **EquivalentDataProperties** **DisjointDataProperties**		
InverseObjectProperties		
ObjectPropertyDomain **DataPropertyDomain**		
ObjectPropertyRange **DataPropertyRange**		
FunctionalObjectProperty **FunctionalDataProperty**		
InverseFunctionalObjectProperty		

Source: Author

Table 5: Conservativity violation detection patterns (To be continued).

Change Type	Aligned Ontology	Conservativity Violation Detection Pattern
ReflexiveObjectProperty		
IrreflexiveObjectProperty		
SymmetricObjectProperty		
AsymmetricObjectProperty		
TransitiveObjectProperty		

Source: Author

Table 5: Conservativity violation detection patterns (Continuation).

Note that, equivalence relation in the alignment correspondences is the only relation considered in this work. At first glance, this may seems like a weakness for our approach. By cons, it is always possible to find a subset of the alignment with only equivalent relations in real semantic web applications. In addition, there are alignments which only accept equivalence relations within their correspondences such as UMLS[6] (https://www.nlm.nih.gov/research/umls/index.html). An equivalence relation expresses that linked entities represent the same thing in the domain of discourse. Kalfoglo and Schorlemmer (2003) consider such alignment as an isomorphism of ontological signature between two ontology vocabularies.

Remedying violations of conservativity. The process of repairing conservativity violations is the task of correcting the alignment to ensure that it fulfills the interoperability between ontologies rather than providing a new description of the domain. In the light of belief base revision theory (Hansson, 1999) and based on the work of Zahaf and Malki (2016) in the context of alignment consistency, we reformulate the alignment repair operation as a contraction operator (Hansson, 1994). Contraction is the act of selecting what to believe. It is the operation of removing a specified belief from the set of initial beliefs. Given an alignment M between two ontologies which generates a set of unwanted knowledge $\Omega = \{\delta \,/\, O_1 \cup_M O_2 \models \delta$ but $\nexists O_i, O_i \models \delta\}$, then the repair of the alignment M can be represented by the operator R defined as follows:

R: $(O_1, M, O_2) \rightarrow (O_1, M', O_2)$ which satisfies the following postulates:

Success: The postulate of success indicates that the retracted belief should not be believed after the contraction, unless it is a tautology. The contraction should be successful, that is, $M - \delta$ should not entails δ. The success postulate is formulated as follows:

If $\not\models \delta$ then $\{ O_1 \cup_M O_2\} - \delta \not\models \delta$

Inclusion: The inclusion postulate implies that the contracted conservative alignment M' is included in the original alignment M, and is formulated as follows:

$M - \delta \subseteq M$

[6] The UMLS, or Unified Medical Language System, is a set of files and software that brings together many health and biomedical vocabularies and standards to enable interoperability between computer systems.

Uniformity: The postulate of uniformity requires that if each subset entailing a logical consequence δ also entails another logical consequence β, then the contraction by δ and β should be the same. The uniformity postulate is formulated as follows:

If it is valid for all then $M - \delta = M - \beta$ $M' \models \delta$ if $M' \models \beta$, then $M - \delta = M - \beta$.

Relevance: the postulate of relevance means that only the correspondences which are responsible for entailing the contracted logical consequence should be discarded. The relevance postulate is formulated as follows:

if $m \in M$ and $m \notin M - \delta$, then there is a subset M' of M such that, $M - \delta \subseteq M' \subseteq M$ and $M' \not\models \delta$ but $M' \cup \{m\} \models \delta$

Core-retainment: the core- retainment postulate is a light version of the relevance postulate: Instead of requiring M' to be interposed between M and $M - \delta$, we are satisfied to require that it be only a sub-set of M. This version is formulated as follows:

If $m \in M$ and $m \notin M - \delta$, then there is a subset M' of M such that, $M' \not\models \delta$ but $M' \cup \{m\} \models \delta$.

Zahaf and Malki (2016) define an alignment α-kernel as the minimal subset of the alignment that imply an ontological axiom *α*. We use this notion to define the Minimal Conservative Upon Revision (MCUR) as the minimal subset of an alignment that violates conservativity principle upon adding an axiom to one of the connected ontologies or adding a correspondence to the alignment. Formally,

Definition 7 (MCUR). Given an alignment M between two ontologies O_1 and O_2, a subset $M' \subseteq M$ is a Minimal Conservative Upon Revision if it satisfies the following conditions:

- M' is conservative
- for all δ is an undesirable logical consequence, M′ and M′ ∪ {c} are MUCRs (δ-kernels) respectively upon adding an axiom α to one of the connected ontologies O_1 or O_2, and a correspondence n to A.

We refer to α-MCURs the set of Minimal Conservative Upon Revision by adding an axiom α to one of the connected ontologies.

In Example 2 , the entailed axiom {1 : Student ⊆ 1 : Employee} δ is an undesirable logical consequence and the subset (m_3 , m_4) is a unique α-MUCR upon adding the new axiom β_5 = {2 : Postgraduate ⊆ 2 : Employee} to the ontology O_2.

To repair the alignment, we should prevent it to generate any undesirable knowledge. Hence the conservativity resolution problem can be reformulated to the alignment contraction problem (Zahaf and Malki, 2016). We define the alignment incision function operator as the operator that discard from M at least one element from each MCUR.

Definition 8 (Alignment Incision Function). An incision function σ for A is a function that for all MCUR:

1. $\sigma(\text{MCUR}) \subseteq \bigsqcup(\text{MCUR})$ and
2. if $\emptyset \neq X \in \sum \text{MCUR}$, then $X \cap \sigma(\text{MCUR}) \neq \emptyset$

As it is proved by Zahaf and Malki (2016), the alignment incision function is characterized by the success, the inclusion, the uniformity, and the core-retainment postulates. Concerning the problem of conservativity resolution, the success postulate corresponds to the conservativity principle which means the undesirable knowledge is successfully removed. The inclusion ensures no new correspondences should be added to alignment when realizing the resolution. The postulate of core-retainment expresses the principle of minimal change which means only correspondences that are somehow responsible for entailing the undesirable knowledge should be discarded. As to the uniformity that expresses determinism in resolution. There is no reason to solve the problem differently for logically related unwanted knowledge. The following representation theorem summarizes these postulates for every alignment incision function operator.

Theorem 1 (Alignment Incision Function Representation). The operator − is an alignment incision function for an alignment M if and only if it satisfies the following postulates:

[Success] if $\not\models \delta$ then $\{O_1 \cup_M O_2\} - \delta \not\models \delta$
[Inclusion] $M - \delta \subseteq M$

[Core−retainment] if $c \in M$ et $c \notin M - \delta$, then there is a subset M′ of M such that, $M' \not\models \delta$ but $M' \cup \{c\} \models \delta$.

Uniformity] if it holds for all $M' \subseteq M$ that $M' \models \delta$ if and only if $M' \models \beta$, then $M - \delta = M - \beta$.

To resolve the problem of conservativity violations, we adapt a set of algorithms proposed in Zahaf (2017) for the resolution of the alignment inconsistency problem. Table 6 presents an algorithm to find an MCUR. It compute a minimal subset of correspondences that is

responsible of alignment conservativity violations. The proposed algorithm consists in testing if M still implies the undesired axiom δ after removing each of its correspondences. If this is not the case the removed correspondence is reintroduced in M. The final result is an MCUR which is a minimal set $M' \subseteq M$ that do imply δ. Algorithm 1 can compute an MCUR in polynomial time in the size of the aligned ontology.

Algorithm 1: MCUR
MCUR (M,o1,o2,δ) Input : o1,o2 // two ontologies M // M is an alignment between o1 and o2 δ // δ is an undesired axiom Output : M // an MCUR 1. for c ∈ M 2. do 3. if $M \setminus \{c\} \vDash \delta$ 4. then M ← M \ {c} 5. return M

Source: Authors

Table 6: MCUR algorithm.

Example 4: Following example 2, Let be Postgraduate ⊆ Researcher the new axiom α added to O_2, and therefore, the axiom Student ⊆ Employee will be an undesirable logical consequence δ in ontology O_1. Algorithm 1 return M = {1:Researcher = $_{0.62}$ 2:Researcher; 1: Student = $_{0.62}$ 2: Postgraduate} which is an MCUR.

α-MCUR and Incision Functions. In order to compute the α-MCUR and the corresponding incision functions, we also adapt the alignment kernel algorithm and it incision functions proposed in by Zahaf (2017) to deal with the alignment consistency problem, itself inspired from the Hitting set algorithm proposed by Reiter (1987) to diagnose systems. Given a collection of sets F, a Hitting set is a set that intersects each set of the collection. Hitting set algorithm builds a Tree for a collection of sets F such that, its root is labeled by √ if F is empty. Otherwise, it is labeled by an arbitrary set of F. If n is a node of the tree, define H(n) to be the set of edge labels on the path from the root to the node n. If n is labeled by √, it has no successor nodes in the tree. If n is labeled by a set $\sum$ of F, then for each $\sigma \in \sum$, n has a successor node n_σ joined to n by an edge labeled by σ. The label for n_σ is a set $S \in F$ such that $S \cap H(n) = \emptyset$, if such a set S exists. Otherwise, nσ is labeled by √.

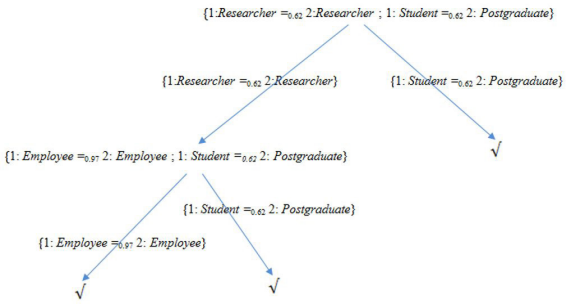
The α-MCUR is the collection of all MCUR upon adding the new axiom α. As defined above (see definition 8), the incision function intersects each MCUR of the collection α-MCUR. Consequently, we can consider the incision function as a Hitting set of the α-MCUR. The nodes of the tree are labeled by MCURs and edges are labeled by the elements of these MCURs. However, the α-MCUR is not given explicitly and we should compute it using the output of algorithm 1 which is the first computed MCUR. At each node, an MCUR of the set $M \setminus H(n)$ is computed if such an MCUR exists. Otherwise, H(n) is an incision function. Unfortunately, the Hitting set algorithm has an exponential time (Rymon, 1991). Table 7 outlines this algorithm. The example 5 as well as Figure 3 illustrate the progress of the algorithm.

Algorithm 2: α-MCUR and Incision functions
α-MCURandIncisionFct (M,o1,o2,δ) Input : o1,o2 // two ontologies M // M is an alignment between o1 and o2 δ // δ is an undesired axiom Output : α-MCUR // an collection of α-MCURs Incision // set of incision functions 1. Incision ← ∅ 2. Stack ← Empty 3. C ← MCUR (M,o1,o2,δ) 4. α-MCUR ← {C} 5. for c ∈ C 6. do insert {c} in the top of the stack 7. While Stack not Empty 8. do Hn ← last element of the stack 9. remove last element of the stack 10. If $M \setminus \{Hn\} \vDash \delta$ 11. Then C ← MCUR (M\{Hn},o1,o2,δ) 12. α-MCUR ← α-MCUR ∪ {C} 13. for c ∈ C 14. do insert Hn∪{c} in the top of the stack 15. Else Incision ← Incision ∪{Hn} 16. End.

Source: Authors

Table 7: α-MCUR and Incision functions algorithm.

Example 5. Following the example 4, we apply Algorithm 2 to compute incision functions. We obtain Incision = {{1: Student = $_{0.62}$ 2: Postgraduate}, {1:Researcher = $_{0.62}$ 2:Researcher; 1: Student = $_{0.62}$ 2: Postgraduate}, {1:Researcher = $_{0.62}$ 2:Researcher ; 1: Employee = $_{0.97}$ 2: Employee}}



Source: Authors

Figure 3: Hitting set tree of α-MCUR incision functions.

Related works. We consider the Consistency Preservation and the Ontology Change Preservation problems as two instances of the conservativity

problem (Atig et al., 2022). Therefore, we examine also literature concerning these two problems.

Violations detection of conservativity principle was subject of study by Jiménez-Ruiz et al. (2011) and Solimando, Jiménez-Ruiz and Guerrini (2016). According to iménez-Ruiz et al. (2011), the violations appeared when the set of inferences after reasoning on an ontology is different if used in conjunction with the alignment. Solimando, Jiménez-Ruiz and Guerrini (2016) defines two types of conservativity violations: subsumption and equivalence. To avoid subsumption violations, the aligned ontology must not introduce new subsumption relationships between concepts within the input ontologies, while equivalence violation is defined as two subsumption violations in both directions. Both approaches rely on confidence values to eliminate the correspondence with smallest value in each conflict set. They propose the locality principle[7] to compute confidence values for conflict correspondences if these values are missing in the alignments to be repaired. For detecting ontology change preservation violation, the study by Zahaf (2012) is based on the signature of the propagated axiom in the versions of the same ontology. Resulting correspondences are ordered using the comparison of their intentional persistence degrees to penalize the weakest.

Consistency principle was the object of study in several works. For instance, Lily (Tang et al., 2018) invokes user decision to repair two types of inconsistencies: mappings that form a circle and mappings that do not meet the equivalentClass/ disjointWith axioms mentioned in the original ontology. YAM++ (Bellahsene et al., 2017) is based on ALCOMO (Meilicke, 2011) to detect alignment consistency violations via disjoint-subsumption patterns. The reparation process defines two type of diagnosis: Global optimal diagnosis which removes the slightest amount of confidence, and Local optimal diagnosis, which an incremental check of the correspondences set. ASMOV (Jean-Mary, Shironoshita, and Kabuka, 2009) introduces the notion of mapping validation in a graph constitutes nodes (pairs of entities) and edges (pairs of properties). The iterative validation process is done in three phases: concept validation, property validation and concept-property validation. All invalid mappings that have been identified are added to the invalid mapping list. If at least one violation was identified, the iteration process resumes and the invalid source-target pairs are ignored. The core of LogMap (Jiménez-Ruiz, 2019) is an iterative process that alternates mapping discovery (using unsatisfiability detection) and mapping repair (with minimum confidence) steps to deal with consistency violations. Most of repair process in the studied approaches are based on computing and discarding diagnosis from alignment. A diagnosis is the set of correspondences that have the lowest confidences values in each conflict set. We follow the same approach in dealing with conservativity principle violations.

Results and discussion

To demonstrate the methods proposed in this research, we have created a Java application based on OWL API (Horridge and Bechhofer, 2009) and Align API (Euzenat, 2004) to manipulate OWL ontologies and alignments between them. This application also integrates pellet (Meilicke, 2011) as the main reasoning engine on OWL ontologies.

Numerous ways exist to assess our suggested approach. For instance, we can gauge its performances based on the minimal change principle, ensuring the least possible information loss during the adaptation process. Another way is to compare these performances against other alignment adaptation methods. But, it seems a priority to investigate whether our proposal deals well with the identified alignment conservative adaptation problem. For this purpose, the goal of this experimentation is to show the limits of alignment evolution w.r.t the conservativity principle upon ontology change.

Data Set. In the current evaluation approach, we need at least two ontologies together with an alignment between them, in addition to the ontological changes either in the form of explicit change logs or in the form of a version of the modified ontology. In this section, we present the used ontologies together with the ontological changes and the alignments.

a. **Agronomy Ontology (AgrO).** Is an ontology for representing agronomic practices, techniques, variables and related entities. According to its founder, the Consultative Group for International Agricultural Research[8] (CGIAR), a global research partnership for a food-secure future,

[7] If two entities e_1 and e_2 from ontologies O_1 and O_2 are correctly mapped, then the entities semantically related to e_1 in O_1 are likely to be mapped to those semantically related to e_2 in O_2 (Jiménez-Ruiz and and Cuenca Grau 2011).

[8] https://www.cgiar.org/

the Agronomy Ontology[9] provides terms from the agronomy domain that are semantically organized and can facilitate the collection, storage and use of agronomic data, enabling easy interpretation and reuse of the data by humans and machines alike. AgrO is of significant size containing in its latest version (uploaded on 11-02-2022 in the AgroPortal repository[10]) 4163 classes, 209 properties and 552 individuals. In this experiment, we use two versions that are sufficiently different (1st and 5th) to generate the set of ontological changes between versions. The first version is the 06-06-2016 version (AgrO-1) while the second one is the 03-04-2022 version (AgrO-5).

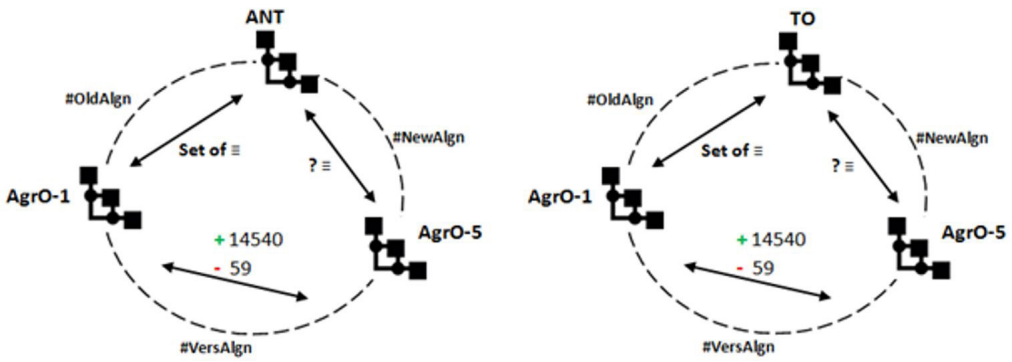
b. **Plant Trait Ontology (TO).** For its owner the Wheat Data Interoperability Working Group[11] (WG), the Plant Trait Ontology is an ontology for describing phenotypic traits in plants. Each trait is a distinguishable feature, characteristic, quality or phenotypic feature of a developing or mature plant. Although the first version of TO was launched in 2016, its most recent version dates from 2022. This version has 5,262 classes in addition to 159 properties and no individuals. This ontology is considered here to be a second ontology allowing to construct an original alignment.

c. **Agricultural and Nutrition Technology Ontology (ANT).** Is an ontology created by the International Food Policy Research Institute[12] (IFPRI), which provides research-based policy solutions to sustainably reduce poverty and end hunger and malnutrition in developing countries. ANT is a small ontology with 127 classes, 4 properties and only 4 individuals. This makes it easy to use as a dataset in this experiment. ANT is released on 07-28-2013 and the last known version is uploaded in the AgroPortal repository on 10-16-2017. Same as TO, ANT is used here to be a second ontology for constructing an original alignment.

To generate the ontological change, we have used the method developed in study by Zahaf (2012) to compute the difference between versions. This method, considers the ontological change operation as the set theoretical difference between signatures and axioms, respectively. Since the conservativity principle is a logical property which might concern only axioms whose signature is fully implied in alignments, we only consider the axiomatic change of matchable signatures. For the used dataset, Figure 4 shows the number of added (+) and deleted matchings (-) between the pair of ontology versions. It also presents the alignment considered as original (#OldAlgn) between the AgrO-1 and the second ontology TO/ANT, also the alignment considered as new (#NewAlgn) between the TO/ANT and the new ontology version AgrO-5.

d. **Ontological changes.** The difference between the two versions of AgrO ontologies is calculated in terms of the number of added and deleted axioms. In total, 14540 axioms have been added and 59 axioms have been deleted. Table 8 shows this difference in detail. We have for each type of axiom (see definition 1) the count calculated for the two versions.

[9] https://bigdata.cgiar.org/resources/agronomy-ontology/
[10] https://agroportal.lirmm.fr/ontologies/AGRO/?p=summary
[11] https://ist.blogs.inrae.fr/wdi/
[12] https://www.ifpri.org/



Source: Authors

Figure 4: Dataset.

Axiom type		Agro V1	Agro V5
Class Axioms	SubClassOf	611	3967
	EquivalentClasses	56	386
	DisjointClasses	11	36
	DisjointUnion	55	376
Object Property Axioms	SubObjectPropertyOf	29	177
	EquivalentObjectProperties	0	22
	InverseObjectProperties	14	44
	DisjointObjectProperties	0	0
	FunctionalObjectProperty	2	3
	InverseFunctionalObjectProperty	0	0
	TransitiveObjectProperty	2	18
	SymmetricObjectProperty	0	2
	AsymmetricObjectProperty	0	0
	ReflexiveObjectProperty	0	1
	IrreflexiveObjectProperty	0	1
	ObjectPropertyDomain	19	55
	ObjectPropertyRange	21	57
	SubPropertyChainOf	6	69
Data Property Axioms	SubDataPropertyOf	0	2
	EquivalentDataProperties	0	0
	DisjointDataProperties	0	0
	FunctionalDataProperty	1	1
	DataPropertyDomain	2	3
	DataPropertyRange	2	2
Individual Axioms	ClassAssertion	179	360
	ObjectPropertyAssertion	27	43
	DataPropertyAssertion	2	0
	NegativeObjectPropertyAssertion	0	0
	NegativeDataPropertyAssertion	0	0
	SameIndividual	0	0
	DifferentIndividuals	2	2
Annotation Axioms	AnnotationAssertion	1058	9106
	AnnotationPropertyDomain	0	0
	AnnotationPropertyRange	0	0

Source: Authors

Table 8: Number of axioms in the AgrO versions.

e. **Alignments.** Concerning the alignments to be repaired, the old alignments are considered to be the one between TO and AgrO-1 and also between ANT and AgrO-1, while the set of matchings between TO/ANT and the version AgrO-5 make the evolved alignments after change. Figure 4 schematizes this situation. To calculate the original alignments, we are based on the results available on the AgroPortal platform[13]. For almost each of the ontologies available in this portal, a set of alignments with the other ontologies of the portal are available in the "Mappings" section.

Accuracy Measures. The considered dataset does not contain reference alignments to measure accuracy w.r.t conservativity principle, which restricts the use of traditional precision methods. Therefore, to measure the effectiveness of our method in the alignment adaptation context, we use the number of conservativity violations by changed axioms. In addition, we calculate the elapsed time, as well as the rate of violations reparation compared to the original alignments. The violations reparation rate of an alignment M is defined by %Rep=($\Delta/\mathcal{M}$)*100%. where Δ is a diagnosis of initial alignment M.

[13] https://agroportal.lirmm.fr/mappings

Experimentation. The experimentation process was conducted in two steps. In the first one, we exploit the change log between the original ontology AgrO-1 and the new version AgrO-5 to detect the set of conservativity violations for the original alignments upon input ontology evolution. Then, in the second step, we use our method to adapt these alignments following the ontological changes applied to the new AgrO-5 version.

a. **Detection Process.** To detect conservativity violations upon ontology evolution, we use the change log between AgrO-1 and the new version AgrO-5. This log contains two types of information: added and removed axioms. We only consider axioms whose signatures represent matchable entities. Then, for each change, we apply the appropriate detection pattern. Then, we count the number of conservativity violations caused by the related ontological changes. Table 9 shows the detailed results for both tests in this experiment. The first line designates the test named by its related ontologies, while the second and third lines show respectively the number of correspondences and conservativity violations in the old alignments.

b. **Reparation Process.** This step aims to show the impact of our proposed method to avoid alignment conservativity violations upon ontology change. The fourth line in Table 9 presents the number of correspondences in every diagnosis. The fifth line shows the size of new alignments considered as conservative upon ontology change.

	AgrO-1↔TO↔ AgrO-5	AgrO-1↔ANT↔ AgrO-5
#OldAlgn	596	10
#Viol	2	1
#Diagnosis	2	1
#NewAlgn	594	9
#Time ns	10.5	0.59
%Rep	0.33	10

Source: Authors

Table 9: Results in the context of alignment adaptation problem.

Comment 1. Despite the relatively high number of matchings in the #OldAlgn (596) in the first test (AgrO-1↔TO↔ AgrO-5), the number of violations detected is very small (2). This is due to the quality of the matchings in this test. 98% of the correspondences are of type (SAME_URI) and are not considered by the detection process. Since the conservativity principle is a logical

property which might concern only axioms whose signature is fully implied in alignments, we only consider the axiomatic change of matchable signatures. As a matter of fact, alignment quality depends on its content and its size. For instance, an empty alignment avoids completely the conservativity violation but it doesn't present any interest.

Traditional assessment methods are mainly designed to rely on benchmarks to compare precision and recall of results. However, in the alignment adaptation context, we haven't these benchmarks. Hence, it's not possible to use the same traditional accuracy measures. Instead, we use the violations repair rate with the related elapsed time. These measures show for each test, at what degree our proposed method reuses the original alignment while respecting the conservativity principle upon ontology change. The two last lines in Table 9 show the results of these measures. The sixth line shows the elapsed time measured in nanosecond to repair old alignments while the seventh line shows the repair rate compared to old alignments size.

Comment 2. Although the repair time is very encouraging for potential automatic use (with normal computational performance), the repair rate is crucial in this experiment. We observe a very tiny rate in the first test (0.33%), while a medium rate is noted in the second test (10%). The latter can be justified by the reduced amount of correspondences in the original alignment (10). It is obvious that in such cases, another experiment is required to fix a threshold which separates between the adaptation approach and calculating a new alignment from scratch. Despite this, we find that this situation drastically confirms the strategy of adapting alignments following the evolution of their input ontologies makes it possible to exploit to the maximum the efforts provided the first time in constructing alignments.

Conclusion

The current work is a continuation of previous works on the alignment adaptation problem in the case of evolution of one of its input ontologies (Atig et al. 2013; Atig, Zahaf, and Bouchiha, 2016; Atig et al., 2022 and Atig, 2022). After identifying the problem via an example, we have confined a set of the possible ontological changes that an OWL-2 ontology can undergo. Then we propose an adequate pattern for each change in order to detect the conservativity violations. Inspired by diagnostics theory, we have adapted two algorithms from the literature designed to the alignment consistency problem to the alignment conservativity problem. This adaptation has served as a satisfactory repair process to deal with conservativity violations. Indeed, the experimentation has shown the applicability of our approach to help improve the quality of alignments between ontologies. However, other research questions are still pending. For instance, in the near future we need to study the repairs impact on the alignment interoperability, as well as improving the techniques to repair correspondences instead of eliminating them. Another promising issue is the study of this problem for other languages outside OWL-2. As general conclusion, we note that alignment adaptation problem has not received the necessary importance given the lack of works provided until this day.

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Rural Attractiveness Index and Its Visualization as Tools to Support Local and Regional Decision-Making

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Abstract

Promoting rural regions is crucial for societies all over the world. Prosperous and vital rural regions can contribute to solving many pressing problems that threaten humanity, such as climate change, poverty, hunger, health or clean energy. The attractiveness of rural regions can be improved through targeted measures and support. For the design of such targeted interventions, high-quality assessments of rural attractiveness can provide a solid information basis. However, the attractiveness of rural regions is a complex construct and therefore difficult to assess. Thus, in this paper, we present tools for the assessment of rural attractiveness that address these complexities and support use and interpretation of the results of rural attractiveness assessments by stakeholders: First, we develop a Rural Attractiveness Index (RAI) which provides a general blueprint for assessing rural attractiveness, yet still is flexible and adaptable to each specific context. As integrated measure of rural attractiveness it also facilitates interpretation by stakeholders. Second, to further enhance interpretation and communication, we propose to visualize the RAI in map-based form. We demonstrate the application of these tools through an illustrative showcase in a European context. We discuss strengths, limitations and challenges of the presented tools and highlight directions for future research.

Keywords

Rural regions, rural attractiveness, thematic map, spatial analysis, clustering, spatial data.

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Introduction

Today, 28% of the total European population lives in rural areas (Perpiña Castillo et al. 2018). Maintaining or creating prosperous and vital rural regions can help address many burning issues facing humanity, such as climate change, poverty, hunger, energy transition, agricultural self-sufficiency, and halting or reversing the prevailing trend of urbanization. Yet, rural areas are often less developed and offer less potential than more urbanized territories, i.e., they are often less attractive than urban areas as places to live and do business. Improving the attractiveness or rural territories to retain existing residents and business and attract new ones is therefore essential for rural areas to become or remain vibrant and to fulfil their functions.

The attractiveness of rural regions can be improved through targeted measures and support. For the design of such targeted interventions, high-quality assessments of rural attractiveness can provide a solid information basis. Indeed, interest in assessing the attractiveness of territories, especially of rural territories, has increased recently (Melece et al., 2020).

However, assessing rural attractiveness in quantitative terms is challenging, on the one hand, because of the complexity of the concept of rural attractiveness (Eimermann, 2015; Grieve et al., 2011; Dax et al., 2018). Its exact meaning and composition depend on the time-frame (Argent et al., 2007) and geographical scale (Russo et al., 2012) for which it is assessed as well as on the kinds of individuals to which a region is supposed to be attractive (Argent et al., 2007; Russo et al., 2012; Lysgård et al., 2013; Détang-Dessendre et al., 2008). Thus, the exact meaning of rural attractiveness is always context-bound. Another challenge is that rural attractiveness is composed of a variety of factors. Thus, its assessment generates a large amount of disparate data that is

difficult for individuals to process and interpret.

In this paper, we present tools for the assessment of rural attractiveness that aspire to address these challenges: First, we develop a Rural Attractiveness Index (RAI) which provides a general blueprint for assessing rural attractiveness, yet still is flexible and adaptable to each specific context. Therefore, it can potentially be used to assess rural attractiveness for any set of regions Additionally, it facilitates interpretation and understanding by integrating the large amount of information generated in rural attractiveness assessments into a single at-glance overview of a region's attractiveness status (Foa and Tanner, 2012). It is important to note that the RAI is meant to be a tool to facilitate local or regional decision-making for rural development, adaptable to the different necessities of such decision-making contexts. It is not an "objective" index for global comparison and ranking – and cannot be because the concept of rural attractiveness is always context-dependent.

Second, to further enhance interpretation and communication, we propose to visualize the RAI in map-based form as maps are an ideal graphical tool for such purposes: They are able to communicate complex data in a simple, clear, comparable, understandable and attractive way, making them "perfect interfaces between geoinformation and human users" (Gartner, 2014).

We demonstrate the application of these tools through an illustrative showcase in a European context. Thus, the results presented this article only show one possible example the use of the RAI and its visualizations. These results were meaningful for the specific context in which they were produced but apart from that mainly serve demonstration purposes.

Accordingly, the article is structured as follows: The next section presents our theoretical framework for the RAI and thus for assessing rural attractiveness. In the Materials and Methods section, we shortly introduce our showcase in the context of the EU-funded Horizon 2020 project PoliRural, in which the authors were directly involved. Afterwards, we describe the methods and data needed to create the Rural Attractiveness Index and its visualizations, both in general and in more detail how these steps were implemented in our showcase. In the Results section, we present and explain for the sake of illustration the visualizations of our showcase. Before drawing our final conclusions, we discuss the strengths, limitations, and challenges of our approach as well as opportunities for future development.

Materials and methods

Towards an adaptable framework for assessing rural attractiveness

Rural attractiveness is often associated with various aspects of quality of life and living conditions in rural and peri-urban areas. Issues related to rural attractiveness have been the subject of research in a variety of fields. The research contexts in which the concept is most frequently instrumentalized are counterurbanization / urban-rural migration (Eimermann et al., 2015; Argent et al., 2007; Détang-Dessendre et al., 2008; Pettersson, 2001; Vuin et al., 2016), (rural) tourism (Vuin et al., 2016; Van Huylenbroeck et al., 2006; Puška et al., 2020; Świdyńska and Witkowska-Dąbrowska, 2021), and regional development (Grieve et al., 2011; Argent et al., 2007; Russo et al., 2012; Lysgård et al., 2013; Brereton et al., 2011; Scott et al., 2011; Lange et al., 2013; Živković et al., 2015; Straka and Tuzová, 2017). Rural attractiveness is a relevant and useful concept also in research about economic issues of territorial marketing and investment (Eimermann, 2015; Hamri et al., 2014; Barborič et al., 2018) as well as for social issues such as rural social innovation or rural gender studies (Lindberg, 2017; Vidickienė, 2017).

However, a number of these works do not directly target rural attractiveness but refer to very closely related concepts such as rural idyll (Pettersson, 2001; Eimermann, 2015), quality of life (Brereton et al., 2011; Grieve et al., 2011), territorial attractiveness (Servillo et al., 2012; Hamri et al., 2014; Živković et al., 2015; Barborič et al., 2018), or rural touristic attractiveness (Puška et al., 2020, Świdyńska and Witkowska-Dąbrowska, 2021), to name a few.

Commonly, rural attractiveness is described to be a complex and multi-faceted concept for which there is no single, universally applicable definition (Melece et al., 2020; Argent et al., 2007, Russo et al., 2012; Lysgård et al., 2013; Barborič et al., 2018; Świdyńska and Witkowska-Dąbrowska, 2021). This is due to the fact that the exact meaning of rural attractiveness depends on a variety of contextual factors: What is considered relevant in determining rural attractiveness depends on

1. the time-frame: The characteristics that determine the attractiveness of a place are different for a short-time visit than for a long-term change of residence (Argent et al., 2007).
2. the scale: When rural attractiveness is

considered at the level of a village, some aspects may be different than when rural attractiveness is to be assessed for a larger region (Russo et al. 2012).

3. the stakeholders: Which features are considered relevant for the attractiveness of a rural area depends on the characteristics of the individuals for whom a territory is supposed to be attractive, on their life stage, family constellation, type of occupation, socioeconomic status, health status etc. (Argent et al., 2007; Russo et al., 2012; Lysgård et al., 2013, Détang-Dessendre et al., 2008).

In addition, the attractiveness of rural areas is not an absolute quality, but a relative one, and can only be determined in comparison to other regions. That is, a territory may become more attractive simply because other territories nearby have become less attractive (Russo et al. 2012). Given these characteristics, any assessment of rural attractiveness can only provide results that are specific to the context and relative to the territories assessed. Absolute or objective assessments of rural attractiveness are not possible!

Because of this variability and relativity, previous publications have proposed and applied a wide variety of indicators for rural attractiveness. Some of these studies consider or evaluate rural attractiveness and its related concepts rather comprehensively (Russo et al., 2012; Servillo et al., 2012; Živković et al., 2015; Barborič et al., 2018). Additionally, only few studies tried quantifying rural attractiveness; and those that did considered only very few aspects of this multi-faceted concept or did not create an integrated overall measure (Russo et al., 2012; Vannoppen, 2021).

While there are few similarities among the specific sets of indicators used in previous studies, there is notable overlap in the general categories into which many authors divide their indicators. Not all publications cover the same aspects, and in some publications the categories are ordered differently than in others. Yet, overall, a picture emerges of general categories relevant to rural attractiveness. Our framework for assessing rural attractiveness consists of the following general categories: social, natural, economic, institutional, cultural, anthropic.

This framework is the basis for an assessment approach that is adaptable to different contexts: On the one hand, it determines which categories are generally relevant for assessing rural attractiveness and thus helps to guide the selection of indicators to measure rural attractiveness. On the other hand, it does not prescribe concrete indicators or even the inclusion of all of the proposed categories. Rather, the selection of concrete indicators can be tailored to the specific context in which rural attractiveness is supposed to be assessed, e.g., in the context of a decision-making process for a (set of) specific regions. To adapt the RAI to the requirements of each situation, the relevance and relative importance of all categories must be evaluated – ideally through stakeholder engagement. If a category is found to be relevant, suitable indicators need to be selected to represent this category. Selection criteria for these indicators are their conceptual fit with the RAI category and their relevance to the context of the rural attractiveness assessment (i.e., its time frame, geographical scale, and stakeholders).

Assessing rural attractiveness with the Rural Attractiveness Index

Data mining

In project PoliRural, we needed datasets covering all of Europe and Israel. Therefore, an extensive search for relevant data was conducted in open databases such as those of Eurostat, World Bank or EEA. We mainly aimed to collect data at the NUTS 3 level. NUTS regions are the statistical units used in Europe, based on the administrative regions of the respective countries. NUTS regions are also comparable in terms of their number of inhabitants (e.g., NUTS 3 corresponds to 150 000 to 800 000 inhabitants (Brandmueller, 2017). However, some relevant information was only available at higher levels, up to NUTS 0 (level of an entire country).

Another option would have been to replace administrative boundaries with homogeneous, non-overlapping area units (so-called grids) (Kowalczyk et al., 2019). We opted for using administrative units for three reasons: (1) Input data provided by statistical organizations are primarily available for administrative units. However, it is possible to recalculate these data for individual grid cells (Sládeková Madajová and Hurbánek, 2016). Nevertheless, this calculation is quite demanding and challenging and puts limits to automated calculations required for example for interactive applications. (2) Grid-based attractiveness assessment is computationally very demanding and would require special hardware or software optimization, which is contrary to the capabilities and needs of the target research group.

(3) If a grid is used, there would be a significant bias in attractiveness values where the cells are crossed by boundaries that sharply separate the input data values.

The data for Israel were obtained from national resources of Israel. However, not all required indicators could be covered by suitable data. For this reason, the maps in the results section (Figures 1 through 3) do not cover Israel.

Data selection and harmonization

For the PoliRural project, 37 data sets were selected as input data for the development of the Rural Attractiveness Index and the visualizations (Figure 1). Decisions about the effect (positive or negative) of each data type on the RAI were largely based on common sense. Because of its preliminary nature, our showcase assessment has some limitations: The datasets were selected solely by researchers, without involvement of the stakeholders; and although we used the best data available to us at the time, not all of the selected datasets meet the highest standards of quality and diversity.

Calculation of the Rural Attractiveness Index (RAI)

Before the selected data are transformed into the composite RAI, stakeholder input is again essential: to reflect stakeholder perceptions and preferences, stakeholders need to discuss and decide whether the different dimensions of rural attractiveness are of equal or different importance to them, and if necessary, assign appropriate weights to the different dimensions. Here, stakeholders may also agree to disagree and draft a number of different sets of weights for the dimensions to reflect and explore different viewpoints in the rural attractiveness assessments rather than forcing consensus (Scott et al., 2011; Lysgård et al., 2013). The RAI is then calculated as weighted mean of the data on the different dimensions according to stakeholder preferences (Formula (1)). This means all datasets pertaining to the same rural attractiveness dimension are included with the weight of this dimension.

$$RAI = \frac{\sum_{i=1}^{n} w_i \cdot x_i}{\sum_{i=1}^{n} w_i}, \quad (1)$$

n - number of input dimmensions

w - weight of particular input dimmensions

x - normalized values of input dimmensions

In our preliminary assessment, the weighting of the different factors was determined through a user survey. In this survey, PoliRural stakeholders were asked to indicate on a scale from 1 (low importance) to 3 (high importance) how important the different dimensions of rural attractiveness were for them. The survey was conducted using Mentimeter (mentimeter.com), posted on social media (Facebook, 23 responses), and distributed at a PoliRural consortium meeting (18 responses). The RAI was calculated accordingly as weighted mean using R software.

Visualising the results of the rural attractiveness assessment

The data were divided into nine intervals constructed using the Natural Breaks methods (Jenks and Caspall, 1971) implemented in QGIS. The implementation of these intervals resulted in a high TAI (Tabular Accuracy Index) of 0.86, which means that this map, including the Natural Breaks data classification, is the most accurate map for the users.

Additionally, we chose the choropleth map as the cartographic interpretation technique as it is one of the simplest and most understandable methods for developing thematic maps. For these maps, we used Lambert equal-area projection to visualise undistorted areas, which are crucial for the representation of thematic information like RAI values. All map-based visualizations use areal cartographic symbols (NUTS 3 regions) for which the spatial data in scale 1:10M and ESRI shapefile format were downloaded from the official Eurostat database.

While mapping the values of RAI focuses on highlighting differences between territories, cluster analysis is able to identify groups of regions that are similar in terms of their rural attractiveness. For the cluster analysis, hierarchical and non-hierarchical clusters methods are viable methods (Jain et al. 1999).

In our showcase, we used the Silhouette method (Rousseeuw, 1987) to indicate the optimal number of clusters. In this method, the number of clusters whose silhouette coefficient is closest to 1 should be chosen. In our showcase, it indicated ten clusters as the optimal number of clusters for our input data.

We tested both hierarchical and non-hierarchical clustering methods as well as different input parameters (types of distance, clustering algorithms). The final parameters were selected based on literature (Jain et al. 1999, Abu Abbas, 2008, Ferreira and Hitchcock, 2009, Singh et al. 2013, Sinwar and Kaushik, 2014, Mohibullah

et al. 2015) and tests with samples of the input data. Euclidean distances were used for all distances used in clustering and imputation. They correspond to the classical understanding of space and distances in geography and cartography (Abu Abbas, 2008; Ferreira and Hitchcock, 2009; Singh et al., 2013, Sinwar and Kaushik, 2014; Mohibullah et al., 2015). Both the literature and the results of the initial test runs pointed to two clustering algorithms that were most appropriate: non-hierarchical clustering with k-means method and Lloyd's algorithm (Abu Abbas, 2008; Murtagh and Legendre, 2014), and hierarchical clustering with Euclidean distances and Ward's option clustering criterion (Lloyd, 1982; Ferreira and Hitchcock, 2009). Hierarchical clustering proved to be most suitable.

We used a qualitative color scheme for the creation of map-like representations of the clusters: The different color shades only differentiate the clusters and are not associated with any order or meaning.

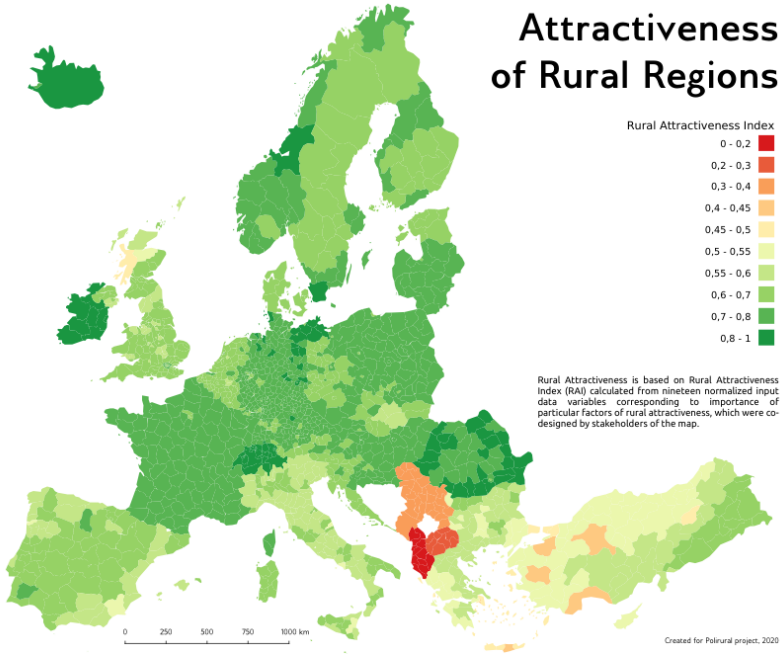
Results and discussion

In this section, we present the outcomes from the showcase application of our approach in the PoliRural project. These results and the illustrations based on them serve illustrative purposes only. Additionally, the presented visualizations only show a few possible ways to visualize rural attractiveness data out of many.

Rural Attractiveness Index values map

The map-based visualizations in Figure 1 through Figure 3 show the RAI values and cluster maps resulting from our showcase rural attractiveness assessment for the PoliRural project based on our framework. Figure 1 shows the RAI scores in NUTS 3 regions in Europe. In our example, the highest attractiveness scores are less associated to regions with increased agricultural activity and more associated with places with a high proportion of pristine nature but also low unemployment rates and good education, such as Sweden or Austria. This spatial pattern is due to the multi-factorial concept of rural attractiveness, which takes into account a variety of aspects. The areas in white could not be properly assessed due to a high share of missing data for these territories.

It is important to note that due to the heterogenous ways of defining rural areas (Jonard et al., 2009; Perlín, 2010; Pászto et al., 2015; Dijkstra et al., 2021), deciding which geographical areas are truly rural and which are not is highly controversial and may even fail to capture existing complex patterns (Hodge and Monk, 2004). Therefore, even maps displaying rural attractiveness may report RAI values for all parts of an investigated territory. For this reason, our maps show the values of RAI for all regions in Europe.

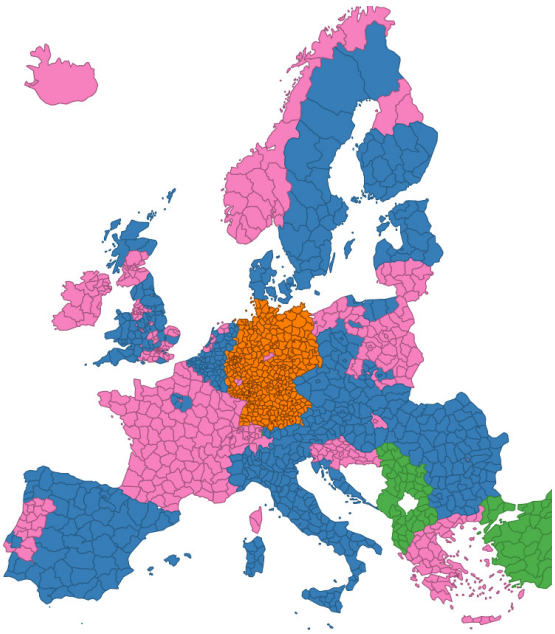


Source: Figure courtesy of the authors of the article

Figure 1: Map of the Rural Attractiveness Index.

Visualizations of clusters of regions with similar rural attractiveness profiles

Figure 2 and Figure 3 show map-like data previews of the cluster analyses with the investigated area divided into ten clusters. The variability in the delineation of the clusters is owed to the use of two different clustering methods – hierarchical and non-hierarchical clustering. Nevertheless, both maps share common features that illustrate the separation of several European regions, e.g., the assignment of the Scandinavian countries, Austria, Italy, Czechia, and parts of Poland to the same cluster.



Note: The colors only indicate to which clusters a region belongs and are not associated to any hierarchy or additional meaning.

Source: Figure courtesy of the authors of the article

Figure 2: Data preview of rural attractiveness clusters (non-hierarchical clustering).

Note: The colors only indicate to which clusters a region belongs and are not associated to any hierarchy or additional meaning.

Source: Figure courtesy of the authors of the article

Figure 3. Data preview of rural attractiveness clusters (non-hierarchical clustering).

Discussion

Our approach to assessing rural attractiveness through a composite index to assess rural attractiveness is not the first of its kind. However, what makes our approach unique is that it comprehensively captures a diversity of aspects of rural attractiveness, is adaptable to different contexts, and still delivers an integrated measure of rural attractiveness.

The adaptability of our approach to assessing rural attractiveness and thus the relativity and context-specificity of the RAI are both its key strength and limitation. The relativity of the RAI is a limitation as this means that the RAI cannot be used for generally valid global assessments like, for example, the Human Development Index. While this is a major limitation of the RAI, this is owed to the fact that absolute and objective assessments of rural attractiveness are not meaningful in any way.

The strength of the RAI lies in the fact that it perfectly mirrors the characteristics of the concept of rural attractiveness, whose exact meaning depends on the time-frame and scale for which it is supposed to be assessed; on the stakeholders that judge the attractiveness of a territory; and on the other territories to which a territory is compared. Accordingly, also the values of the RAI and the distribution of clusters change according to the kinds of included indices/data, to the weighting of to the different dimensions of rural attractiveness, and to the territories that make up a sample. Thus, the RAI can be a very useful tool for assessments realized for a specific purpose (e.g., a decision-making process about rural development) and based on local/regional perceptions to support decision-making on these scales.

This function can be further enhanced through the visualization of the RAI, for instance in the form map-like visualizations. Such visualizations that show which regions present which values of the specific RAI can help to identify patterns as well as best and worst-practice examples according to the applied notion of rural attractiveness. Visualizations that highlight clusters of regions with similar rural attractiveness profiles support the identification of regions that face similar challenges and present similar opportunities. These similar regions can, for example, start exchange and collaboration to address shared problems.

Notwithstanding, our approach to assessing and visualizing the attractiveness of rural territories is intended to be universally applicable to a variety of contexts. Yet, it also presents a number of technical and other challenges that must be addressed in order to produce useful and appropriate results. The issues discussed below do not represent an exhaustive list of challenges, but are a selection of challenges that we have found to be particularly relevant.

One challenge that we encountered in the rural attractiveness assessment in our showcase is the interpretation of the results of the cluster analyses in light of the fact that their outcomes vary widely, depending on the method used. However, some aspects remain the same regardless of the clustering method. For example, in our showcase, Austria and the Scandinavian countries were always in the same cluster in both hierarchical and non-hierarchical cluster analyses. Therefore, it can be assumed that such results that persist in the outputs of different cluster analyses are of distinct robustness and validity. Therefore, conducting cluster analyses using different methods does not necessarily lead to randomness of results. In fact, it can be helpful in identifying the most valid findings.

A critical issue specifically with our showcase application, which should be avoided in future applications of our approach, is that it was based only on a single set of weights determined through a stakeholder survey. This is justifiable in that it was a preliminary assessment that was primarily for demonstration purposes. Nevertheless, the problem here is that rural attractiveness is not only contextual and relative, but also presents another complex element: Even when applied to a particular context/territory, rural attractiveness cannot be reduced to a single shared vision; “rather, it is subject to a diversity of local discursive positions” (Lysgård et al., 2013, p.2879).

If this diversity of views on rural attractiveness is not adequately accounted for and a consensus on a single shared vision is forced, there is a certain risk that the interpretation of rural attractiveness will be dominated by powerful interests that often favor a neoliberal understanding. In such a view, the solution to all rural problems would be to attract new in-migrants by creating jobs and infrastructure, as well as to emphasize visual attractiveness and to develop the tourism sector to attract tourists (Lysgård et al., 2013). While such a strategy has some merit, it may not be in the interest of all stakeholders, especially populations already living in rural areas (Scott et al. 2011). Thus, rural

attractiveness assessments should ideally provide a range of different possible outcomes based on different views in order to make differences visible and to encourage debate (Lysgård et al. 2013).

One way to facilitate the inclusion and exploration of different views of rural attractiveness is the development of an interactive application that would allow not only experts, but all types of stakeholders to create visualizations of rural attractiveness based on their individual preferences. Such an application could include standard functionalities such as zooming or panning as well as the ability to change the weighting of the different categories of rural attractiveness or even to change input datasets. A first version of a web map client of Rural Attractiveness Maps built on HS Layers (Šimek et al., 2013) is available from the PoliRural Digital Innovation Hub (hub.polirural.eu).

Conclusion

Rural attractiveness is a vague and complex concept that is relative and context-dependent and cannot be assessed in absolute and objective ways, rendering its evaluation a real challenge. In this article, we present an adaptable Rural Attractiveness Index (RAI) for the assessment of rural attractiveness. While this approach is supposed to be widely applicable, it still pays heed to the context-dependency and relativity of the concept of rural attractiveness. The RAI is based on a set of categories that are supposed to be generally relevant to rural attractiveness (natural, social, economic, anthropic, cultural, institutional), yet integrates all of these categories into a single integrated measure to facilitate interpretation and communication of the assessment results. To further promote and facilitate the communication of the results of rural attractiveness assessments to stakeholders, we propose to use visualizations in maps based form.

The RAI and the map-based visualizations can provide information about the potential of rural territories, the search for common characteristics of regions, spatial patterns and similarities that can be used for further cooperation and specific and targeted development of rural regions. Hence, they are particularly relevant for policy- and decision-makers, people involved in regional development, strategic planning or investment, people interested in entrepreneurship or citizens living in rural areas. Furthermore, these tools can also be useful for academic regional development studies.

However, key to any of these activities is the inclusion of the relevant stakeholders since any notion of rural attractiveness can only be meaningfully defined by those who ultimately decide whether a territory is attractive to them or not.

Aside from their own value, these tools also present a first step in the development of an interactive online application that allows users of any kind to create maps of rural attractiveness according to their needs and preferences. As this application (which is still under development) helps explore the diversity of views of rural attractiveness, it can help make planning processes based on rural attractiveness assessments more inclusive and increase the acceptability and appropriateness of planning outcomes.

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A Multi-Method Approach to Assess the Adoption of Precision Agriculture Technology in Brazil

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Abstract

Precision Agriculture (PA) application aims to increase crop productivity while minimizing environmental impacts. We analyzed the topics most studied in the advancement of crop production in Brazil by applying the concepts of PA using the systematic literature review (SLR). A multi-method approach combined an SLR applying the PRISMA method and secondary data analysis. We found five clusters of technologies using the PA concept related to hardware development and four clusters related to applying technologies to software development in the PA concept. Most topics focused on using sensors to control water (soil and environment), soil electrical conductivity, and data communication. The focus on sustainability led researchers to reduce chemical products related to fertilizers and pesticides using Variable Rate Fertilizers (VRT) and reducing the environmental loading. According to the research results, it was evident that PA technology might help farmers make more accurate decisions about cultivation, production, harvest, and soil management. The availability of decision support systems powered by big data and artificial intelligence to select the best crop for a given season and soil might assist Brazil's sustainable growth of food production.

Keywords

Agricultural production, crop production, food production, hardware, software, sustainability.

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Introduction

Agriculture has undergone significant upgrades, starting thousands of years ago with the domestication of plants and animals, followed by the 'green revolution,' with systematic breeding and the widespread use of pesticides and fertilizers. Nowadays, precision agriculture, with advances in information and communication technology applied to all stages of the food production process, allowed increased productivity and minimization of environmental impacts (Walter et al., 2017).

With the increase of the world population in recent years and following the growth trend, there will be significant challenges concerning non-renewable energy sources, water, food, and the environment. Just as in the industrial segment, where the fourth industrial revolution arrived to increase productivity, quality, customization, and costs involved in production, we are already experiencing the use and application of these technologies in the Precision Agriculture (PA) segment. The application of this technology raises productivity and efficiency in using inputs, reduces labor costs, improves work quality and worker safety, and reduces environmental impacts (Massruhá et al., 2017).

Precision agriculture uses equipment with embedded technology, automated with a satellite steering system, autopilot, sensors, and seed and pesticide flow controls. Software aimed at obtaining, processing, and managing georeferenced data is also applied, as well as technology for soil fertility mapping for a straightforward application of fertilizers and pesticides, according to the variable rate, and remote sensing for crop monitoring. All technology is connected via IoT, and all data generated from its use is stored and processed via software to support decision-making, aiming to increase productivity (Bassoi et al., 2014).

The grain production area in Brazil is quite extensive, and in 2021, according to data from the National Food Supply Company (CONAB, 2022), the planted area was about 68.7 million hectares. The main grains grown are soy, corn, cotton, rice, and beans. In 2021, grain production in Brazil reached a record 271.7 million tons.

The record crop was driven by the increasing use of advanced agricultural technologies, including precision farming. As the Ministry of Agriculture, Livestock, and Food Supply (MAPA, 2019) states, Brazil ranks among the world's leading grain producers, boasting a projected harvest of 288.2 million tons during the 2020/2021 season. Regarding grain exports, Brazil is one of the world's largest exporters, emphasizing soy, corn, and coffee. Data from the Foreign Trade Secretariat (SECEX, 2022) in 2021 indicates that around 85.8 million tons of soybeans and 37.2 million tons of corn were exported.

Precision Agriculture (PA) aims to enhance food production efficiency while mitigating adverse environmental effects. PA helps sustainability in several ways: (1) By using precision agriculture, farmers can reduce the waste of resources such as water, fertilizers, and pesticides. Precision agriculture technologies like soil sensors, Global Positioning Systems (GPS), and drones help farmers apply these resources only where and when needed rather than uniformly across the entire field. Such initiatives reduce waste and ensure that resources are used more efficiently. (2) PA also reduces greenhouse gas emissions by improving crop production, and this optimization is achieved through decreased energy consumption in farming operations. Furthermore, precision agriculture technologies such as GPS and drones enable farmers to minimize fuel consumption by reducing the time and distance required to execute tasks like planting and harvesting. (3) PA can also enhance soil health, a crucial aspect of sustainable agriculture. Farmers can better understand soil nutrient levels and moisture content by utilizing PA technologies, enabling them to adapt their farming practices accordingly. Such improvement can help to reduce erosion, increase soil fertility, and promote the growth of beneficial microorganisms. Furthermore, (4) PA can also help protect biodiversity by reducing harmful pesticides and fertilizers.

Precision agriculture has gained space in Brazil lately, allowing better use of resources and increasing productivity. According to a study by EMBRAPA (2022), precision technologies can increase soybean productivity by up to 30% (Goldmeier, 2019). As information and communication technologies grew, PA became broadly used in Brazil in the last decade. The present study aims to evaluate the application of PA technologies in Brazilian crop production and the scientific and technological development of the knowledge field by using the Systematic Literature Review (SLR). The SLR makes it possible to analyze and map the scientific productions around the studied subject, seeking to understand the correlation between the keywords and the evolution of the theme in recent years (Gil et al., 2020; Kipper et al., 2020). The study aimed to determine the predominant areas of research focused on enhancing crop production in Brazil by utilizing Precision Agriculture principles.

Materials and methods

An SLR using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol, with the support of the VOSViewer software (Van Eck and Waltman, 2020), was developed to reach the objective. Employing the PRISMA protocol (Harris et al., 2014) in this SLR on PA in Brazil provides a methodologically sound framework that enhances the study's transparency, comprehensiveness, and reliability.

The extent of our study led us to come across a significant number of pertinent citations that presented a noteworthy obstacle in adequately handling and assessing this information. In order to rise above these limitations and guarantee an accurate and open methodical review, we opted to implement the PRISMA framework. Utilizing PRISMA, our review was systematically organized to assess all pertinent citations and reduce publication bias. Moreover, the integration of PRISMA elevates the reproducibility and credibility of our findings by enabling fellow researchers to replicate our methodology and validate our outcomes. Although initial limitations arose from the high volume of citations, utilizing PRISMA facilitated efficient data management and upheld the integrity and quality of our systematic review.

Three research questions (RQ) were proposed to guide this review RQ1 - Which are the most strategic themes related to PA studied by Brazilian researchers? RQ2 - Which technologies are most applied in Brazilian agricultural production?; and RQ3 – What are the future challenges and trends?

RQ1: PRISMA helps systematically identify and analyze the most strategic themes in PA research by Brazilian scholars, ensuring that the review covers a comprehensive range of studies without bias. RQ2: PRISMA's structured approach aids in the identification and synthesis of technologies applied in Brazilian agricultural production,

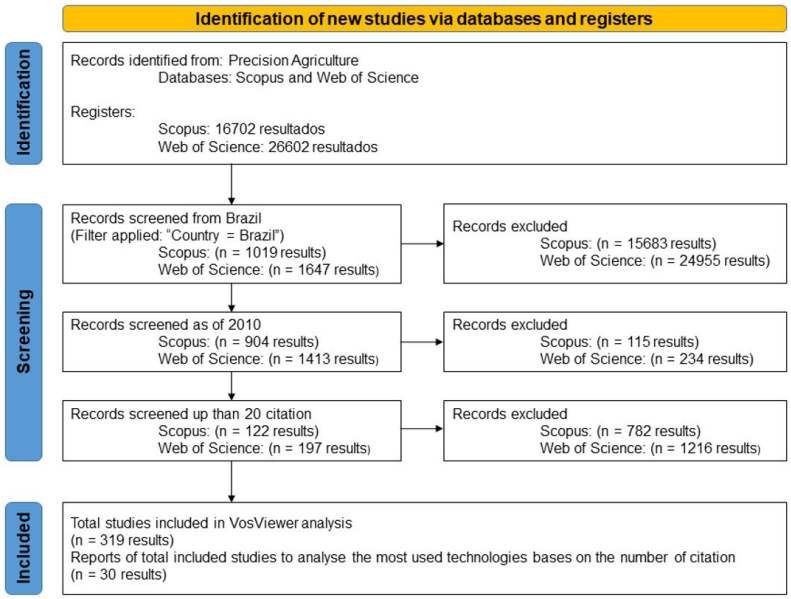
providing a clear overview of technological adoption and innovation. RQ3: By facilitating a systematic and comprehensive literature search and analysis, PRISMA supports the identification of emerging challenges and future trends in PA, guiding stakeholders in strategic planning and research.

A multi-method approach was employed (Aitken et al., 2020; Lui et al., 2020; Broekhuizen et al., 2021), combining an SLR with secondary data analysis. We proceeded with literature research (Pereira et al., 2018) and analyzed the data and information collected through scientific publications across an inductive process. We used the integrative bibliometric review to summarize and categorize the articles (Botelho et al., 2011). We searched the Scopus and Web of Science databases for data recording and applied the PRISMA 2020 checklist and flowchart for justification. The search about PA in Brazil covered all the years that the search returned relevant results to the researched subject. In this first stage, we only performed exclusion by country.

We applied the word filter only related to Brazil, as the objective was to have a general perspective of the growth and evolution of the theme in the country. For the second and third filters, we applied the selection of articles published from 2010 with citations greater than 20 to select the most current and relevant works. This filter returned 319 articles that were later analyzed in VosViewer software (Van Eck and Waltman, 2020). In this phase, we also chose the 30 most current articles with the highest citations to survey the technologies and applications related to the topic. Figure 1 shows the schematic of SLR applying the PRISMA method (Harris et al., 2014). The flowchart shows the methodology applied and all the results obtained for each exclusion and selection criteria, which follows the PRISMA guidelines.

Figure 1 depicts a flow chart outlining the SLR process to identify Precision Agriculture (PA) studies from specific databases and registers. The process is segmented into three stages: Identification, Screening, and Inclusion, visually represented by separate rows with accompanying descriptive text and numerical data. The initial search was conducted in Scopus and Web of Science (WOS) databases, yielding 16,702 and 26,602 results, respectively. In the screening phase, the records were first filtered by country, with the term "Brazil" applied, resulting in 1,019 records from Scopus and 1,647 from WOS. A further temporal filter was applied to include only studies as of 2010, narrowing down the results to 904 from Scopus and 1,413 from WOS.

An additional citation-based filter was applied to include only records with more than 20 citations, resulting in 122 from Scopus and 197 from WOS. After each screening step, the number of records excluded from both databases is noted. In the inclusion phase, 319 studies were included for VosViewer analysis, a tool for constructing and visualizing bibliometric networks. Additionally, reports of included studies were generated for further analysis based on the number of citations, amounting to 30 results.



Source: The authors

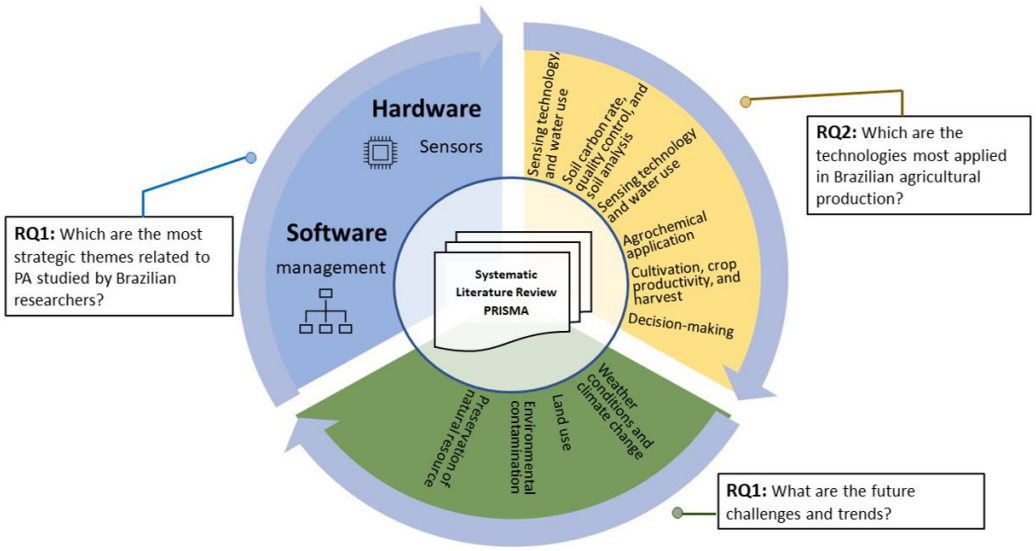
Figure 1: Schematic of the SLR using the PRISMA method.

In the second stage of the SLR, we used the VOSViewer software (Van Eck and Waltman, 2020) to map keywords separated by cluster, aiming to verify and understand the correlation and the most explored technologies in Brazil's scenario of precision agriculture. The most researched subjects and their correlations were analyzed. The number of appearances by the sphere size categorizes the appearance of keywords in the searched studies. Related words are connected by a line, and the repetitions between them through their thickness. For the second step of the multi-method approach, the subjects of the published articles related to technology-based achievement with increased crop yield in the same period were analyzed.

The relevant keywords related to crop yield and technology-based approaches, including "precision farming," "remote sensing," "farming 4.0," and "smart farming," were examined. We searched the Scopus and Web of Science databases to locate articles examining the connection between the most commonly used technologies. The focus was on seeking some association between the most used technologies and the increase in agricultural production in Brazil, analyzing the potential benefits of adopting these technologies to sustainably improve global food security and agricultural productivity. The schematic view of the methods used to answer the research questions is presented in Figure 2.

Figure 2 presents a schematic diagram outlining the structure of a systematic literature review (SLR) based on the PRISMA framework applied to Precision Agriculture (PA) in the context of Brazilian agricultural research. It is divided into three main components: hardware, software, and systematic management, subdivided into thematic elements. The component hardware as a sensor icon symbolizes physical tools and equipment used in PA, such as sensors. Depicted by a management interface icon, this element emphasizes the software and decision-making tools used for data analysis and interpretation in PA. The systematic management section of the diagram indicates the management strategies in PA and shows no specific icons; it forms the base supporting the hardware and software components. In the central part of the diagram is the SLR process based on PRISMA, suggesting that the review is a methodical effort to compile and analyze literature on specific thematic areas in PA. The thematic areas of focus for the SLR are represented in the surrounding yellow ellipse, highlighting topics such as Agrochemical application, crop cultivation, productivity, harvest, and decision-making. The surrounding green area outlines broader, context-specific themes pertinent to PA in Brazil, including Environmental laws and land use, Communication and rural extension, and Climate change and its impacts. The diagram relates to the research questions guiding the thematic exploration of the SLR.

To address the bias that could be raised during the SLR process, we focused on the following



Source: The authors

Figure 2: Schematic view of the methods used to answer the research questions.

questions: (1) Were the databases and search terms used in the identification phase comprehensive enough to capture all relevant studies, or were they biased toward certain publications or disciplines? (2) Does including studies with more than 20 citations introduce a bias towards more popular or positive results, potentially overlooking significant negative or null findings? (3) Were the studies included in the analysis limited to those published in specific languages, which might exclude relevant research published in other languages? Moreover, by limiting the studies to those published as of 2010, there is a possibility of excluding relevant historical data or trends that could influence the interpretation of the evolution of PA technologies in Brazil.

Results and discussion

The Scopus base search returned a total of 16,557 published studies that were searched for as "Precision Agriculture" when applied to the filter of works only related to Brazil. We had 1009 published studies, as we see the division by year in Figure 1. The first study was published in 1997, followed by a relatively low number of publications until 2005. In the mid-2010s, the subject experienced a notable surge in growth, reflecting its increasing influence within the academic dominion.

The Web of Science (WOS) database search returned 26521 articles published and searched as "Precision Agriculture," with only 1645 articles of Brazilian origin. Figure 3 shows that the published articles have a similar profile to the results obtained from the Scopus database. The articles continued with minor presences until 2007 and assumed a high growth around 2012.

In addition to research related to PA in Brazil, the numbers in Figure 4 reflect a significant increase in grain production in Brazil. Despite a marginal rise in the cultivated land area post-2000, the surge in production was notably greater, signaling a substantial boost in productivity (EMBRAPA, 2022; CONAB, 2022).

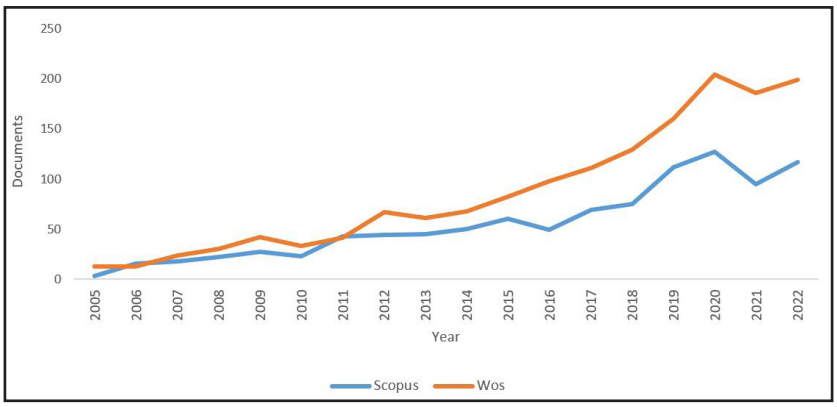


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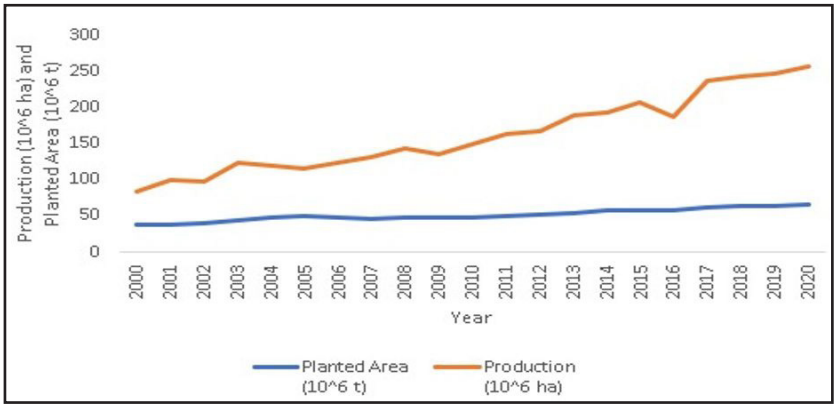
Figure 3: Curve of the studies published in the Scopus and Web of Science (WOS) websites each year from 2005 to 2023.



Source: EMBRAPA (2022), CONAB (2022)

Figure 4: Curve of Brazil's grain production and crop area from 2000 to 2020.

For the second analysis stage, a filter was performed on all selected articles, taking only the keywords related to technologies applied to Precision Agriculture (Table 1). From the data obtained, we performed a literature review to validate the correlation and application of the subject and understand which part of the process was applied. For instance, how each technology works and whether it is related to use as the equipment itself (hardware) or if it is more focused on supporting decision-making using software solutions.

The keywords were examined, and the scientific articles were selected and classified to analyze the clusters and their behavior. It was observed that the keywords were divided into four distinct fields correlated with the SLR presented in Table 1.

The technologies related to hardware are shown in Figure 5. The clusters are highlighted by colors, where we have colored the sensing technology and points related to water used to produce the dots in green. In yellow, the subjects are related to the soil, such as carbon rate, quality control, and soil analysis; in blue, we have chemical products related to fertilizers and pesticides with greater importance. The themes in red are related to cultivation, crop productivity, harvest, and electrical conductivity, which link next to the yellow field corresponding to the soil. In purple, we identified the topics related to land use, cover, and deforestation.

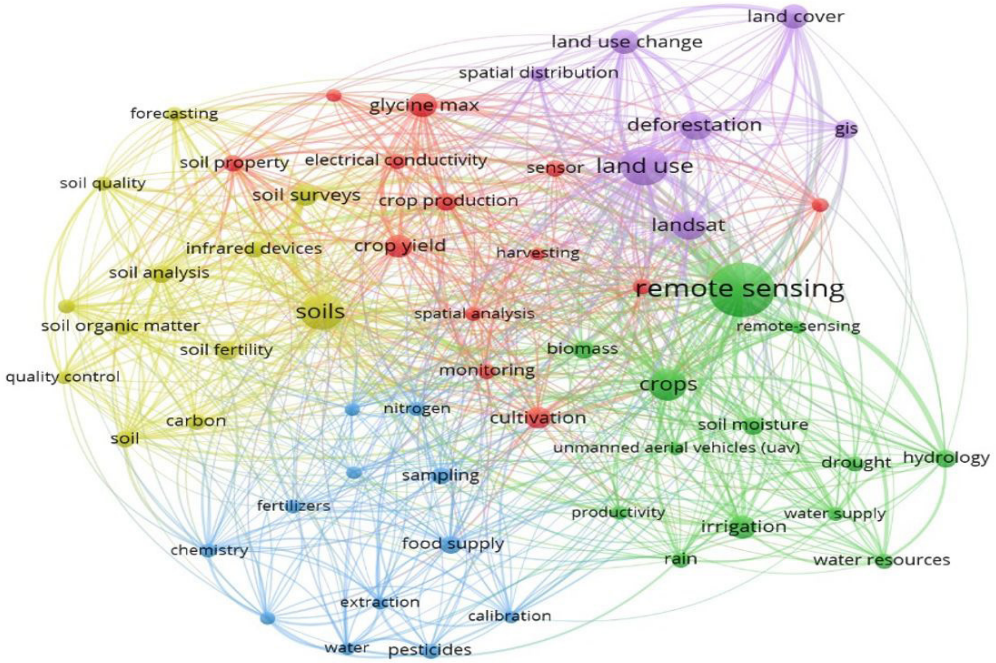
In the Figure 6, we present the processes of management-related keywords via software development. The figure represents a complex bibliometric network visualization mapping the interconnected research topics in soil science, agriculture, and environmental monitoring. The visualization illustrates how various concepts and themes are related within the literature. Central themes such as "soils," "remote sensing," "crops," "land use," and "water resources" are depicted as large nodes, indicating their prominence in the research. Each theme is connected to many related sub-themes, indicating interdisciplinary connections. For example, "remote sensing" is closely associated with "GIS," "drought," "hydrology," and "soil moisture," highlighting the role of remote sensing technologies in understanding and managing water-related aspects of agriculture.

The strong connection between "soils" and "fertility," "organic matter," and "crop yield" underscores the critical importance of soil in agricultural productivity. The link between "remote sensing" and "drought" or "hydrology" suggests a significant focus on using remote

Application	Description	References
	Hardware	
Soil, pest control, and harvest	Agricultural machines with integrated electronics (plows and seeders) and automated steering system. Remotely piloted aircraft (RPAs) or Unmanned Aerial Vehicles (UAVs) act in mapping using a global positioning system (GPS). Sensors to measure organic matter, soil characteristics, and contamination. Seal mapping using electrical conductivity measurements (ECa).	Bolfe et al. (2020); dos Santos et al. (2019); Iost Filho et al. (2020); Cardoso et al. (2022); Magalhães al. (2007); Souza et al. (2016); Lassalle et al. (2021).
	Sensing and mapping to measure productivity, fertility, and compaction attributes, based on topography, terraces, and soil type, for further dosing and localized application. Monitoring of temporal variability. Survey of diseases and illnesses through RPAs or UAVs. Optical sensors and sprayers for spot application. Use of multispectral images, together with GIS tools.	Tavares et al. (2019); Tavares et al. (2020); Molin et al. (2019); Molin et al. (2008); Morlin et al. (2020); Braunger et al. (2017); Demattê et al.(2015); Schepers et al. (2019).
	Harvesters equipped with GNSS (Global Navigation Satelite System) and productivity sensors. Harvesters with autopilot and harvest monitor.	Gavioli et al., 2016); (Valente et al., 2020).
	Software	
Management of production, processes, and inputs	Images are linked to data interpolation and transformation to generate index maps, crop health, soil conditions, management, and crop productivity estimates. The use of data for decision-making, climate forecasting, phytosanitary management, and financial market perspectives. Use Graphic Information Systems (GIS), geostatistics, and data mining in databases.	Schwalbert et al. (2018); Acorsi et al. (2019); Oldoni et al. (2016); Issad et al. (2019); Agostinho et al. (2008).
	Productivity sensors used in production. Use of Variable Rate Technology (VRT) as inputs at a variable rate. Modeling via geographic information system (SIG).	Bazame et al. (2021); Schepers et al. (2004); Kamienski et al. (2019); Keswani et al. (2019).
	Analytical methods and solutions to process data and build support systems for crop management decision-making. Use of the Internet of Things. IoT, sensors, and implements reduce operating costs, increase productivity, and create new business and service opportunities. Use computational tools based on artificial intelligence.	Patricio et al. (2018); Santos et al. (2020); Spekken et al. (2013); Kamienski et al. (2019); Camili et al. (2007); Faiçal et al. (2017); Franceschini et al. (2018).

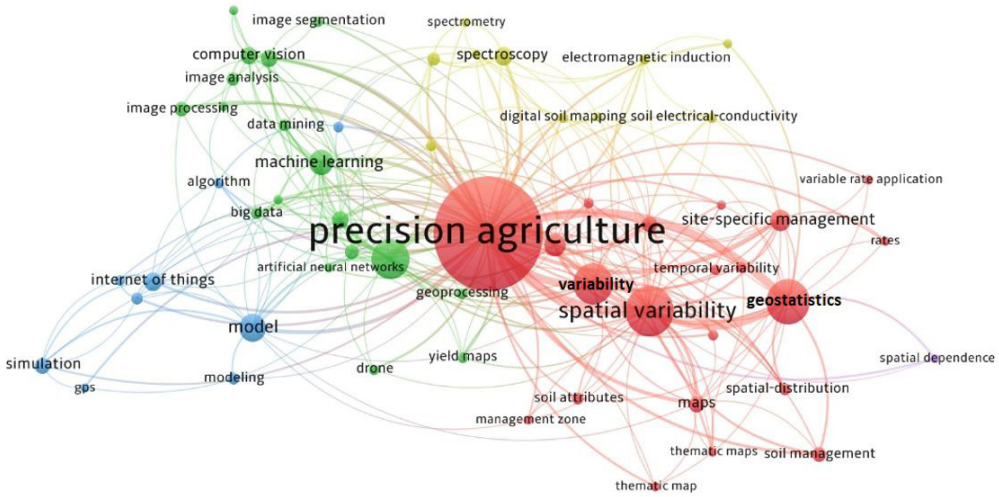
Source: The authors

Table 1: Technologies used in Precision Agriculture in Brazil.



Source: The authors

Figure 5: Technologies related to hardware development in the Precision Agriculture concept.



Source: The authors

Figure 6: Technologies applied to software development in the Precision Agriculture concept.

sensing for water management and assessment of environmental conditions affecting agriculture. The node "land use" connected to "land cover," "land use change," and "deforestation" indicates ongoing research on the impact of agricultural practices on land use patterns and environmental conservation. The network visualization provides insights into the current research landscape, identifying well-established research areas and emerging topics. It would also be essential to discuss how these themes contribute to understanding the complex interactions between agricultural practices, environmental management, and sustainable development.

Keywords such as modeling, IOT, image processing, soil analysis, simulations, variation rates, spatial variation, and geostatistics are highlighted. All words are linked to software development, processing, and supporting decision-making (Table 1).

The figure represents a bibliometric network

visualization related to precision agriculture. The nodes (terms) are sized according to their occurrence frequency within the literature, and their proximity to one another indicates a strong co-occurrence or thematic linkage. The central and most prominent node is "precision agriculture," underscoring its role as the primary focus of the analyzed literature. Surrounding this central node are clusters of interconnected terms, each representing a sub-theme within precision agriculture. For example, a prominent cluster in red, centered around "variability" and "spatial variability," also includes "geostatistics," "site-specific management," and "temporal variability." This cluster suggests significant research interest in understanding and managing agricultural fields' spatial and temporal variation to optimize inputs and outputs. Another significant cluster in green includes terms like "computer vision," "image analysis," and "data mining," which are linked to "machine learning" and "artificial neural networks." This indicates a strong focus on using advanced analytical techniques and AI to process and interpret data in precision agriculture. The presence of "Internet of Things" (IoT) in the blue cluster suggests the relevance of interconnected devices and sensors in precision agriculture. This cluster also includes terms such as "model," "simulation," and "GPS," pointing towards the use of modeling and geospatial technologies for farm management. Precision agriculture topics interconnect and potentially create interdisciplinary approaches to solving complex problems in agriculture.

Most included studies were concentrated on a few key technologies within Brazilian Precision Agriculture, indicating a trend or a gap in the research. A consensus or strong correlation between certain agricultural practices and outcomes such as yield improvement, cost reduction, or environmental benefits might be identified. The VosViewer revealed that topics such as "sustainable farming practices" or "IoT in agriculture" are emerging as highly cited areas, suggesting increasing academic and practical interest. Many studies focus on specific crops or regions, highlighting a potential research bias or a regional priority.

Future research should cross-validate findings with additional databases or systematic reviews. Consider also including studies with fewer citations to provide a more comprehensive overview. We also suggest including studies across different languages and periods if relevant.

Conclusion

We analyzed the scientific development of PA in the academic scenario and identified the most researched technologies in Brazilian agricultural production that answered research question 1 (RQ1). The most strategic themes studied by the researchers can be grouped into five clusters, one related to sensors and hardware, which are also associated with soil and water use. Maia et al. (2017) describe an application of the Internet of Things (IoT) designed to monitor the water-soil balance, composed of temperature and humidity sensors (soil and environment), the soil electrical conductivity, Global Positioning System (GPS) and a ZigBee radio for data communication. The approach to the use of sensors in controlling water use with sensors is shared by other authors (Allen et al., 1998; Kim et al., 2008; Jabro et al., 2020). The sensing technology and points related to water produced the dots in green.

Various topics related to soil, such as the amount of carbon present, the methods used to maintain quality, and the analysis of soil composition, have come together to form another cluster. These topics focus on the techniques and technologies that can aid farmers in managing unique aspects of their production, such as soil properties, fertilization methods, and harvest strategies, aiming to increase efficiency, productivity, and overall quality of the crops. Farmers can better understand their soil by utilizing this data, including its characteristics, nutrient requirements, climate patterns, weed growth, and manual practices. Other studies have employed sensors and geostatistics to identify the soil type, measure micronutrients and plant nutrition levels, and analyze the contents of soil fertilizers. These methods allow for a spatial analysis that is both cost-effective and less prone to uncertainty, ultimately leading to improvements in productivity (Bottega et al., 2013; Valente et al., 2014; Silva et al., 2015; Sott et al., 2020).

The cluster involving chemical products related to fertilizers and pesticides is called Variable Rate Technology (VRT). Pesticides are chemical products that aim to reduce the environmental impact by using them only when and where they are needed. This approach helps farmers to decrease the overall amount of inputs used and, as a result, reduce the environmental loading. Avoiding overuse provides several environmental benefits, such as more targeted use of information that decreases losses caused by excess applications and nutrient imbalances, weed escapes, insect

damage, and more. Additionally, a precision application can help reduce the development of pesticide resistance. Through the precise provision of nutrients and effective pest management, farmers can enhance their crop yields. VRT aids in reducing the application of fertilizers and pesticides, thus mitigating the risks of water contamination and lessening the environmental impact on local ecosystems (Bongiovanni et al., 2004; Pathak et al., 2019; Raj et al., 2022). PA technology can help farmers make informed decisions about cultivation, production, harvest, and soil management. Farmers can use decision support systems powered by big data and artificial intelligence to select the best crop for a given season and soil type by collecting and analyzing data related to factors like soil type and electrical conductivity. These systems consider multiple input factors to determine the best crop, such as the fertilizers required, irrigation methods and schedules, weed control measures, insecticides, and harvest periods. Using technology to optimize these factors, farmers can increase crop yields and obtain a higher-quality harvest. The decision-making process is facilitated by software that helps analyze the data and provide recommendations based on the input parameters. Ultimately, these tools can help farmers make more informed decisions, improving crop and business outcomes (Venkatalakshmi et al., 2014; Tantalaki et al., 2019).

Finally, we identified study fields of land use, land cover, and deforestation. To plan sustainable land cover, we can use spatial land-cover models. The adverse effects of the population's constant desire for more land lead to deforestation, the loss of agricultural land, and the conversion of grasslands to urban and industrial zones. It is possible to reduce or prevent these consequences using technologies such as multitemporal remote sensing data, spatial criteria, and predictive models, which can efficiently monitor these changes and assist in developing sustainable land use strategies (Tariq et al., 2023). We believe Brazilian farmers mostly use the above-listed technologies, at least the large ones who produce crops for export, answering research question 2 (RQ2).

Our findings agree with previous results of a survey by EMBRAPA (2022). Precision Agriculture in Brazil application, in general, focuses mainly on the soil. This encompasses the application of soil correctives, care for the soil quality, application of fertilizers and pesticides, and harvest output, with equipment with embedded technology, guided via GPS, autopilot, and applying inputs at varying rates (Bernardi et al., 2014).

The current crop production scenario demands productivity, cost reduction, and product requirements with ever-better quality, which are economic factors that support the need for precision agriculture. Environmental factors such as weather conditions, scarce natural resources, and environmental contamination lead us to answer research question 3 (RQ3). This technological scenario increasingly demands multidisciplinary training, where automation and precision agriculture are essential. However, government support is needed to access technologies and investment in education and practice for technicians and products, items that did not stand out in our analysis. Nowadays, the absence of human development factors is visible in public policies and investment in education (Bassoi et al., 2019), decreasing farm labor opportunities.

Future studies should focus on the development of human resources and governmental actions applied to precision agriculture in Brazil. To mitigate the lack of education and governmental policies related to the training of the farmers to use and apply the technologies and to help them with financial programs.

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Implementation of a Secret and Verifiable Personal Remote Electronic Election of an Agrarian Organization per the Recommendation of the Council of Europe

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Abstract

Lockdowns and social progress have increased hours of work from home, often requiring remote methods of communication. Agricultural organizations from associations to cooperatives to joint stock companies must prepare to carry out more activities online. This article proposes a procedure for the possible implementation of a remote electronic election in personnel matters of the organization using the Belenios system, based on an evaluation of expectations from a questionnaire survey of agricultural college students and graduates. The proposed procedure is subsequently verified based on an evaluation of compliance with the Council of Europe recommendation on standards for electronic voting.

Keywords

Internet voting, E-voting, E-democracy, Open-Source, Belenios, E-elections.

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Introduction

Online voting is becoming an increasingly prevalent method of casting a ballot. In Estonia, 51% of participating voters cast a ballot online in the 2023 Parliamentary elections (Valimised.ee, 2023). While the COVID-19 pandemic has promoted the use of ICT tools for remote communication, i-voting has not developed as much in national politically binding elections (Driza Maurer et al., 2023). Remote electronic dialing is one of the possibilities of using ICT. So that the members of the institution do not have to all meet in one place for the elections, but elections can be instead conducted remotely.

If it is a public election without the secrecy of individual ballots, such an election can be carried out in many ways. The problem arises if the principle of secrecy of elections is to be observed, i.e. the secrecy of ballots so that even the administrator of the election system cannot find out the form of individual ballots. I-voting is developing in its use in the primary elections of political parties (Blanchard et al., 2022) and their other intra-party decision-making (Martínek and Malý, 2024), in academic elections (Adida et al., 2009) and in other institutions. In our paper, we focus on secret personnel ballots in agricultural enterprises, which can be agricultural or food production cooperatives, or limited liability companies or joint stock companies with a focus on agriculture and food production. The proposed methodological procedure may also be suitable for agricultural unions and associations.

Food cooperatives began to be established in the Czech Republic in the first half of the 19th century, and agricultural cooperatives were also established in the second half. Among the basic principles of cooperatives is democratic control, requiring also voting by cooperative members (Kořínková et al., 2017). After 1989, other types of agricultural enterprises using voting within the ownership structure began to emerge in the Czech Republic in the form of limited liability companies or joint stock companies. The Act on Companies and Cooperatives (Czech Republic, 2012) allows voting using technical means. The voting conditions must ensure that the identity of the voting person is verified and that the shares or stocks associated with the voting right are identified. These conditions are determined by the articles of association or the articles

of association and are set out in the invitation to the general meeting or in the draft resolution. In the case of a cooperative, each member has 1 vote in the voting and secret ballots are generally permitted. In the case of limited liability companies, a secret ballot is excluded in certain cases, for example when the law requires the voting members to be named in the notarial deed. A secret ballot is required for the election and removal of employee members of the supervisory board.

In the Czech Republic, agrarian enterprises already use a number of digital services, which include e-mail, electronic signature, the Ministry of Agriculture's eAgri portal, data box, public administration portal, tax portal, electronic procurement, e-customs and others (Rysová et al., 2013). Agricultural enterprises are also gradually starting to use social networks (Kánská et al., 2013). Secret ballot via the Internet is not among the commonly used systems. With the use of information and communication technologies (ICTs), farms can enjoy benefits that may include better accessibility of elections, greater voter interaction, voter time savings, and others. At the same time, however, potential threats and risks must be addressed where the security of the constitutional principles of personal elections, which commonly include universal, equal, free and secret suffrage, may be compromised. Legislative documents that should be considered when i-voting in the Czech Republic include the recommendations of the Council of Europe, of which the Czech Republic is a member (Driza Maurer et al., 2023).

Council of Europe Recommendation on standards for e-voting

The Council of Europe's core legislative document for i-voting is Recommendation CM/Rec(2017) 5 of the committee of ministers to member states on standards for e-voting (Council of Europe, 2017). While the Recommendation is not binding on members, compliance with it is expected. Norway and Sweden have voluntarily adopted the Recommendation, the Supreme Court in Estonia has referred to the Recommendation, and in Belgium the Recommendation has been used as a benchmark in the evaluation of e-voting (Rodríguez-Pérez, 2022).

Based on the results of a questionnaire survey among students and graduates of agricultural colleges, this paper aims to propose a sufficiently transparent and verifiable methodological procedure using the open source Belenios system for conducting a secret remote electronic election in an agricultural enterprise or union. The methodological procedure should be subsequently validated using the requirements of the Council of Europe (2017) recommendations.

Materials and methods

In this article, a methodical procedure for the implementation of a secret remote electronic election using the Belenios test system was proposed. To achieve the goal of the article, a survey of professional literature was conducted from the scientific databases Web of Science and Scopus. To process the literature search, the article further focuses on professional texts, legislation and other sources related to agricultural enterprises.

Questionnaire survey on the characteristics of remote electronic voting

In order to find out the opinions on the features of remote electronic voting, a questionnaire survey was conducted among students and graduates of Czech universities with agricultural specialization. We assume that these are people with higher technical literacy who may be potential users of i-voting systems on farms in the near future. The Agbesi et al. (2023) framework with identical questions was used to construct the questions, which explored dimensions of Internet voting transparency, supplemented with a few specific questions. Agbesi et al. (2023) identify five core dimensions, namely Information Availability, Understandability, Monitoring and verifiability, Remedial Measures, Testing, these dimensions affect the perception of transparency which in turn affects the trustworthiness in the whole system. The anonymous questionnaire survey was conducted online via the Dotaznik.czu.cz platform operated by the Czech University of Life Sciences Prague. The invitation to participate in the survey was extended primarily to Czech students and graduates of agricultural universities. The survey was conducted from 24 October 2023 to 12 May 2024. Participants were shown all information including consent to data processing on the survey homepage.

Respondents answered questions on a seven-point Likert scale ranging from Strongly Disagree (0) to Strongly Agree (6) on five defined dimensions. A total of 177 people were recorded as completing the questionnaire. A total of 108 questionnaires were completed in full. Of these, 8 more questionnaires

were removed because the control question "This question is not part of the survey and just helps us to detect bots and automated scripts. To confirm that you are a human, please choose 'Strongly agree' here" was answered differently than Strongly agree. Out of the 100 responses, 64 were male, 35 were female and 1 respondent did not indicate their gender. 72 respondents are aged 18-30, 18 aged 31-40, 5 aged 41-50, 2 aged 51-60 and 3 aged 61-70. 72 respondents have completed secondary education, 10 have a Bachelor's degree, 12 have a Master's degree and 6 have a PhD.

The questionnaire survey is evaluated in aggregate according to the defined dimensions and transparency, which consist of individual questions. The rating describes the average frequency of responses on a Likert scale and the degree of expectation of fulfilling a given dimension on a scale from 0 (not at all expected) to 1 (fully expected), where from 0.5 upwards a given characteristic is expected. The level of expectation for a given attribute is the ratio of the average rating to the maximum possible rating within the aggregate of the whole dimension. The value is rounded to 2 decimal places.

The Statistica 14 software was used to do the descriptive statistics. We calculated fundamental information such as the mean, minimum, and maximum values, various measures of variation, and data regarding the shape of the variable's distribution (including the standard deviation and the standard error). An important aspect of the description of a variable was the shape of its distribution, which indicates the frequency of values within different ranges of the variables. More precise information was obtained by performing normality tests to determine the probability that the sample originated from a normally distributed population of observations, specifically using the Shapiro-Wilk test. These statistics were included in the dataset (Martínek and Tyrychtr, 2024).

Methodology for the testing the software used

Our methodology was developed to be used with the Belenios system, which, according to Cortier et al. (2019), offers a compromise between simplicity and security. Belenios is based on the Helios system (Adida et al., 2009). For the testing purposes of this article, the Belenios system installation at *https://volba.odvolit.cz* is used, which also verifies the correct functionality of the open-source code of the official system installation at *https://vote.belenios.org*. To specify the new methodological procedure, the general characteristics of the organization's information systems and their requirements were considered. The proposed methodological procedure combines the instructions of the Belenios voting system (Belenios team, 2023) embedded in the practical paper voting common in Czech organizations.

Methodology for the design of the election procedure

The methodological procedure is designed to meet the expectations identified in the questionnaire survey. The methodological procedure is tested by experimental voting in the form of a secret personnel election of a model organization. In our case, the model organization is a medium-sized agricultural cooperative, which has its information system for members and which uses the procedure for the election of the board. The cooperative thus uses an ERP system that enables the display of personalized information for individual members of the cooperative as well as communication through encrypted messages.

Methodology for verification of the proposed methodological procedure

Subsequently, the proposed methodological procedure of the election was verified by checking against the fulfillment of Recommendation CM/Rec(2017)5 of the Committee of Ministers to member States on standards for electronic voting of the Council of Europe (Council of Europe, 2017) through answers created based on the methodological evaluation of the Helios electronic system (Panizo Alonso et al., 2018), professional literature, security analysis (Cortier et al., 2020) created by the authors of the Belenios system, by testing the system. Considering the limitation of the length of the paper, the basic 49 standards (Brunet and Essex, 2023) are evaluated descriptively. Each requirement is also evaluated in brackets as fulfilled (○), not fulfilled (✗), or fulfilled under certain conditions - partial according (Δ) to the symbols in the framework of Panizo Alonso et al. (2018).

Results and discussion

Based on the evaluation of the questionnaire survey, it can be determined that students and graduates of agricultural colleges expect the i-voting system to meet all 5 defined dimensions and transparency, so in the proposal of the methodological procedure of e-voting of agricultural organizations, we will try to meet the expectations (Table 1).

Dimensions (number of questions within a dimension)	Average frequency of responses							Level of expectation
	0	1	2	3	4	5	6	
Information Availability (4)	1.25	1.75	3.25	9	15	25.5	44.25	0.81
Understandability (5)	0	0.2	0.8	3.4	17	33	45.6	0.86
Monitoring and verifiability (5)	0.4	0.4	1.8	8	17.2	30	42.2	0.83
Remedial Measures (5)	0.6	1.6	4	9.6	15	30.8	38.4	0.80
Testing (4)	0.75	0.75	1.75	8	16.5	27.25	45	0.83
Transparency (4)	1.5	0.75	2.25	12.5	19.25	29	34.75	0.79

Source: Authors (Martínek and Tyrychtr, 2024)

Table 1: Evaluation of a questionnaire survey of expected characteristics of i-voting systems among students and graduates of agricultural colleges.

Methodical procedure for remote secret electronic election

The basis for the possibility of conducting an electronic election is to use a trusted electoral system under an administration that voters trust. For the purposes of this article, we use the open-source system Belenios, the functionality of which was verified by our installation. The following method of conducting an election is designed to be conducted, for example, during a remote meeting via an online conference of the membership to participate in the election.

Voters should be informed in advance of the plan to conduct electronic elections, for example in an invitation to a meeting. In accordance with the GDPR, voters should be informed about the way personal data is protected within the organization's information system. The organization should prepare or refer to detailed instructions for using the voting system. In the first phase, it is necessary to designate an election administrator who, as a member of the election commission, will ensure the technical setup and administration of the election. This can be the secretary of the membership body, in the case of ensuring greater credibility, it can be, for example, the independent IT administrator of the given organization.

The administrator can create a new option after logging in. Access codes and authentication are important in the system, which can be via email and password or a trusted third-party system (CAS). In the basic mode, access codes and passwords are sent by the election server; to increase security, access codes should be sent to voters in a different way than by e-mail sent by the election server. This activity can be ensured by an authorized authority, which could distribute the access codes to invited voters in a paper invitation to the meeting, or send them, for example, via the organization's internal communication system. If access codes or passwords are transmitted in a way other than those sent by the election server to the voter's e-mail, there is less chance of discrediting the election, as the potential risk of "eavesdropping" on encrypted e-mail communication or breaking access to the voter's e-mail box is reduced. The administrator thus enters the name of the authorized authority and gives it a link for generating access codes. In the case of a test election, the individual personal access codes are imported by an authorized authority, which can be the election administrator, into the organization's internal system, which then displays the specific access code after logging in to the given voter with a link to the specific election. The authorized authority has at its disposal a list of voters, which it can also provide to other members of the electoral commission. After the end of the elections and their successful audit verification, this information is removed from the internal system in order to increase the long-term security of the secrecy of the vote.

After setting the voter authentication methods, the administrator further enters a clear name and description of the election, sets questions and answers for the first round of the election, and adds his name and contact, which should be on the authorized identity in case of obtaining a lost access code. It also sets the language of choice, in the Czech Republic the default is Czech (cs), or for people who do not know Czech, they can add other languages of choice, including English (en).

The administrator further populates the voter register by adding a voter email list with one email per line. The system allows you to enter the login of each user in case of using a more sophisticated method of authentication connected to the central authentication service (CAS). The number of whole votes of a given voter can be added to the third place

of the line, separated by a comma, in the case of, for example, different ownership shares of the voters. The same vote weight is used in the experiment. Members of the electoral commission should also have access to the list of voters, including information about their participation in the vote, before the start and after the end of the vote.

As in the case of paper elections, it is necessary to choose persons who will take care of the security of the election in the given institution. In the case of using Belenios, at least two other members of the electoral commission can be elected by public election, who will also be guarantors of the election. The guarantors should not have a personal interest in the outcome of the election so they have no motivation to influence the election after the agreement. Alternatively, the guarantors could be appointed by each of the candidates so that each candidate has one trustworthy person in the electoral commission without whose participation the election results cannot be influenced. After selecting the guarantors, the administrator enters their names and e-mails into the selection settings of the Belenios system. Subsequently, the administrator gives the guarantors, for example, using a confidential secure communication system, their links for generating keys.

When preparing for the election, it is necessary to fill in the voting questions and answers by the administrator. Although the Belenios system allows for various alternative voting methods, including ranking and scoring, for testing purposes, traditional two-round voting, which is often used in organizations as well, will be used. Thus, all nominated candidates participate in the first round. The method of nomination is determined by each organization itself, just as it is already done in paper elections. If any of the candidates receives more than half of the votes, they will be elected in the first round. Otherwise, the two candidates with the highest number of votes advance to the second decisive round. In order to reduce the risk of a tie election in the second round, it is possible to define a condition in the approved voting procedure that in case of equality of votes in the second round, the number of votes in the first round is taken into account.

Before starting the election, the guarantors carry out its encryption, when they save and enter a private key and a unique fingerprint. Immediately after the election is started by the administrator after it has been encrypted, the guarantors will verify the identity of their unique fingerprint with the publicly displayed fingerprint on the front page of the given election next to their name.

The Electoral Commission shall determine in advance the beginning and end of the voting, which shall be clearly announced to the voters, and the administrator shall set the given times. If an event occurs that may limit voters' access to casting their vote in the electronic ballot box, the electoral commission may agree to extend the deadline for voting.

The voter accesses the election at the URL sent by email with the password or displayed together with the access code. First, he enters the access code, then he fills in the ballot when it should be possible to submit an empty ballot. After it has been encrypted, the voter should save a printout of the ballot for verification and then insert it into the electronic ballot box by logging in using the password sent. At any time after that, he can verify the presence of the ballot in the ballot box using the stored fingerprint.

After the end of the election, the administrator has the encrypted result calculated and then waits for the decryption of the result by all the guarantors. The administrator will provide the guarantors with a URL to enter their private keys to decrypt the election. Admin can also postpone the publication of the result to the exact time. After the evaluation of the elections, the administrator should hand over to the members of the electoral commission the list of voters, including information on participation in the vote. The members of the electoral commission should subsequently audit the voting results (Belenios team, 2023), and anyone else can also do this.

After the audit, both the administrator and the members of the election commission should delete all stored keys and voter lists from their PCs and the organization's internal systems. The choice itself is subsequently archived and deleted after a longer period of time. If all verifications are carried out, the choice can be immediately deleted to ensure the greater long-term security and secrecy of votes.

In the event of an incident or violation of the procedure, in any part for which the members of the election commission are responsible, they immediately inform their superiors - the presiding organization, so that correction can take place. Similarly, voters or auditors should immediately inform the electoral commission of any suspicious event.

Verification of the electoral methodological procedure with the Recommendation CM/Rec(2017)5 of the Committee of Ministers of Member States on standards for electronic voting of the Council of Europe (2017)

1. *The voter interface of an e-voting system shall be easy to understand and use by all voters. (○)*

The Belenios system has already been used in many elections and thousands of different users have managed the election (Cortier et al., 2019). The election process is intuitive and is supplemented with instructions that help less technically literate election participants.

2. *The e-voting system shall be designed, as far as is practicable, to enable persons with disabilities and special needs to vote independently. (Δ)*

The Belenios system achieves a rating of 72 % in the accessibility test (Accessibility Checker, 2023), but at the same time, it is open source, which, if necessary, allows modifications for greater accessibility to electronic voting.

3. *Unless channels of remote e-voting are universally accessible, they shall be only an additional and optional means of voting. (○)*

The proposed method takes into account the availability of the voting system online via the Internet. A classic paper election is not excluded for users who do not want to vote online.

4. *Before casting a vote using a remote e-voting system, voters' attention shall be explicitly drawn to the fact that the e-election in which they are submitting their decision by electronic means is a real election or referendum. (○)*

In the proposed procedure, information regarding the meaning of the election is passed on to the voters within the given meeting and the organization's internal information system, which is related to the election.

5. *All official voting information shall be presented in an equal way, within and across voting channels. (○)*

In the proposed procedure, all voters receive the same information using the organization's internal information system or e-mail communication. Basic information about the election is displayed on the initial page of the vote and in the public data for the election.

6. *Where electronic and non-electronic voting channels are used in the same election or referendum, there shall be a secure and reliable method to aggregate all votes and to calculate the result. (○)*

The proposed procedure allows for electronic voting. If it is necessary to hold a non-electronic election, a classic paper election could be held for voters who do not participate in an electronic election. To ensure that voters are not influenced, the publication of electronic results must be set only after the end of the paper election. Subsequently, the results of the electronic and non-electronic election commissions would have to be merged. Since the Electoral Commission has information about the participation of individual voters, it can allow paper voting for those who did not participate in the electronic election, in which case it is assumed that the non-electronic election will take place only after the end of the electronic election.

7. *Unique identification of voters in a way that they can unmistakably be distinguished from other persons shall be ensured. (○)*

The list of voters is compiled based on the identification of voters using a defined e-mail address. Each email address will receive its authentication information. Members of the electoral commission, including the administrator, have access to the list of voters' e-mails, including information about the voter's turnout. Belenios provides authorization verifiability, where anyone can check that votes come from eligible voters (Cortier et al. 2019). According to Baloglu et al. (2021a), it has been shown to satisfy formal requirements for the verifiability of elections, both in the symbolic model for a particular variant (Cortier et al., 2019) and in the computational model (Cortier et al., 2018). Still, there are issues regarding possible attacks on verifiability in case of registrar corruption. Even if the registrar and server are not compromised, individual verifiability can be compromised (Baloglu et al., 2021a).

8. *The e-voting system shall only grant a user access after authenticating her/him as a person with the right to vote. (○)*

The voter is authenticated using two elements, the login name and password on the one hand and the voting code on the other. These two elements

are transmitted separately, one by the voting server, and the other by the voting code generator. In case of loss or theft, the voter can request a new password. In this case, the old password is invalid. The voting code can also be sent back to the voter by the voting code generator (without change) - possibly by the authorized authority. If in the meantime the voting documents were used by a usurper, the voter can vote again with his new identifiers and the old vote will be canceled. In addition, identity theft voting generates an automatic receipt sent to the legitimate voter, greatly increasing the likelihood of detection of potential fraud (Cortier et al., 2020).

9. *The e-voting system shall ensure that only the appropriate number of votes per voter is cast, stored in the electronic ballot box, and included in the election result. (○)*

The ballot containing the choice confirmed by the voter and signed with his valid code is completely prepared on the client side, including encryption. Registration to the ballot box is performed by the server on the condition that the ballot is valid (cryptographically) and that the voter's authentication has been successful. In this case, and only in this case, the attendance register is updated, the voter is sent a confirmation email with a tracking number that serves as a receipt, and the public ballot box also provides a way for the voter to check that their vote has been counted (Cortier et al., 2020).

10. *The voter's intention shall not be affected by the voting system, or by any undue influence. (○)*

The Electoral Commission should ensure that questions are asked impartially and correctly. The voting system itself is then displayed to all voters in the same way.

11. *It shall be ensured that the e-voting system presents an authentic ballot and authentic information to the voter. (○)*

The voter will receive the voting URL of the election in e-mail and in the organization's internal information system. The voter can always verify that he is voting at the correct URL, and that the tracking code of his ticket is inserted in the correct ballot box, which is at the same URL of the sent election extended by "/ballots". The voter can check the submitted form of the ballot after authentication in publicly accessible election data.

12. *The way in which voters are guided through the e-voting process shall not lead them to vote precipitately or without confirmation. (○)*

The voting process has several steps that can always be repeated. It is even possible to submit a completely new ballot before the end of voting, which invalidates the originally submitted one.

13. *The e-voting system shall provide the voter with a means of participating in an election or referendum without the voter exercising a preference for any of the voting options. (○)*

After the voter's identity is verified, he is redirected to the blank ballot. A voter can also hand in a blank ballot. The neutral form of the ballot is ensured by the electoral commission through settings by the administrator. The resulting form can be verified using publicly available election data. Alternatively, the form of the ballot can be challenged and the electoral commission can be forced to correct it, including repeating the election in a correct form. The system does not allow you to set a benefit in the form of a pre-selection of one of the options.

14. *The e-voting system shall advise the voter if he or she casts an invalid e-vote. (○)*

After casting a valid vote in the ballot box, this information is displayed to the voter on the last page of the election and an information e-mail is sent. The system does not allow an invalid vote to be inserted into the ballot box. It is possible to allow the submission of a blank ballot, which is not inherently a validity error, but an opportunity to express the voter's will.

15. *The voter shall be able to verify that his or her intention is accurately represented in the vote and that the sealed vote has entered the electronic ballot box without being altered. Any undue influence that has modified the vote shall be detectable. (○)*

The confidentiality of the ballot during its processing and storage in the ballot box is ensured by the encryption used. Its integrity is ensured by double protection. On the one hand, the signature associated with the slip becomes invalid if the slip is modified (Cortier et al., 2020).

After the ballot is encrypted, a unique tracking code is displayed, which is also sent to the voter's e-mail after it is inserted into the ballot box. The ballot box publicly displays a list of tracking codes, according

to which the voter can verify the counting of his vote in the original encrypted form.

16. *The voter shall receive confirmation by the system that the vote has been cast successfully and that the whole voting procedure has been completed. (○)*

Information about the successful submission of the ballot is displayed on the last page of the voting process, information about the submission of the vote is also sent to the voter's e-mail address.

17. *The e-voting system shall provide sound evidence that each authentic vote is accurately included in the respective election results. The evidence should be verifiable by means that are independent from the e-voting system. (○)*

Voters can check the presence of their ballot in the ballot box, and external audits ensure that the ballot box only grows. By auditing, anyone can verify, based on public data, that the cryptographic data is consistent (for example, consistency between the public keys of decryption authorities and the public key of elections). After counting, it is possible to make sure that the result corresponds to the encrypted ballots of the ballot box, thanks to the cryptographic evidence provided by the decryption authorities (Cortier et al., 2020). In the Belenios system, no single party needs to be fully trusted, as verifiability is ensured as long as neither the election server nor the registrar is compromised. The registrar generates public credentials, posts them on a bulletin board, and distributes the associated private credentials to voters. The public login serves as the authentication key of the newly created signature key pair, while the private login is the corresponding signature key. The votes are signed and the election authorities can verify on the bulletin board that all votes have been cast by the expected eligible parties (Baloglu et al., 2020).

18. *The system shall provide sound evidence that only eligible voters' votes have been included in the respective final result. The evidence should be verifiable by means that are independent from the e-voting system. (○)*

The voting server does not have a signing key, so it cannot create a valid signature. In theory, only unauthorized vote deletion could occur. But this would be revealed because voters can check the presence of their ballot in the ballot box and external audits ensure that the ballot box is only growing. The ballot box (that is, the list of encrypted ballots), the public election key, the list of questions, and the list of public parts of the election codes can be viewed publicly by anyone who knows the election URL. Automatic programs, apart from the voting server, regularly monitor this data (external auditors can also perform this monitoring). Modification of election data (deletion of the ballot paper, change of the list of public voting codes, etc.) would therefore be detected immediately (Cortier et al., 2020).

19. *E-voting shall be organized in such a way as to ensure that the secrecy of the vote is respected at all stages of the voting procedure. (○)*

The ballot is encrypted and sent to the server via an HTTPS channel, which adds a second layer of encryption and ensures integrity. On the other hand, the ballot is authenticated thanks to the signature derived from the voting code, it is not possible to modify the ballot while maintaining a valid signature. Finally, the integrity of the ballot is again ensured by the fact that the voter can verify the presence of his own ballot in the ballot box with his tracking number (Cortier et al., 2020). The open-source election system Belenios allows the use of homomorphic programming (Glondu, 2023) to carry out an election by keeping individual ballots secret, enabling their verification and simultaneously displaying the overall election results.

Currently, there is no formal, universal definition for End-to-End Verifiability (E2Ev) because the associative and commutative operators are inaccessible to symbolic analysis tools, which for example makes it impossible to analyze the following homomorphic property as stated in (Cortier, 2015):

$$enc(pk; v_1) * enc(pk; v_2) = enc(pk; v_1 + v_2) \quad (1)$$

where * and + are associative and commutative operators. Thanks to them it is possible to sum the contents of votes (v_1 and v_2) encrypted (*enc*) with the public key (*pk*) without further decrypting them individually.

After the election results have been evaluated and confirmed, voter lists including access codes as well as decryption keys should be deleted. The choice itself is archived and subsequently deleted.

20. *The e-voting system shall process and store, as long as necessary, only the personal data needed for the conduct of the e-election. (○)*

Voter lists are separate from the ballot box. After the election is over and the results are confirmed, the entire election, including voter lists containing email addresses, can be deleted.

21. *The e-voting system and any authorised party shall protect authentication data so that unauthorised parties cannot misuse, intercept, modify, or otherwise gain knowledge of this data. (○)*

Authentication data is encrypted on the election server, or on a third-party server in the case of using CAS. The voter will receive the password by e-mail, in case of losing the password, they can have a new password generated by the administrator.

22. *Voters' registers stored in or communicated by the e-voting system shall be accessible only to authorised parties. (○)*

The voter register is not public. It is updated by the server and made available to election administrators. In case of doubts about its integrity, the compliance of the voter registers with the ballot box can be checked by the voting code generator (authorized authority), which knows the link between the codes used to sign the ballot boxes and the voters. The voter list is accessible to the administrator and authorized authority, who should make it available to the electoral commission for review.

23. *An e-voting system shall not provide the voter with proof of the content of the vote cast for use by third parties. (Δ)*

The system does not allow you to find out the content of the submitted vote. The voter can only verify that the vote in the ballot box is the same as the one he cast.

The system is not resistant to coercive voting, when the voter would be influenced by the participation of a third person to make the election, if he voluntarily gave the third person a public imprint of the ballot submitted in front of him to verify the counting of the given vote in the ballot box (Cortier et al., 2019).

24. *The e-voting system shall not allow the disclosure to anyone of the number of votes cast for any voting option until after the closure of the electronic ballot box. This information shall not be disclosed to the public until after the end of the voting period. (○)*

The counting option can only be activated after the voting is closed. Each decryption authority then performs the calculation on its own computer using its private key. After reaching the contribution threshold, the result is announced. Partial counting cannot be done during the election, because the counting operation can only be activated once and requires the active participation of the decryption guarantors.

25. *E-voting shall ensure that the secrecy of previous choices recorded and erased by the voter before issuing his or her final vote is respected. (○)*

The content of the voter's previously submitted ballot is always overwritten by the newly submitted ballot. The results of earlier elections are not archived for a long time.

26. *The e-voting process, in particular the counting stage, shall be organised in such a way that it is not possible to reconstruct a link between the unsealed vote and the voter. Votes are, and remain, anonymous. (○)*

Tightness between the voter's identity and the expression of his vote is ensured by two means. The keys needed for decryption are generated and stored on separate, independent machines, managed by different persons or entities, as it is on the one hand the server and on the other hand the decryption authorities chosen by the electoral commission. It is even unlikely that they all have the same operating system, for example. Thus, while a link is established between the voter and his encrypted ballot, it is not possible to establish a link between the voter and the cast of the vote. During analysis, the keys necessary for decryption remain on separate, independent computers managed by different people or entities. Voters' encrypted ballots are never deciphered. Belenios uses two decryption solutions depending on the voting method used: homomorphic counting or verifiable mixnets. In both cases, no link can be established between the expression of the vote and the voter (Cortier et al., 2020).

27. *Member States that introduce e-voting shall do so in a gradual and progressive manner. (Δ)*

In the Czech Republic, it is not possible to vote electronically in major political national elections, on the other hand, it is not prohibited to vote electronically in elections of private or public organizations. As electronic voting is only possible in minor elections, the rollout can be considered gradual and progressive.

28. *Before introducing e-voting, member States shall introduce the required changes to the relevant legislation. (Δ)*

Electronic voting in national elections has not yet been introduced in the Czech Republic. Electronic voting within organizations should be governed by statutes and other legal regulations.

29. The relevant legislation shall regulate the responsibilities for the functioning of e-voting systems and ensure that the electoral management body has control over them. (○)

Within the organization, responsibility can be defined by its own statutes, regulations or resolutions, including the designation of the election commission. In the event of a possible future introduction to national elections, a significant change in the country's laws will be needed.

30. *Any observer shall be able to observe the count of the votes. The electoral management body shall be responsible for the counting process. (Δ)*

The decryption of the tallied results is carried out by guarantors who are part of the electoral commission. Anyone with access to the election URL can verify the data used in the census based on publicly available data.

31. *Member States shall be transparent in all aspects of e-voting. (Δ)*

In the event of the eventual introduction of nationwide electronic voting, the state must be transparent, similar to the proposed procedure for electronic voting in organizations.

32. *The public, in particular voters, shall be informed, well in advance of the start of voting, in clear and simple language, about: any steps a voter may have to take in order to participate and vote; the correct use and functioning of an e-voting system; the e-voting timetable, including all stages. (○)*

The organization informs voters of the plan for conducting electronic elections in the invitation to the meeting, the voter obtains information using the internal information system and e-mail. Detailed instructions should also always be available.

33. *The components of the e-voting system shall be disclosed for verification and certification purposes. (○)*

Belenios is open source, which is free to download and verify the code. Likewise, certain election data required for certification is publicly available.

34. *Any observer, to the extent permitted by law, shall be enabled to observe and comment on the e-elections, including the compilation of the results. (Δ)*

Anyone who knows the election URL can view the ballot box and public data. After the election result is decrypted, anyone can perform verification based on public data and third-party tools.

35. *Open standards shall be used to enable various technical components or services, possibly derived from a variety of sources, to interoperate. (Δ)*

Belenios is open source, and it also offers a tool for calculating a unique fingerprint as open source. The system allows the development of other third-party control systems.

36. *Member States shall develop technical, evaluation and certification requirements and shall ascertain that they fully reflect the relevant legal and democratic principles. Member States shall keep the requirements up to date. (Δ)*

State assessment and certification requirements should be developed for possible national elections in the future.

37. *Before an e-voting system is introduced and at appropriate intervals thereafter, and in particular after any significant changes are made to the system, an independent and competent body shall evaluate the compliance of the e-voting system and of any information and communication technology (ICT) component with the technical requirements. This may take the form of formal certification or other appropriate control. (○)*

We checked the functionality of the Belenios system by testing our own installation. A security analysis (Cortier et al., 2020) compares the fulfillment of the technical requirements

of the CNIL (La Commission nationale de l'informatique et des libertés, 2019). The Belenios voting platform meets levels 1 and 2 defined by the CNIL as well as level 3 depending on the chosen implementation (Cortier et al., 2020).

38. *The certificate, or any other appropriate document issued, shall clearly identify the subject of evaluation and shall include safeguards to prevent its being secretly or inadvertently modified.* (✗)

Belenios allows anyone who knows the election URL to audit voting results. The standards for issuing the certificate have not yet been defined.

39. *The e-voting system shall be auditable. The audit system shall be open and comprehensive, and actively report on potential issues and threats. (Δ)*

The auditor regularly downloads the contents of the ballot box and checks its consistency. These tests ensure that no votes have disappeared and that only legitimate (properly signed) votes have been added. This audit is performed at least by an automatic program set up by the Belenios team, but it can also be performed by third parties. Software tools enabling these tests are available in the open-source Belenios code. On the other hand, the detailed specification of Belenios also allows to reprogram all the tests. In addition, voters can check at any time whether their ballot is in the ballot box. This last point means that security does not rely as much on attendance as with a traditional system. However, verification that this is consistent with the ballot box can be permanently done by the voting code generator (Cortier et al., 2020).

Belenios has an active academic community working on updates as well as third-party solutions for greater control and auditing of the elections made. Belenios publishes public data that allows for an audit. The Belenios system, compiled in the object-oriented programming language OCaml, is open source, including the auditing part. The academic community also informs about potential problems and threats in professional publications (Baloglu et al., 2021b).

40. *The electoral management body shall be responsible for the respect for and compliance with all requirements even in the case of failures and attacks. The electoral management body shall be responsible for the availability, reliability, usability and security of the e-voting system. (○)*

The electoral commission is responsible for the correctness of the election, which may also have tools for correction, including the possibility of extending the vote or repeating it.

41. *Only persons authorised by the electoral management body shall have access to the central infrastructure, the servers and the election data. Appointments of persons authorised to deal with e-voting shall be clearly regulated. (Δ)*

In the case of using the official Belenios installation, the server of the Belenios platform is hosted by the LORIA high-security laboratory. It thus benefits from associated services: controlled physical access, activity monitoring, and logical separation with other hosted services. The system is a stable version, with a limited number of services and regular updates. The list of people with physical and logical access to the server is limited and controlled (Cortier et al., 2020).

Only members of the elected electoral commission have access to voter lists including e-mails, the connection with the access code is handled by the authorized authority.

42. *Before any e-election takes place, the electoral management body shall satisfy itself that the e-voting system is genuine and operates correctly. (Δ)*

We verified the correct functionality of the system by installing it ourselves. Before the start of the election, the functionality of the system is verified by the administrator and other members of the election commission.

43. *A procedure shall be established for regularly installing updated versions and corrections of all relevant software.* (✗)

In the case of using the official Belenios installation, the system developers themselves ensure that the system is kept up-to-date.

44. *If stored or communicated outside controlled environments, the votes shall be encrypted. (○)*

All ballots are encrypted.

45. *Votes and voter information shall be kept sealed until the counting process commences. (○)*

Only members of the election commission have access to personal information in the form of e-mail. Votes are encrypted, the electoral commission

only obtains information about the participation of individual voters in the vote.

46. *The electoral management body shall handle all cryptographic material securely. (○)*

Guarantors whose private keys are needed to decrypt the election results are advised to store the decryption keys securely. The authorized authority is informed of the need to handle voters' access codes with care.

47. *Where incidents that could threaten the integrity of the system occur, those responsible for operating the equipment shall immediately inform the electoral management body. (Δ)*

Voters and auditors immediately inform the electoral commission of suspicious events, in case of a suspicious event with a member of the electoral commission, the superior/chairman of the given organization should be informed immediately.

48. *The authenticity, availability, and integrity of the voters' registers and lists of candidates shall be maintained. The source of the data shall be authenticated. Provisions on data protection shall be respected. (○)*

The list of voters is entered into the systems by the administrator based on e-mails delivered, for example, from the organization's internal systems. The list of voters does not change throughout the election and, including personal data in the form of e-mail, is available exclusively to members of the electoral commission. Voters should be familiarized with the protection of personal data under the GDPR, the organization can extend its personal data protection conditions beyond the requirements of the Belenios system itself, for example within the registration conditions for the organization's internal information system.

49. *The e-voting system shall identify votes that are affected by an irregularity. (○)*

As part of the audit carried out by the electoral commission, which can be carried out by anyone who has access to the URL of the given election, possible irregularities should be identified.

Discussion

Even though the recommendation of the Council of Europe is important for the member states, the verification of the internet voting system or the proposed method of the voting procedure following the Recommendation of the Council of Europe is not a common part of the documentation. Even the documentation (Cortier et al., 2020) of the investigated French Belenios system evaluates its security only in accordance with the national requirements for electronic voting. The methodological procedures for evaluating electronic elections focus more on the system itself (Panizo Alonso et al., 2018) and only exceptionally evaluate the entire methodological procedure of real elections.

As evidenced by the assessment, elections in Ontario would not meet the requirements of the Council of Europe recommendations (Brunet and Essex, 2023). Token and envelope protocols are evaluated in more detail by academic staff often not directly connected to the development of the given system, while for example evaluating their strengths and weaknesses in relation to the recommendations of the Council of Europe CM/Rec(2017)5. The findings show that envelope protocols do not meet the requirements of the recommendation, while token protocols can meet the requirements if certain technical provisions are met (Bagnato, 2022).

The independent evaluation of voting procedures using the electronic voting system by a trusted authority is fundamental in terms of its application use by the general public, therefore it is advisable to strive for greater standardization of the evaluation and the way it is made available to all users of the system. The transparency of the i-voting system is important in terms of the Council of Europe (2017) recommendations and for building credibility. Similarly, research on the Swiss electoral system (Driza Maurer, 2019) calls for an emphasis on the transparency of the system. The requirement for public source code is also highlighted by Buckland et al. (2012) who conclude that the lack of transparency in the Australian e-voting system may negatively affect voter attitudes towards e-voting. Volkamer et al. (2011) also rate the transparency of an electoral system as crucial with respect to credibility. Few countries have developed adequate legislation or standards for online voting systems (Brunet et al., 2022).

Conclusion

From the described analysis, it follows that the proposed method of conducting a remote electronic secret election can to a certain extent meet most of the requirements

of the Council of Europe (2017) recommendation in the case of a less important election within the agricultural organization. The proposed procedure methodology does not provide for the certification required by Requirements 38 and 43. The proposed methodological procedure does not meet requirement 23, which requires the prevention of the possibility of transferring information about the choice to a third party. On the other hand, this requirement is better addressed by the possibility of repeated voting than in the postal elections that operate in many EU countries, and is less essential for elections in private institutions, since the verification of the voter's choice in this case can be legitimate. For example, in the case when a cooperative member/shareholder delegates a representative to express his will when electing the board. BeleniosRF should bring an improvement in resistance to coercion (Chaidos, 2016). Points 27, 28, 29, 31, and 36, which deal primarily with requirements for the state, are obviously relevant to national elections to the Parliament, etc., even so, they are fulfilled to a certain extent for electronic voting in the organization. A greater level of security could be provided by the use of a third-party authentication system (CAS), which will simultaneously require two-factor authentication.

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Regional Heterogeneity in Livelihood Strategies and Its Implications for Household Welfare: A Panel Data Analysis of Rural Vietnam

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Abstract

This study undertakes a meticulous examination of the Livelihood Strategy Diversity Index (LSDI) and its nuanced implications on household welfare in heterogeneous regions of rural Vietnam. Employing a unique panel dataset derived from the Vietnam Access to Resources Household Survey (VARHS) spanning from 2010 to 2018, the study employs both Ordinary Least Squares (OLS) and instrumental variable (IV) methods to investigate the intricate relationship between LSDI and household welfare, with a specific focus on income and dietary diversity. The empirical findings reveal compelling evidence of pronounced regional heterogeneity, highlighting the distinctive impacts of the LSDI on household welfare across diverse geographical areas. This study underscores the importance of region-specific strategies, advocating for a tailored and diversified approach to agricultural activities aligned with the unique context of each region. Furthermore, the findings emphasize the pivotal role of consolidating small plots as a strategic measure to alleviate agricultural land fragmentation, offering valuable insights into region-specific interventions for the enhancement of household well-being, encompassing both income and nutritional diversity.

Keywords

Livelihood diversity, welfare impact, regional disparities, Vietnam.

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Introduction

In Vietnam, economic development relies heavily on the agricultural sector, which provides substantial income for a significant proportion of rural households (Phan et al., 2022; Ngo et al., 2022). Following trade liberalization and agricultural reforms in the 1980s, Vietnam transformed into a net exporter of crucial agricultural products, such as rice, coffee, pepper, and cashew nuts. As of 2021, the agriculture, forestry, and fishing sectors constitute 12.36 percent of the Gross Domestic Product (GDP) (GSO, 2022). The agricultural sector has made commendable progress in both scale and production, restructuring the industry towards achieving national food security and increasing exports. However, the vulnerability to market fluctuations, natural disasters, and epidemics poses a threat to the sustainable development of the sector, impacting the welfare of farmers.

The role of smallholders in Vietnam's agricultural system is pivotal, yet their susceptibility to risks and uncertainties creates instability in farmers' welfare. To address this, effective livelihood strategies have become imperative for enhancing household welfare and promoting sustainable agricultural development in rural areas. A household livelihood strategy is defined as an organized set of economic actions undertaken by that household and its members, considering the social context and available resources (Lingam, 2016). In rural areas, farmers have various options for their agricultural production activities to increase their income based on their resources. Diversifying operations is a strategy employed by farmers to manage risk, cope with economic and climate

shocks, and escape stagnation in agriculture (Zhao and Barry, 2014). Both on-farm production systems and off-farm livelihood sources contribute to mitigating climate-induced production and market uncertainties, thereby enhancing farm households' resilience (Asfaw et al., 2019). The complex interaction between push and pull pressures affecting family capital, labor, and land allocation has major consequences for understanding diversification's welfare effects (Atamanov and Van den Berg, 2012; Habib et al., 2022; Musumba et al., 2022; Rahman and Mishra, 2020).

Livelihood diversification strategies are heavily influenced by off-farm and on-farm revenue, agricultural markets, infrastructure, and information (Sisay, 2024). A full examination is needed to understand how these components interact across national settings, strategic approaches, and household conditions. Acknowledging country variety is crucial because economic structures, policy contexts, and institutional frameworks shape household opportunities and limits (Mehraban and Ickowitz, 2021). In regions with strong agricultural markets, crop demand may affect diversification decisions more. Push factors like restricted traditional farming alternatives may prevail in underdeveloped markets. Household strategies play a key part in diversification, offering vertical integration or horizontal expansion into unrelated industries and these decisions affect the environment, society, and economy (Zhao and Barry, 2014). Households can better respond to market signals and grab opportunities in places with advanced infrastructure and knowledge, while diversification may be harder in areas with inadequate infrastructure and knowledge. Diversification has different welfare consequences on households because education, risk tolerance, and household resources are important socioeconomic determinants (Asfaw et al., 2019). Understanding the complex dynamics of push and pull variables in families' capital, labor, and land allocation is essential to understanding alternative diversification approaches' welfare effects. Also, recognizing differences across regions, techniques, and households helps create customized policies that maximize diversification advantages while avoiding risks and injustices.

While studies in Vietnam have documented the widespread adoption of diversified livelihood strategies by farmers, primarily focusing on income diversification and employing the Simpson's index to assess income source diversity (Minot et al., 2006; Giller, 2020; Tran and Vu, 2020), a critical knowledge gap remains regarding the broader impacts of this diversification on household well-being. Specifically, the influence on dietary diversity across diverse regional contexts in rural Vietnam remains largely unexplored. Previous studies have often relied heavily on Simpson's index to measure income diversification, neglecting the inherent complexities of livelihood strategies in rural Vietnam. This index fails to capture the full spectrum of agricultural activities, which can significantly impact dietary diversity through self-produced food consumption (Leroy et al., 2015). Additionally, the existing literature lacks a regionalized perspective, overlooking the diverse ecological, cultural, and socio-economic contexts that can influence the relationship between diversification and dietary diversity (Abeje et al., 2019).

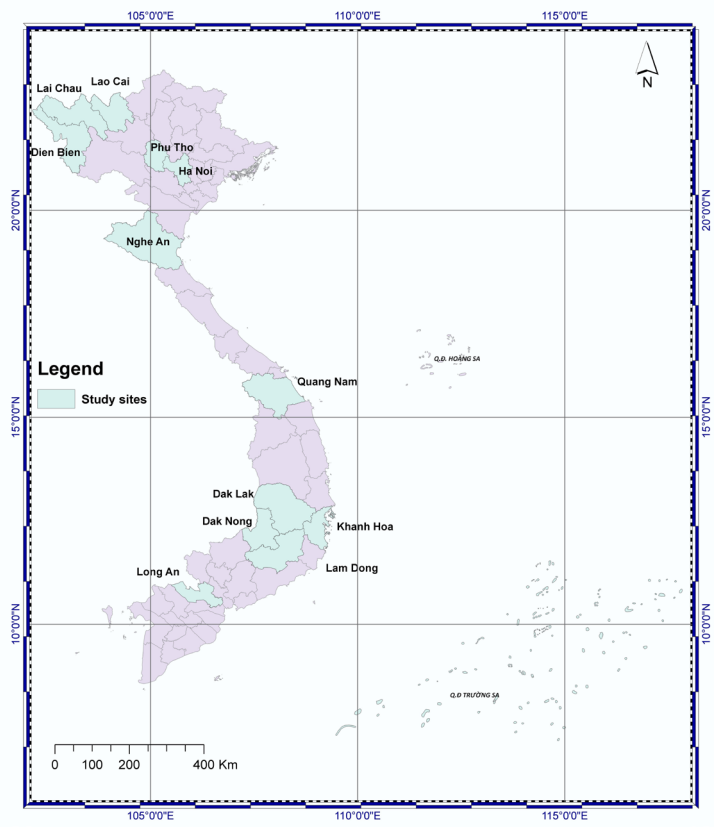
This study aims to address this gap by delving into the intricate relationship between livelihood strategy diversification and household income and dietary diversity, employing a nuanced approach that accounts for regional heterogeneity. We used the Livelihood Strategy Diversity Index (LSDI), derived from a count index of household activities in agricultural fields. Using a unique panel dataset spanning from 2010 to 2018 and covering households across Vietnam, our study explores the influence of LSDI on household welfare, considering both income and dietary diversity. Filling a significant gap in the literature, this study delves into the multidimensional impact of livelihood strategy diversity on household welfare, emphasizing the interconnected dimensions of income and food diversification. Notably, our findings reveal regional heterogeneity in the effects of LSDI on household welfare across diverse geographical areas. This highlights the need for region-specific strategies, emphasizing the importance of tailored and diversified agricultural approaches aligned with the unique contexts of each region. As Vietnam experiences economic growth similar to that seen in other developing nations across Asia and Africa, the insights gleaned from this study can serve as vital guidance for addressing issues such as poverty reduction, income generation, and food security. These findings hold significance beyond Vietnam, as they recognize the shared challenges and opportunities faced by developing countries worldwide. The lessons drawn from the livelihood strategies employed by small-scale farmers in Vietnam can serve as a valuable reference for their counterparts in different regions around the world.

Materials and methods

Data

Five-round surveys were conducted as part of the Vietnam Access to Resource Households (VARHS) project from 2010 to 2018 (2010, 2012, 2014, 2016, and 2018). The surveys covered 12 provinces across the country (Figure 1), including the northern region (Ha Tay, Lao Cai, Phu Tho, Lai Chau, and Dien Bien), central region (Nghe An, Quang Nam, and Khanh Hoa), highland region (Dak Lak, Dak Nong, and Lam Dong) and southern region (Long An). VARHS collected data biannually from rural households in these provinces, resulting in a dataset comprising 1,345 households each year and totaling 6,725 observations after merging the data.

This study delves into the relationship between livelihood strategy diversity and household welfare. Drawing from a comprehensive review of prior research (Musumba et al., 2022; Nguyen et al., 2021; Asfaw et al., 2019; Lafevor and Pitts, 2022; Pratiwi et al., 2018; Chilimo and Ngulube, 2011; Zhao and Barry, 2014; Mahama and Nkegbe, 2021; Ciaian et al., 2018), we have carefully selected a set of independent variables to construct our estimation model. These variables encompass a range of crucial elements, including the education level of the household head, family size (Habib et al., 2022; Li et al., 2020; Mahama and Nkegbe, 2021; Nguyen and Tran, 2018; Shekuru et al., 2022), access to rural credit, investment in agricultural activities, time allocated to agricultural extension services, presence of an irrigation system, willingness to invest in crop insurance, and access to the Internet (Asfaw et al., 2019; Musumba et al., 2022; Nguyen and Tran, 2018; Wu et al., 2017). Additionally, we consider critical household head characteristics, including age, gender, and education (Beyene et al., 2023; Habib et al., 2022; Sisay, 2024). To provide a holistic perspective, we also integrate land-related factors such as the number of plots, total agricultural areas, and the land fragmentation index (Asfaw et al., 2019; Nguyen and Tran, 2018; Sisay, 2024). A comprehensive overview of the descriptive statistics for these variables is available in Table 1.



Source: Authors

Figure 1: Study area indicating the data collection sites in Vietnam.

Variable	2010		2012		2014		2016		2018	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Household income[1]	10.93	0.76	10.95	0.76	11.17	0.79	11.29	0.81	11.47	0.89
Household food diversity index	6.26	1.82	6.26	1.64	6.03	1.74	6.19	1.79	6.33	1.68
Livelihood strategy diversity index	1.18	0.61	1.07	0.61	1.06	0.58	1.01	0.64	0.98	0.59
Crop Index	0.13	0.12	0.10	0.10	0.11	0.11	0.07	0.08	0.13	0.14
Livestock	0.81	0.39	0.76	0.43	0.75	0.43	0.71	0.45	0.68	0.47
Non-farm index	0.24	0.43	0.21	0.41	0.20	0.40	0.23	0.42	0.17	0.38
Investing to agricultural activities (1 = yes)	0.60	0.49	0.36	0.48	0.18	0.38	0.21	0.41	0.28	0.45
Visiting agricultural extension services (times)	1.24	1.77	1.32	2.08	1.68	2.60	2.44	1.79	2.10	2.52
Irrigation system (% of plots irrigated)	0.89	0.31	0.93	0.26	0.94	0.24	0.95	0.21	0.97	0.17
Accessing to rural credit (1 = yes)	0.55	0.50	0.44	0.50	0.39	0.49	0.33	0.47	0.27	0.44
Willingness to pay for crop insurance (Million VND)	0.15	0.14	0.70	13.71	0.24	0.43	0.07	0.42	0.16	0.43
Accessing to the internet (1 = yes)	0.21	0.41	0.44	0.50	0.44	0.50	0.45	0.50	0.58	0.49
Number of the family member (persons)	4.63	1.67	4.57	1.69	4.49	1.71	4.37	1.74	4.28	1.82
Gender of household head (1 = Male)	0.84	0.37	0.83	0.37	0.82	0.39	0.81	0.39	0.79	0.41
Age of household head (years)	50.80	11.84	52.31	11.62	53.92	11.59	55.49	11.60	57.02	11.42
Education of household head (years)	7.88	3.20	8.04	3.15	8.61	3.00	8.77	2.85	8.04	3.23
Number of land plots	5.30	2.98	5.10	2.79	4.54	2.67	4.20	2.53	3.88	2.32
Total area for agricultural production1 (m^2)	8.34	1.14	8.34	1.15	8.27	1.18	8.25	1.16	8.17	1.27
Land fragmentation index	0.60	0.25	0.60	0.25	0.56	0.26	0.54	0.26	0.50	0.27

Note: [1] in log
Source: Calculated by authors from VARHS

Table 1: Summary statistics of variables in the study.

Methods

Definitions of livelihood strategy diversity index and household dietary diversity index

Livelihood diversification, the reliance on various income sources for household sustenance, has emerged as a crucial indicator of community resilience and vulnerability in an increasingly dynamic world. In this context, the LSDI serves as a valuable tool for quantifying the extent of this diversification, providing insights into the overall well-being and adaptability of households and communities. The indicator is essential for quantifying the extent of livelihood diversification among households and communities. Livelihood diversification refers to the range of activities and sources of income that individuals or communities engage in. A greater diversity index indicates a broader range of livelihood strategies. Furthermore, the diversity index provides vital insights into the overall welfare of households and communities. The presence of diverse livelihood methods indicates the ability to withstand economic shocks, natural disasters, and other difficulties. The presence of many income sources inside families indicates that they have diverse sources of income, which in turn decreases their vulnerability to external risks. Furthermore, the index functions as a good instrument for evaluating the flexibility of households and communities. In dynamic socio-economic and environmental contexts, the ability to adjust to changes is crucial. A higher diversity index signifies that households possess greater adaptability, as they participate in a wider range of income-generating endeavors. However, while its strengths are undeniable, a critical examination of the index reveals limitations that require consideration for its effective application. The focus on quantifying diversification may overlook the quality of livelihoods and the well-being of individuals within the households. Furthermore, the LSDI's reliance on income data alone may not account for non-monetary aspects of livelihoods, such as access to education, healthcare, or social capital. A comprehensive understanding of community resilience requires a more holistic approach that considers both economic and non-economic dimensions.

Variables	Description
Household dietary diversity index (HDDS)	Sum up the scores for all food groups to obtain the total HDDS score. For each food group, determine whether the household consumed any food items belonging to that group during the reference period (1 = yes, 0 = no).
Livelihood strategy diversity index (LSDI)	An index to capture diversity as the number of livelihood activities conducted (from 1 to 3). The livelihood is the sum of the crop, non-farm, and livestock indexes.
Crop activities	If the household has any activity related to crop farming (rice, maize,…) during the study period (1 = yes, 0 = no).
Non-farm activities	If the household has any activity related to non-farm activities during the study period (1 = yes, 0 = no).
Livestock activities	If household have relate to livestock activities during the study period (1 = yes, 0 = no).

Source: Adopted from Cholo et al.(2019); Musumba et al., (2022)

Table 2: Definitions of key indexes used in the study.

The LSDI's key strength lies in its simplicity, utilizing accessible income data and employing measures like Simpson's or Herfindahl Index for quantifying diversification. This enables cross-context comparisons (Adato and Meinzen-Dick, 2002; Ellis, 2000), aiding in monitoring development goals for poverty reduction and food security (Niehof, 2004). In our study, LSDI, represented by the count of income sources from crop, non-farm, and livestock activities (Table 2), indicates livelihood diversification. A higher LSDI signifies greater resilience to shocks, as diversified income sources buffer against declines in specific areas. By identifying households with limited income sources, interventions can be targeted to promote diversification and enhance resilience (Matsuura et al., 2023). To assess LSDI's impact on household welfare, the HDDS metric was used. HDDS measures the diversity of consumed food groups, providing a comprehensive evaluation of the household diet's breadth and nutritional adequacy (Cholo et al., 2019), surpassing a focus solely on calorie intake (Smith and Subandoro, 2007).

The effect of the livelihood strategy diversity index on household welfare

In this study, we delve into the intricate relationship between livelihood strategy diversity and household welfare using full sample, as captured by the following equation:

$$Y_{it} = \alpha LSDI_{it} + \beta X_{it} + \delta \bar{X}_{it} + \chi HID_i + \lambda location_i + \varepsilon_{it} \quad (1)$$

Here, Y_{it} represents household welfare, encapsulating dimensions such as income and the HDDS of household i in year t. X_{it} is a set of control variables. HID_i is the household fixed effect. $\bar{X}_{it}$ are within-household averages for the time-varying independent variables capturing unobserved heterogeneity. Notably, LSDI is employed as an explanatory variable in this study. The IVs methods include two stages: first stage show the linking between LSDI with explanation variables and instrumental variable (result show in appendix 1) and the second stage show the causal effect of LSDI on household welfare (Table 5 and 6) based on Equation (1).

Regional heterogeneity in the effect of the livelihood strategy diversity index on household welfare

To capture regional heterogeneity using Equation (2), we separate the estimations for the effect of LSDI on household welfares based on different regions (r), including Northern, Central, Highland, and Southern regions (Table 7 and 8). The results from Table 7 and 8 provide how difference about the casual effect of LSDI on household welfares in various regions.

$$Yitr = \alpha LSDI_{itr} + \beta X_{itr} + \delta \bar{X}_{itr} + \chi HID_i + \varepsilon_{itr} \quad (2)$$

Here, Y_{itr} represents household welfare, encapsulating dimensions such as income and the HDDS of household i in year t at region r. X_{itr} is a set of control variables. HID_i is the household fixed effect. $\bar{X}_{itr}$ are within -household averages for the time-varying independent variables capturing unobserved heterogeneity. Again, LSDI is employed as an explanatory variable. After consider the Hausman test and reduce the potential biases, the study only provides the casual relationship between LSDI and household welfare based on the Instrumental variable and fixed effect. The estimation also includes two stage as previous presentation: first stage shows the linking between LSDI with explanation variables and instrumental variable by various region (result show in appendix 2) and the second stage show the causal effect of LSDI on household welfare by various region (Table 7 and 8) based on Equation (2).

Dealing with potential endogeneity and unobserved heterogeneity

The simultaneous determination of LSDI and household welfare introduces potential biases, leading to inconsistent estimates when using the Ordinary Least Squares (OLS) method based on Equation (1) and (2). To address this, instrumental

variables (IVs) are incorporated to ensure the creation of consistent estimators. The LSDI itself is characterized by three dummy variables, each representing distinct household production types: crops, livestock, and non-farms. The selection of these categories is informed by observed variations in LSDIs across different groups, as detailed in Table 4. The close association between these dummy variables and LSDI aligns with the criterion of instrumental relevance. To validate the strength of the instruments, the study employs the F-statistic form, specifically the Cragg-Donald Wald F statistic. This statistical measure, as advocated by Stock and Yogo (2005), serves to assess the weakness of instrumental variables. Notably, the F-statistic for the Cragg-Donald Wald test records a substantial value of 88,923.6 (Table 5 and 6), significantly surpassing the critical threshold of 22.30. This outcome attests that the instruments are robust, meeting the requisite criteria for relevance in the estimation process.

Unobserved heterogeneity is the term used describe these unobservable variables, which include farmers' management skills and their individualized perspectives on the adoption of conservation measures. These are hard to quantify or extract, but they have an impact on a farmer's decision-making process to choose livelihood activities. We can, however, appropriately account for time-invariant unobserved variability among respondent farmers thanks to the panel character of our data. By permitting correlated random effects (CRE), Mundlak (1978) presents a strategy for controlling for unobserved heterogeneity. Wooldridge (2005) has further refined this technique. By including the vectors of within-household averages for the time-varying independent variables, $\bar{X}_{it}$, we used the CRE technique in Equation (1) for estimation in both the random effect (RE) and fixed effect (FE) settings for Table 5 and 6.

Results and discussion

Livelihood strategies of surveyed households

Table 3 provides an overview of the livelihood strategies adopted by households for income generation spanning the years 2010 to 2018. Notably, a trend toward production specialization emerges over this period. In terms of agricultural production, there is a general increase in the number of households specializing in crops. Specifically, the count rose from 192 households in 2010 to 322 in 2018. However, it is noteworthy that the proportion of households engaged in crop production constitutes only around 20% of the total dataset.

Similarly, households combining crop production with non-agricultural activities increased from 60 in 2010 to 112 in 2018, but this still represents less than 10% of the total. Examining households involved in both crop and livestock production, a significant proportion embraced this dual model. Nevertheless, there is a decline observed, from 62.01% in 2010 to 58.88% in 2018. Moreover, households participating in all three areas - crop production, animal husbandry, and non-profit agricultural activities - decreased from 19.26% in 2010 to 8.85% in 2018.

There is a noticeable increase in households exclusively involved in crop production, accompanied by a decrease in those engaged in multiple agricultural activities (refer to Table 4). This evolving landscape is reflected in the decreasing livelihood diversification index for rural Vietnamese households over the years. Notably, the Mekong and Red River areas exhibit the lowest and highest diversification indices, respectively. This trend toward reduced diversification is attributed to the growing inclination of households in rural Vietnam towards production specialization. The decision to diversify can pose challenges as it requires additional

Livelihood activities	2010		2012		2014		2016		2018	
	No.	%	No.	%	No.	%	No.	%	No.	%
Only crops	192	14.28	254	18.88	245	18.22	305	22.68	322	23.94
Crops and livestock	834	62.01	802	59.63	837	62.23	732	54.42	792	58.88
Crops and non-farm	60	4.46	75	5.58	90	6.69	88	6.54	112	8.33
Crops and livestock and non-farm	259	19.26	214	15.91	173	12.86	220	16.36	119	8.85
Total	**1,345**	**100**	**1,345**	**100**	**1,345**	**100**	**1,345**	**100**	**1,345**	**100**

Source: Calculated by authors from VARHS

Table 3: The number of households participating in the different livelihood activities.

financial, temporal, and labor resources. When these resources cannot be effectively managed, there may be negative implications for household well-being.

Livelihood strategy diversity index	2010	2012	2014	2016	2018
Northern area	1.30	1.20	1.19	1.16	1.06
Central area	1.19	1.05	1.08	1.02	1.02
Highland area	1.02	0.99	0.86	0.79	0.98
Southern area	0.86	0.57	0.71	0.64	0.62
Mean	**1.09**	**0.96**	**0.96**	**0.90**	**0.92**

Source: Calculated by authors from VARHS

Table 4: Livelihood diversification index by regions from 2010 to 2018.

The effect of livelihood strategy diversity index on household welfare

This study concentrates on evaluating the impact of LSDI on household welfare, encompassing factors like income and food diversity. Recognizing the limitations of OLS estimation in handling endogeneity concerns, the IV method is employed to uncover the intricate relationship between LSDI and household welfare components, such as income (refer to Table 5) and food diversity (refer to Table 6) (Tran and Vu, 2019). In Table 5, we present the results using both Random Effects (RE) and Fixed Effects (FE) for OLS and IV estimators. To guide our choice between RE and FE, we conduct a Hausman test, yielding a p-value below 1%. Consequently, we accept the fixed effect for further discussion.

Our findings reveal a consistently positive and statistically significant coefficient for the livelihood strategy diversity index across all estimators. Notably, the effective coefficient on household income in the (IV estimator is slightly lower than that in the OLS estimator by the fixed effects estimation, registering values of 0.048 and 0.035, respectively. While this study is not the initial exploration of household livelihood diversity's impact on income, it pioneers the development of a specific diversity index tailored to production activities in rural Vietnam. This unique index contributes to our understanding of how livelihood diversity influences household income, with results indicating that as the livelihood strategy diversity index increases, household income also rises - a trend mirrored in previous studies by Asfaw et al. (2019) and Mahama and Nkegbe (2021). In addition, some previous research also show the similar result that imply that there was a positive and statistically significant relationship between livelihood diversification and the outcome variables indicated, including welfares (Sisay, 2024; Sun et al., 2023). Furthermore, our investigation into investments in agricultural activities, particularly those related to irrigation, soil, and water conservation in household land plots, yields intriguing insights. Surprisingly, both estimators by fixed effects reveal negative coefficients at -0.053, suggesting that these investments do not positively impact household income. The financial resources required for these activities contribute to increased total agricultural production costs, resulting in a reduction in household income. Our study underscores the significant role of agricultural extension services, revealing a positive correlation between time invested in visiting these services and household income. With a statistically significant coefficient of 0.023 at a p-value of 1% for both model estimators by fixed effects, participating in agricultural extension services emerges as a pathway to improving household income by enhancing access to better-quality inputs and effective production processes. The finding is similar to the previous research (Pan et al., 2018) since the author indicated records of success for access to agricultural extension services.

Additionally, our investigation into the relationship between household income and irrigation systems indicates a positive correlation, with a statistically significant link at a p-value of 10%, aligning with findings by Tesfay (2021) and Adetoro et al. (2022). Surprisingly, our results suggest a decrease in household income associated with access to rural credit, with a coefficient of -0.087 and a p-value of 1%. This unexpected outcome could be attributed to the informal nature of rural credit, resulting in less effective utilization by households due to reduced regulations and supervision by credit providers. Moreover, our research highlights the positive and significant impact of Internet access on household income, supporting this correlation with a coefficient of positive significance at a p-value of 1%. Access to the Internet proves beneficial as households can leverage information related to input and output markets, along with technological advancements, thereby expanding their output markets for agricultural products.

Our study highlights key findings on family size, age of household heads, and land fragmentation's impact on household income. A positive and statistically significant coefficient of 0.109

Variables	CRE estimation			
	OLS estimator		IV estimator	
	RE	FE	RE	FE
Livelihood strategy diversity index	0.050***	0.048**	0.052***	0.035*
	(0.018)	(0.021)	(0.018)	(0.021)
Investing in agricultural activities	-0.053***	-0.054***	-0.053***	-0.053***
	(0.020)	(0.020)	(0.020)	(0.020)
Times for visiting agricultural extension services	0.024***	0.023***	0.024***	0.023***
	(0.005)	(0.005)	(0.005)	(0.005)
Irrigation system	0.078*	0.087**	0.078*	0.086**
	(0.040)	(0.040)	(0.040)	(0.040)
Accessing rural credit	-0.090***	-0.088***	-0.090***	-0.087***
	(0.022)	(0.022)	(0.022)	(0.022)
Willingness to pay for crop insurance	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Accessing to internet	0.165***	0.164***	0.165***	0.163***
	(0.020)	(0.021)	(0.020)	(0.021)
Number of family members	0.108***	0.109***	0.108***	0.109***
	(0.010)	(0.010)	(0.010)	(0.010)
Gender of household head	0.038	-0.084	0.039	-0.084
	(0.035)	(0.065)	(0.035)	(0.065)
Age of household head	0.020***	0.019***	0.020***	0.019***
	(0.002)	(0.002)	(0.002)	(0.002)
Level education of household head	0.001	0.000	0.001	0.000
	(0.004)	(0.004)	(0.004)	(0.004)
Number of land plots	-0.009	-0.031***	-0.009	-0.031***
	(0.006)	(0.009)	(0.006)	(0.009)
Total area for agricultural production1	0.022	0.104***	0.022	0.104***
	(0.016)	(0.020)	(0.016)	(0.020)
Land fragmentation index	-0.191***	-0.144*	-0.191***	-0.147*
	(0.073)	(0.081)	(0.073)	(0.081)
Northern area	-0.271***	-	-0.272***	-
	(0.057)	-	(0.057)	-
Central area	-0.457***	-	-0.458***	-
	(0.058)	-	(0.058)	-
Highland area	-0.105*	-	-0.105*	-
	(0.060)	-	(0.060)	-
Constant	9.398***	8.899***	9.404***	8.912***
	(0.206)	(0.219)	(0.206)	(0.219)
Hausman Test (p-value)	0.000		0.000	
Weak identification test (Cragg-Donald Wald F-statistics)			88923.6	
Stock-Yogo weak ID test critical value at 10%			22.30	
Endogeneity test of LSDI (p-value)			0.00	

Note: Standard errors in parentheses; Household income in the log; *** p<0.01, ** p<0.05, * p<0.1
Source: Calculated by authors from VARHS

Table 5: Effect of the diversification index on household income.

(at the 1% level) suggests that larger family sizes contribute to higher household incomes, aligning with the reliance on family labor in the agricultural sector. Additionally, the positive correlation between the age of household heads and income supports the idea that experience helps navigate

production and market risks, leading to higher incomes. Regarding land fragmentation, an IV estimation with fixed effects shows a significant coefficient of -0.147 (at a 10% significance level), indicating that increased land fragmentation is associated with a decrease in household income, consistent with previous research by Tran and Vu (2019).

In Table 6, the findings are presented using both Random Effect (RE) and Fixed Effect (FE) models for OLS and IV estimators. The Hausman test, revealing a p-value below 1%, prompts the acceptance of the fixed effect for further discussion. Across all models, the coefficient associating LSDI with the HDDS index is consistently positive and statistically significant at a 1% p-value. This indicates that higher livelihood diversification is linked to an elevated HDDS index, reflecting improved food security. Notably, IV estimator coefficients are slightly lower than OLS estimator coefficients by 0.139 and 0.132, respectively, aligning with findings by Kassegn and Endris (2021), Endiris et al., (2021) and Abera et al. (2021). These studies showed that households with individuals engaged in activities outside of farming had a greater likelihood of being food-secure compared to those without such individuals. Additionally, the results show a positive correlation between family size and HDDS, with statistical significance at a 1% p-value in the IV estimator with fixed effects. The increase in family size corresponds to an increase in HDDS, suggesting a direct connection between household size and food consumption—a pattern consistent with studies by Cordero-Ahiman et al. (2021), Mehraban and Ickowitz (2021), Abera et al. (2021), and Christian et al. (2019).

The age of the household head is positively correlated with food diversity (coefficient = 0.014, p-value < 0.01), reflecting greater agricultural experience among older household heads, leading to increased food sources, consistent with Sambo et al. (2022). In terms of land characteristics, factors like the number of plots, total area, and land fragmentation index significantly impact Household Dietary Diversity Score (HDDS) across different estimators. Specifically, in IV estimation with fixed effects, only the total area for agricultural production is significant at a 10% level (coefficient = 0.94). This suggests that expanding the agricultural production area positively influences household food security, aligning with Phan et al. (2022).

Variables	**CRE estimation**			
	OLS estimator		IV estimator	
	RE	FE	RE	FE
Livelihood strategy diversity index	0.132***	0.139***	0.139***	0.137***
	(0.041)	(0.052)	(0.042)	(0.052)
Investing in agricultural activities	0.052	0.069	0.052	0.069
	(0.050)	(0.051)	(0.050)	(0.051)
Times for visiting agricultural extension services	-0.003	-0.004	-0.003	-0.004
	(0.012)	(0.011)	(0.012)	(0.011)
Irrigation system	0.098	0.116	0.099	0.116
	(0.100)	(0.102)	(0.100)	(0.102)
Accessing rural credit	0.014	0.019	0.014	0.019
	(0.055)	(0.056)	(0.055)	(0.056)
Willingness to pay for crop insurance	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Accessing to internet	0.080	0.080	0.080	0.079
	(0.051)	(0.052)	(0.051)	(0.052)
Number of family members	0.120***	0.125***	0.120***	0.126***
	(0.024)	(0.025)	(0.024)	(0.025)
Gender of household head	-0.034	0.127	-0.034	0.126
	(0.073)	(0.164)	(0.073)	(0.164)

Note: Standard errors in parentheses; Household income in the log; *** p<0.01, ** p<0.05, * p<0.1
Source: Calculated by authors from VARHS

Table 6: Effect of the Livelihood strategy diversity index on household dietary diversity. (To be continued).

Variables	CRE estimation			
	OLS estimator		IV estimator	
	RE	FE	RE	FE
Age of household head	0.017***	0.014**	0.017***	0.014**
	(0.006)	(0.006)	(0.006)	(0.006)
Level education of household head	-0.012	-0.018	-0.012	-0.018
	(0.011)	(0.011)	(0.011)	(0.011)
Number of land plots	0.072***	0.003	0.072***	0.003
	(0.013)	(0.021)	(0.013)	(0.021)
Total area for agricultural production[1]	-0.202***	0.094*	-0.202***	0.094*
	(0.036)	(0.051)	(0.036)	(0.051)
Land fragmentation index	-0.293*	-0.087	-0.292*	-0.087
	(0.176)	(0.205)	(0.176)	(0.205)
Northern area	-1.558***	-	-1.561***	-
	(0.114)	-	(0.114)	-
Central area	-1.412***	-	-1.415***	-
	(0.116)	-	(0.116)	-
Highland area	-0.921***	-	-0.921***	-
	(0.119)	-	(0.119)	-
Constant	6.183***	0.139***	6.186***	3.917***
	(0.434)	(0.052)	(0.433)	(0.551)
Hausman Test (p-value)	0.000		0.000	
Weak identification test (Cragg-Donald Wald F-statistics)			88923.6	
Stock-Yogo weak ID test critical value at 10%			22.30	
Endogeneity test of LSDI (p-value)			0.00	

Note: Standard errors in parentheses; Household income in the log; *** p<0.01, ** p<0.05, * p<0.1
Source: Calculated by authors from VARHS

Table 6: Effect of the Livelihood strategy diversity index on household dietary diversity. (Continuation).

Regional heterogeneity in the effect of livelihood strategy diversity index on household welfare

This study explores the regional variations in the impact of LSDI on household well-being in rural Vietnam (Table 7). Results reveal significant positive coefficients for LSDI in the Mekong River delta (Southern area) at a 5% p-value. Particularly noteworthy is the Northern region, showing the highest impact on household income with a substantial coefficient of 0.146. Additionally, the study identifies the statistical significance of visiting agricultural extension services in the Northern region and Mekong River areas, with coefficients of 0.036 and 0.032, respectively.

The study reveals significant factors influencing household income across different provinces. Agricultural production investment significantly impacts income in Coastal, Highland, and Southern provinces, with the Southern area experiencing the most substantial negative influence (-0.231) and the Highland provinces having the lowest impact (-0.094). Rural credit access negatively affects income in the Mekong Delta (-0.188) and to a lesser extent in the Northern area (-0.080) and coastal provinces (-0.130). The irrigation system shows a significant effect only in the highland area (0.162). Internet access has a noteworthy impact on household income, particularly in coastal provinces, where the coefficient is highest at 0.222. Both the number of family members and the age of the household head have significant impacts on income across all study areas, with the highest age coefficient (0.027) recorded in the highland region. Regarding land characteristics, an increase in the number of plots decreases household income in the Northern and coastal areas, while expanding the total agricultural production area proves beneficial, suggesting that reducing land fragmentation can uplift household incomes (Phan et al., 2022; Tran and Vu, 2019).

Variables	IV estimator by CRE with fixed effect			
	Northern area	Central area	Highland area	Southern area
Livelihood strategy diversity index	0.045	-0.008	-0.019	0.146**
	(0.031)	(0.043)	(0.049)	(0.058)
Investing in agricultural activities	0.025	-0.113***	-0.094**	-0.231***
	(0.030)	(0.038)	(0.044)	(0.073)
Times for visiting agricultural extension services	0.036***	0.010	0.011	0.032***
	(0.008)	(0.007)	(0.013)	(0.010)
Irrigation system	0.050	-0.009	0.162***	-0.033
	(0.077)	(0.083)	(0.061)	(0.142)
Accessing rural credit	-0.080**	-0.130***	-0.019	-0.188***
	(0.032)	(0.043)	(0.052)	(0.072)
Willingness to pay for crop insurance	-0.000	-0.000	-0.000	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
Accessing to internet	0.168***	0.222***	0.155***	0.010
	(0.031)	(0.039)	(0.048)	(0.067)
Number of family members	0.106***	0.139***	0.066***	0.158***
	(0.014)	(0.021)	(0.023)	(0.041)
Gender of household head	-0.153	0.156	-0.011	-0.294
	(0.093)	(0.120)	(0.167)	(0.234)
Age of household head	0.015***	0.019***	0.027***	0.019***
	(0.003)	(0.005)	(0.006)	(0.007)
Level education of household head	-0.007	0.018*	-0.005	0.008
	(0.006)	(0.010)	(0.010)	(0.014)
Number of land plots	-0.038***	-0.049***	0.120***	-0.049
	(0.011)	(0.017)	(0.034)	(0.059)
Total area for agricultural production	0.107***	0.181***	-0.070	0.013
	(0.033)	(0.033)	(0.055)	(0.057)
Land fragmentation index	-0.182	0.043	-0.431*	-0.110
	(0.118)	(0.151)	(0.220)	(0.286)
Constant	9.212***	7.727***	10.100***	9.950***
	(0.343)	(0.397)	(0.569)	(0.661)

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1
Source: Calculated by authors from VARHS

Table 7: Effect of the Livelihood strategy diversity index on household income by regions.

Table 8 provides valuable insights into the regional variations in the impact of LSDI on HDDS using IV with FE. The findings reveal a positive relationship between increased LSDI and heightened HDDS in different regions. Notably, the results attain statistical significance for the Northern and Southern areas, underscoring the robustness of these associations. Specifically, the Mekong River Delta stands out with the highest effective coefficient of LSDI on HDDS, registering at 0.316. Furthermore, certain region-specific factors exhibit statistical significance, including the number of visits to agricultural extension services, irrigation systems, willingness to pay for agricultural insurance, and access to rural credit. Interestingly, positive correlations with HDDS are observed for the number of family members and the age of the household head in distinct regions such as the Northern, Coastal, and Highland areas. These nuanced findings contribute to a comprehensive understanding of the intricate dynamics between livelihood strategy diversity and dietary diversity across diverse geographical contexts.

Variables	IV estimator by CRE with fixed effect			
	Northern area	Central area	Highland area	Southern area
Livelihood strategy diversity index	0.190***	0.039	-0.077	0.316*
	(0.072)	(0.116)	(0.125)	(0.177)
Investing in agricultural activities	0.004	0.211**	0.124	0.007
	(0.070)	(0.104)	(0.112)	(0.222)
Times for visiting agricultural extension services	-0.005	0.029	0.038	-0.074**
	(0.019)	(0.020)	(0.033)	(0.031)
Irrigation system	0.170	-0.187	0.341**	-0.690
	(0.180)	(0.224)	(0.157)	(0.431)
Accessing rural credit	0.031	-0.247**	0.234*	0.043
	(0.076)	(0.117)	(0.133)	(0.219)
Willingness to pay for crop insurance	-0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Accessing to internet	0.055	0.153	0.134	-0.086
	(0.072)	(0.106)	(0.124)	(0.204)
Number of family members	0.151***	0.097*	0.216***	-0.164
	(0.032)	(0.057)	(0.060)	(0.124)
Gender of household head	-0.295	0.774**	0.910**	-0.367
	(0.218)	(0.325)	(0.428)	(0.707)
Age of household head	0.014*	0.025**	0.032**	-0.035*
	(0.008)	(0.013)	(0.015)	(0.021)
Level education of household head	-0.024*	-0.044*	-0.003	0.046
	(0.015)	(0.026)	(0.026)	(0.043)
Number of land plots	0.009	0.022	-0.072	0.181
	(0.026)	(0.047)	(0.087)	(0.179)
Total area for agricultural production	0.003	0.116	0.152	0.143
	(0.078)	(0.088)	(0.140)	(0.174)
Land fragmentation index	-0.082	0.047	-0.008	-0.158
	(0.277)	(0.409)	(0.564)	(0.865)
Constant	4.607***	3.151***	1.167	8.870***
	(0.803)	(1.073)	(1.458)	(2.001)

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1
Source: Calculated by authors from VARHS

Table 8: Effect of the Livelihood strategy diversity index on the household dietary diversity by regions.

Conclusion

In recent years, Vietnam has made remarkable progress in agricultural development, transitioning from a traditional agricultural country to a significant player in the regional and global commodity agriculture landscape. Rural households have played a pivotal role in this transformation by engaging in various agricultural activities to improve their well-being. This study aims to uncover the factors that influence the Livelihood Strategy Diversity Index (LSDI) and assess its impact on household welfare, particularly in terms of income and the Household Dietary Diversity Scale (HDDS) index.

Findings from the period between 2010 and 2018 reveal a declining trend in livelihood strategy diversity, with the Red River Delta showing the highest diversity index. The study identifies positive associations between LSDI and various factors such as agricultural investments, access to rural loans, family size, gender of the household head, and the number of plots. To evaluate the influence of LSDI on household welfare, robust methodologies including Instrumental Variables and Ordinary Least Squares with fixed effects were employed. Results affirm that an enhanced LSDI is positively correlated with increased household income and improved HDDS scores. Regional differences are evident, with LSDI

significantly enhancing well-being in the Red River and Mekong Delta regions. The study underscores the importance of diversifying farming strategies strategically to increase income. Encouraging crop and livestock diversification not only enhances agricultural production diversity but also reduces input costs through efficient resource utilization, such as recycling cattle-derived fertilizers.

Despite its contributions, this study also highlights areas for further exploration. Longer-term analysis, spanning multiple decades, is crucial to understanding how the influence of LSDI on household welfare evolves over time. This would entail capturing dynamic changes in factors like farm productivity, market access, and government policies. Additionally, unanticipated negative impacts from seemingly beneficial factors, such as increased agricultural investment in certain regions, particularly those with land constraints or water scarcity, warrant further investigation. Exploring these nuances, along with household-level risk-mitigation strategies, such as the willingness to pay for agricultural insurance in high-risk areas, can provide valuable insights into enhancing both well-being and resilience in the agricultural sector. Addressing these gaps will pave the way for more effective strategies that promote sustainable agricultural development, improve rural livelihoods across diverse regions of Vietnam, and foster greater resilience in the face of evolving challenges.

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Appendix

Variables	RE		FE	
	Coefficient	P-value	Coefficient	P-value
Investing in agricultural activities	0.019	0.001	0.01908	0.001
Times for visiting agricultural extension services	0.001	0.614	0.00096	0.441
Irrigation system	0.004	0.695	-0.0026	0.811
Accessing rural credit	0.014	0.027	0.01391	0.021
Willingness to pay for crop insurance	0.000	0.399	2.80E-07	0.448
Accessing to internet	-0.006	0.303	-0.0049	0.399
Number of family members	-0.008	0.003	-0.0082	0.002
Gender of household head	0.035	0.001	0.03062	0.082
Age of household head	-0.001	0.300	-0.0009	0.232
Level education of household head	0.001	0.253	0.00146	0.230
Number of land plots	0.024	0.000	0.02461	0.000
Total area for agricultural production1	0.032	0.000	0.01116	0.041
Land fragmentation index	-0.070	0.001	-0.0362	0.100
Production types	0.602	0.000	0.60753	0.000
Constant	-0.674	0.000	-0.3786	0.000

Source: Calculated by authors from VARHS

Table A1: The factors linking between LSDI and explanation variables (First stage of instrumental variable method for Table 5 and 6).

Variables	Northern area		Central area		Highland area		Southern area	
	Coefficient	P-Value	Coefficient	P-Value	Coefficient	P-Value	Coefficient	P-Value
Investing in agricultural activities	0.026	0.001	0.023	0.058	-0.003	0.828	0.025	0.297
Times for visiting agricultural extension services	-0.002	0.274	0.004	0.025	0.007	0.075	0.003	0.392
Irrigation system	-0.010	0.593	0.027	0.229	-0.027	0.129	0.057	0.205
Accessing rural credit	0.015	0.061	0.029	0.013	0.002	0.886	-0.002	0.936
Willingness to pay for crop insurance	0.000	0.426	0.000	0.412	0.000	0.339	0.000	0.063
Accessing to internet	-0.018	0.023	-0.010	0.353	-0.004	0.767	0.001	0.950
Number of family members	-0.006	0.078	-0.014	0.018	-0.003	0.684	-0.014	0.263
Gender of household head	0.019	0.412	0.022	0.504	0.076	0.104	0.014	0.849
Age of household head	-0.002	0.016	0.000	0.731	0.003	0.199	0.000	0.999
Level education of household head	0.001	0.589	0.002	0.430	0.003	0.348	-0.002	0.675
Number of land plots	0.023	0.000	0.024	0.000	0.048	0.000	0.050	0.007
Total area for agricultural production1	0.027	0.001	0.012	0.188	-0.020	0.204	-0.023	0.202
Land fragmentation index	-0.027	0.350	-0.083	0.042	0.027	0.659	-0.040	0.655
Production types	0.568	0.000	0.620	0.000	0.685	0.000	0.706	0.000
Constant	-0.316	0.000	-0.439	0.000	-0.596	0.000	-0.444	0.039

Source: Calculated by authors from VARHS

Table A2: The factors linking between LSDI and explanation variables by regions (First stage of instrumental variable method for Table 7 and 8).

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Comparing the Effects of Information Globalization on Agricultural Producer Prices in Developing and Developed Countries

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Abstract

Existing studies claim that the Internet of Things (IoTs) raises agricultural producer prices while others claim the contrary. Meanwhile, no studies have been conducted to investigate the impact of IoTs at the macro level, as represented by information globalization. The main objective of this study is to determine the impact of information globalization on agricultural producer prices in developing and developed countries. This study used time series data from 1991 to 2020 and cross-section data from 66 developing and 26 developed countries. The data was analyzed using two-stage least squares. The first stage of analysis shows that pesticides and farm machinery increase agricultural production in developing and developed countries, while employment in agriculture, forestry, and fishing has the opposite effect. Meanwhile, nutrient nitrogen, manure, and irrigation have differing effects on agricultural production in the two areas. The second stage of analysis shows that agricultural producer prices in developing and developed countries will rise when agricultural production, agricultural import, and human capital increase. Agricultural value-added, food consumer price inflation and population growth have varying impacts on agricultural producer prices. Meanwhile, the main variable investigated in this study, information globalization, has been proven to increase agricultural producer prices in both developing and developed countries.

Keywords

Agricultural production, agricultural import, agricultural value added, food consumer price, population, human capital.

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Introduction

Agriculture is one sector that has been severely impacted by many disruptions. Food production and supply chains are disrupted, resulting in higher food prices and reduced food access. Many countries are putting in place various strategies and regulations to counteract these disruptions and increase agricultural yield (Saboori et al., 2023). This is consistent with the Cobb-Douglas production theory, which states that the production function is attained using two inputs, capital and labor. Based on the needs, some of these factors can change and others remain constant in the short run, while all production factors can change in the long run (Pindyck and Rubinfeld, 2013). The combination of production factors has been shown to increase food yield in the long run (Chandio et al., 2023).

The Cobb-Douglas production theory also emphasizes the importance of technology to accelerate agricultural production growth (Pindyck and Rubinfeld, 2013). Technology is an instrumental action design that eliminates uncertainty in the cause-effect linkages involved in reaching a desired outcome. According to Rogers' innovation adoption theory, these numerous technologies will be adopted by agricultural participants (Rogers, 2003). The adoption of technology in agriculture has succeeded in speeding up the production process, improving product quality, and overcoming labor shortages (Sun et al., 2023).

One of the most important packages of technological innovation that has influenced the world over the previous five decades is the green revolution. This technological package combined with irrigation and intense use of chemical fertilizers, herbicides, and agricultural equipment in various crops, is the primary source of global

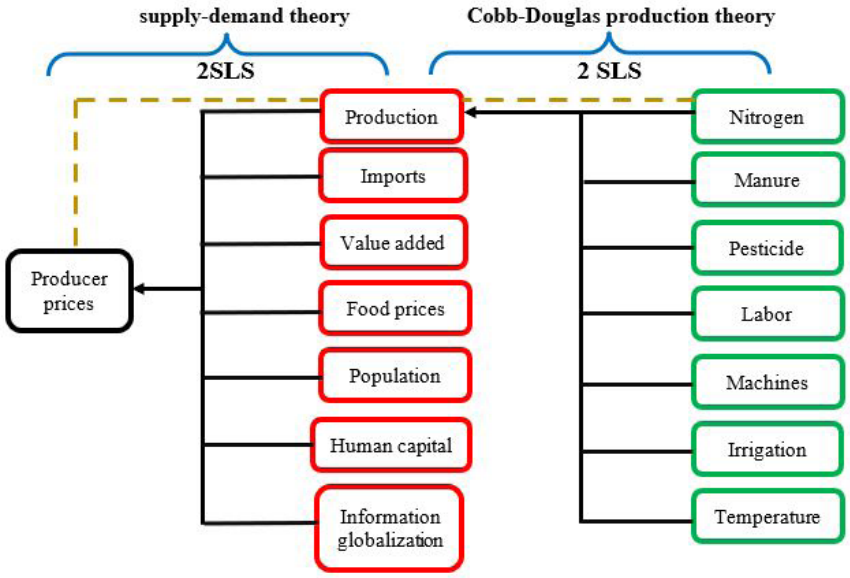
agricultural growth (Jeder, 2023). Agriculture has now embraced the smart and precise integration of technologies like the Internet of Things (IoTs), sensors, robotics, artificial intelligence, intelligent supply chains, big data analysis, and blockchain. The primary goal of technological integration is to increase agricultural productivity and efficiency (Chandio et al., 2023; Jararweh et al., 2023). The technology also addresses information issues that impede farmers' market access, introduces new methods of offering extension services, and enhances agricultural supply chain management (Deichmann et al., 2016).

In the macro aspect, IoTs can be linked to information globalization, which means the ability to share information across countries. It is measured by the number of television sets per capita and the number of individuals who have access to the Internet. Furthermore, the press freedom index measures the accessibility of news-related information (Gygli et al., 2019).

IoTs can improve agribusiness buyer recognition and be more helpful to farmers by increasing product prices (Jararweh et al., 2023). Much research on the impact of IoTs on producer prices has been carried out but most of this research was carried out at the micro level (Chandio et al., 2023; Deichmann et al., 2016; Subejo et al., 2019). Meanwhile, no investigations at the macro level have been conducted and this is the novelty of this study. Existing studies also produce different findings, with some claiming that IoTs raise agricultural producer prices (Chandio et al., 2023) while others claim that IoTs have no significant impact on agricultural producer prices (Deichmann et al., 2016). This is a research gap and encourages us to conduct studies at the macro level. So, the main objective of this study is to determine the impact of information globalization on agricultural producer prices in developing and developed countries.

Research framework

This study uses two main interrelated theories, namely aggregate supply-demand and Cobb-Douglas production (Figure 1). The supply-demand theory relates to price changes in the market, including the producer level. The concept of supply and demand is at the foundation of current economic theory, describing how the total output amount and aggregate price level can be established to reach equilibrium. This approach emphasizes the importance of demand in influencing prices. Demand is measured by the quantity of consumers, their purchasing power, and their characteristics (Pindyck and Rubinfeld, 2013). Hence, this study attempts to characterize demand using variables such as population size, consumer food prices, and consumer education quality. On the other hand, supply influences prices, particularly those of goods produced by producers, as well as the quality of these goods and the ability to supply goods from abroad. This study represents this circumstance with numerous explanatory variables: production, value added, and imports.



Source: Authors identification, 2024

Figure 1: Research framework

Another key consideration is the function of technology in accelerating the flow of information between producers (supply) and consumers (demand). Currently, macro-level information can be represented as information globalization. Globalization of information aims to measure the flow of ideas, knowledge, and pictures. Information globalization is quantified using various variables: 1) Internet bandwidth measures the used international internet bandwidth capacity and serves as a proxy for international incoming and outgoing digital information; 2) high technology exports describe the flow of technological and scientific information; 3) the number of television sets per capita; 4) the number of people with internet access; and 5) the press freedom index measures the availability of news-related information (Gygli et al., 2019).

Meanwhile, Cobb Douglas' theory suggests that supply (in this case agricultural production) is influenced by a variety of production inputs utilized by farmers, including fertilizer, pesticides, manpower, and agricultural equipment. The utilization of these production inputs has the potential to increase agricultural production in both developed and developing countries (Pindyck and Rubinfeld, 2013).

These conditions demonstrate that agricultural production has an impact on farm prices, but it is also influenced by the usage of production inputs. If this condition is evaluated using econometrics, it will create a problem known as endogeneity, which will bias the analysis results. To address this, a particular technique is required, specifically the use of simultaneous least squares analysis (Greene, 2003).

Material and methods

Data source

This study used time series data from 1991 to 2020 and cross-section data from 66 developing and 26 developed countries (Appendix A1). We classified countries using IMF indicators, which included developing and developed countries. There are 23 developing countries in Africa, 18 countries in Asia, 18 countries in Latin America and the Caribbean, and the rest are in Europe and Oceania. The developed countries for this study sample are spread across America, Asia, Europe, and Oceania. As stated in Table 1, this study will also use several other explanatory variables and data sources.

Effective chemical fertilizer management is very important to increase agricultural productivity, while improving water and air quality and mitigating climate change (Gourevitch et al., 2018). The main obstacle of using chemical fertilizers is that they are expensive and impact soil degradation, nutrient depletion, and are one of the main sources of greenhouse gas (GHG) emissions. As a result, many farmers are switching from conventional fertilizers to organic fertilizers. Organic fertilizer reduces GHG intensity greatly

Variable	Symbol	Source
Gross production index number (2014-2016 = 100)	GPI	FAO
Agricultural producer price index (2014-2016 = 100)	PPI	FAO
Nutrient nitrogen N (total)	NIT	FAO
Manure applied to soils (ton)	MAN	FAO
Pesticides (litre)	PES	FAO
Employment in agriculture, forestry, and fishing (000 persons)	EMP	ILO
Farm machinery per unit of agricultural land	MAC	Our data in World
Land area equipped for irrigation (000 ha)	IRRI	FAO
Temperature change	TEMP	FAO
Agricultural import value index (2014-2016 = 100)	IMP	FAO
Agricultural value added (million US$)	AVA	FAO
Food consumer price inflation (%)	FCPI	World Bank
Population growth (%)	POP	World Bank
Human capital index	HCI	Penn World Table
Information globalization index	IGI	KOF Globalization Index

Source: Authors identification, 2024

Table 1: Variable and data source.

as compared to conventional fertilizer. Furthermore, the usage of organic fertilizer helps to prevent crop losses caused by bio-physical stress to a certain extent and increases crop production and economic profitability (Gholkar et al., 2022).

Hypothesis 1: The use of nitrogen fertilizer will increase agricultural production.

Hypothesis 2: The use of manure will increase agricultural production.

Like chemical fertilizers, pesticides have the potential to significantly boost global agricultural production and technical efficiency. Global pesticide use continues to increase due to the increasing number of pest species following climate change and land degradation (de Souza et al., 2023). However, their excessive usage has put water resources and individual health at risk. Water contaminated with pesticides causes chronic toxicity, carcinogenic, and detrimental environmental impacts (Singh et al., 2023). This shows the importance of human resource capabilities in managing the use of agricultural inputs.

Hypothesis 3: The use of pesticides will increase agricultural production.

An increase in agricultural labor quality will lead to an increase in agricultural production, value-added, and competitiveness (Dait, 2022). Human capital is also a key part of agricultural research and development innovation. Innovation has the potential to boost food availability and accessibility, economic development, and well-being (Usman et al., 2021). However, several issues still exist in agriculture, including the gender gap. Women are still rarely involved in agricultural activities and receive lower wages than men (Zaman et al., 2022). The next issue is the shift of labor from the agricultural sector to the non-agricultural sector. Agriculture is considered not an attractive sector since it cannot provide a decent income for labors (Usman et al., 2021). The decline in the share of employment in the agricultural sector encourages modern production factors in this sector and there is a continuous increase in the combination of modern and traditional factors (agricultural modernization) (Liu and Wang, 2022). Many modern machine tools are used in agriculture today such as tractors, pumps, threshers, harvesters, and power tillers. Robots and artificial intelligence are no longer limited to typical agricultural production tasks (such as plowing and combined harvesting) but are also used to conduct non-standard tasks (such as fruit picking, selective weeding, and plant sensing) (Marinoudi et al., 2019).

Hypothesis 4: The use of labor will increase agricultural production.

Hypothesis 5: The use of machines will increase agricultural production.

Agricultural production is also vulnerable to climate change. This increases floods and droughts, soil degradation, water shortages, pests and diseases; jeopardizes agricultural productivity; disrupts production efficiency; and declines in GDP, consumption, household income across all economic sectors, and food security (Liu and Wang, 2022). The worst thing is water scarcity puts a strain on agricultural production. Hence, it can be overcome by implementing innovative water management technology and effective water consumption. One of which is the use of smart irrigation technology to increase crop yields, overcome water scarcity and climatic challenges, conserve water and soil, mitigate soil salinity, and manage groundwater quantity and quality (Usman et al., 2021).

Hypothesis 6: The use of irrigation will increase agricultural production.

Hypothesis 7: The increasing temperature will disrupt agricultural production.

According to supply theory, the abundance of products in the market causes the price to fall and vice versa. This theory outlines the rational behavior of producers seeking to maximize profits by altering production volumes in response to price changes (Pindyck and Rubinfeld, 2013). Excessive growth in agricultural production leads to market saturation, a fall in domestic producer profitability, and a worsening of the industrial sector's financial status (Yakovenko et al., 2018). Aside from quantity, producer prices are also influenced by product quality which can be represented as value-added. The rise of value-added has a favorable impact on product prices and producer incomes (Bassett et al., 2018).

Hypothesis 8: the increase in agricultural production will reduce producer prices.

Hypothesis 9: the increase in agricultural value-added will increase producer prices.

Consumer prices are the next factor that drives producer pricing, as consumer prices cause price rises at the producer level (Levin and Vimefall,

2015). Inflation raises production costs and prices while decreasing product competitiveness (Amiri et al., 2021). The final economic factor that influences producer prices is economic openness. The entry of imported products causes excessive supply in the domestic market and product prices will fall. Meanwhile, the imposition of tariffs raises the price of imported products, which in turn raises the price of domestic products (Krugman and Obstfeld, 2003).

Hypothesis 10: the increase in food price inflation will increase producer prices.

Hypothesis 11: the increase in agricultural imports will reduce producer prices.

Apart from economic factors, producer prices are also influenced by non-economic factors. The first is population, both quantity and quality. Population growth raises the demand for food products. In these circumstances, producers have the opportunity to increase prices to meet market demand (Pindyck and Rubinfeld, 2013). Population quality or human capital has also an important role in reducing transaction costs, increasing the effectiveness of managerial decisions in agricultural businesses, and ensuring the sustainability of the agricultural food supply chain (Oliveira and Turčínková, 2019).

Hypothesis 12: the increase in population growth will increase producer prices.

Hypothesis 13: the increase in human capital will increase producer prices.

The second is related to the information globalization. This is critical because agricultural market participants, especially farmers, often do not receive information. The oligopsony agricultural market structure makes some market participants hide market information. The use of information and communication technologies (ICTs) makes it easy for farmers to access agricultural information, from upstream to downstream. As a result, farmers will get a decent price (Nugroho, 2021).

Hypothesis 14: the increase in information globalization will increase producer prices.

Data analysis

The empirical analysis begins with Augmented Dicky Fuller (ADF) unit root test to eliminate spurious regression due to the usage of nonstationary time-series data throughout the period (Levin et al., 2002):

$$\Delta Y_{it} = \alpha Y_{it-1} + \sum \beta_{it} \Delta Y_{it} - j + X_{it}\delta + v_{it} \quad (1)$$

Y_{it} is the pooled variable, X_{it} is an exogenous variable, v_{it} is the error term.

Following that, we ran the two-stage least squares (2SLS). The 2SLS model was chosen because the study model, particularly the GPI, has an endogeneity issue. Endogeneity occurs when the GPI is supposed to influence PPI; while other variables also influence the GPI (Batmunkh et al., 2022). The conventional least squares model cannot solve the endogeneity problem because it cannot eliminate the error terms and correlate with one another.

The 2SLS model employs an instrumental variable technique to integrate calculations. The residuals from step 1 are then utilized to estimate the covariance matrix of the disturbance equation consistently. Finally, it estimates the correlation structure in each equation using the generalized least squares (GLS) model (Greene, 2003).

Equation 2 based on Cobb Douglas or constant elasticity of substitution (CES) production functions:

$$GPI = \beta_0 + \beta_1 NIT + \beta_2 MAN + \beta_3 PES + \beta_4 EMP + \\ + \beta_5 MAC + \beta_6 IRRI + \beta_7 TEMP + \mu \quad (2)$$

Equation 3:

$$PPI = \gamma_0 + \gamma_1 GPI + \gamma_2 IMP + \gamma_3 AVA + \gamma_4 FCPI + \\ + \gamma_5 POP + \gamma_6 HCI + \gamma_7 IGI + \sigma \quad (3)$$

The reformulation of Equations (2) and (3) is called the reduced form of the structural equations system. The reduced form is obtained by substituting TEMP Equation (2) into Equation (3):

$$PPI = \gamma_0 + \gamma_1 (NIT + MAN + PES + EMP + \\ + MAC + IRRI + TEMP) + \gamma_2 IMP + \gamma_3 AVA + \\ + \gamma_4 FCPI + \gamma_5 POP + \gamma_6 HCI + \gamma_7 IGI + \sigma \quad (4)$$

$$PPI = \gamma_0 + \gamma_1 NIT + \gamma_1 MAN + \gamma_1 PES + \gamma_1 EMP + \\ + \gamma_1 MAC + \gamma_1 IRRI + \gamma_1 TEMP + \gamma_2 IMP + \\ + \gamma_3 AVA + \gamma_4 FCPI + \gamma_5 POP + \gamma_6 HCI + \\ + \gamma_7 IGI + \sigma \quad (5)$$

Abbreviations are explaned below the Table 3.

The 2SLS model must pass several post-estimation tests to be valid. Post-estimation tests for the 2SLS model include (Greene, 2003): 1) the Hausman method was used as an endogeneity test, 2) the Stock & Yogo method was used as a weak instrument test, and 3) the Sargan method was used as an identification restriction test.

Results and discussion

Results

We ran two-unit the Augmented Dicky Fuller (ADF) root tests, one for developing countries and one for developed countries. Unit root test for developing countries shows that *GPI, PPI, NIT, MAN, PES, EMP, MAC, IRRI, TEMP, IMP, AVA, FCPI, POP, HCI*, and *IGI* are stationary at level (Table 2). Meanwhile, unit root tests for developed countries show that *GPI, PPI, MAN, MAC, TEMP, IMP, FCPI, POP, HCI*, and *IGI* are stationary at level. At the same time, *NIT, PES, EMP, IRRI*, and *AVA* are stationary at the first-difference level.

The 2SLS model was used to assess all variables after the data became stationary. Equation (2) demonstrates that the endogeneity test has a significance level of 0.038 in developing countries and 0.030 in developed countries, but Equation (3) has a significance level of 0.043 in developing countries and 0.021 in developed countries (Table 3). Both models exhibit endogeneity significance levels lower than the 5% alpha level, indicating that endogeneity issues exist in their respective structural equations. Both the overidentification and weak instrument tests show a significant value at the 5% alpha level, indicating that the structural model is over-identified and that each equation contains a strong instrument variable.

The Cobb-Douglas function is used in this study to depict the technological relationship between the amounts of two or more inputs (especially physical capital and labor) and the quantity of output that those inputs can produce. Nutrient nitrogen (NIT), pesticides (PES), farm machinery (MAC), and irrigation (IRRI) are some inputs that can boost agricultural production (GPI) in developing countries. According to our findings, NIT, PES, MAC, and IRRI boosted agricultural output by 0.000002, 0.00008, 4.2834, and 0.0006, respectively. Two inputs cause a decline in GPI in developing countries, namely manure (MAN) and employment in agriculture, forestry and fishing (EMP) of -0.00002 and -0.0001. Meanwhile, temperature change (TEMP) does not have a significant effect on GPI in developing countries. In developed countries, MAN, PES, and MAC are inputs that can raise GPI by 0.000006, 0.0003, and 0.7873 respectively. On the other hand, GPI will decrease by -0.000009, -0.0063, and -0.0012 due to increases in NIT, EMP, and IRRI in developed countries. TEMP does not have a significant effect on GPI in developed countries, as it does in developing countries.

Following that, we examine the determinants influencing agricultural producer prices (PPI) in both developing and developed countries. PPI in developing countries experienced an increase when GPI, agricultural import (IMP), agricultural

Symbol	Developing countries		Developed countries	
	Stage	Statistic	Stage	Statistic
GPI	At level	-12.351***	At level	-5.734***
PPI	At level	-40.482***	At level	-8.369***
NIT	At level	-6.782***	1st difference	-9.219***
MAN	At level	-6.612***	At level	-6.025***
PES	At level	-7.369***	1st difference	-9.263***
EMP	At level	-7.300***	1st difference	-9.758***
MAC	At level	-6.598***	At level	-3.922***
IRRI	At level	-6.699***	1st difference	-8.913***
TEMP	At level	-10.458***	At level	-7.998***
IMP	At level	-20.390***	At level	-11.886***
AVA	At level	-8.089***	1st difference	-8.546***
FCPI	At level	-10.330***	At level	-8.429***
POP	At level	-8.737***	At level	-4.884***
HCI	At level	-7.119***	At level	-4.604***
IGI	At level	-11.865***	At level	-8.907***

Note: Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.
Source: Authors computation, 2024

Table 2: ADF unit root test.

Variable	Developing countries		Developed countries	
	Coeff.	Std. Error	Coeff.	Std. Error
Dependent variable: GPI				
NIT	0.000002*** (3.2540)	0.0000007	-0.000009*** (-6.9571)	0.000001
MAN	-0.00002*** (-6.1569)	0.000004	0.000006 (1.8768)	0.000003
PES	0.00008*** (5.5184)	0.00001	0.0003*** (7.3947)	0.00004
EMP	-0.0001*** (-3.8108)	0.00004	-0.0063*** (-5.6950)	0.0011
MAC	4.2834*** (5.9397)	0.7212	0.7873*** (4.3374)	0.1815
IRRI	0.0006*** (4.2886)	0.0001	-0.0012** (-2.6462)	0.0005
TEMP	0.8927 (-0.7363)	1.2124	0.8486 (1.2807)	0.6626
Cons.	66.0374*** (59.7929)	1.1044	93.5784*** (89.8068)	1.042
Adj R^2		0.2066		0.1228
F test		56.7627		16.554
Overidentification test		6.8752		12.8604
Weak identification test		8.7293		21.0952
Endogeneity test		4.9017		5.8949
Dependent variable: PPI				
GPI	0.9381*** (3.3854)	0.2771	0.8426*** (5.8533)	0.1439
IMP	0.3319*** (3.9423)	0.0842	0.2088*** (5.6229)	0.0371
AVA	0.00002* -2.352	0.000009	-0.00002 (-0.7809)	0.00002
FCPI	0.0093 (-1.3811)	0.0067	-0.0663*** (-5.4595)	0.0121
POP	1.8582. (1.9679)	0.9443	-4.6078*** (-6.0843)	0.7573
HCI	9.3717*** (3.8963)	2.4053	13.0113*** (5.4584)	2.3837
IGI	0.3369* (2.3595)	0.1428	0.2225* (2.193)	0.1015
Cons.	-33.5000** (-2.4336)	13.7654	-62.6327*** (-3.3961)	18.4425
Adj R^2		0.4865		0.3210
F test		327.2783		120.9312
Overidentification test		6.3312		9.7267
Weak identification test		8.8872		14.4309
Endogeneity test		4.1870		8.3691

Note: Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.
Source: Authors computation, 2024

Table 3: Determinant factors of agricultural production and producer price in developing and developed countries

value added (AVA), population growth (POP), human capital (HCI), and information globalization (IGI) rose. PPI increased by 0.9381, 0.3319, 0.00002, 1.8582, 9.3717, and 0.3369, respectively, due to increases in GPI, IMP, AVA, POP, HCI, and IGI. Another explanatory variable, food consumer price inflation (FCPI), has no influence on PPI in developing countries. The phenomenon

in developed countries shows that PPI will rise by 0.8426, 0.2088, 13.0113 and 0.2225 due to increases in GPI, IMP, HCI and IGI. Meanwhile, increases in FCPI and POP reduced PPI by -0.0663 and -4.6078. The only explanatory variable that has no effect on PPI in developed countries is AVA.

Based on the findings, there are several explanatory variables that support and do not support the hypothesis of this study (Table 4).

Hypotheses	Developing countries	Developed countries
Hypothesis 1: The use of nitrogen fertilizer will increase agricultural production.	Supported	Unsupported
Hypothesis 2: The use of manure will increase agricultural production.	Unsupported	Supported
Hypothesis 3: The use of pesticides will increase agricultural production.	Supported	Supported
Hypothesis 4: The use of labor will increase agricultural production.	Unsupported	Unsupported
Hypothesis 5: The use of machines will increase agricultural production.	Supported	Supported
Hypothesis 6: The use of irrigation will increase agricultural production.	Supported	Unsupported
Hypothesis 7: The increasing temperature will disrupt agricultural production.	Unsupported	Unsupported
Hypothesis 8: the increase in agricultural production will reduce producer prices.	Unsupported	Unsupported
Hypothesis 9: the increase in agricultural value-added will increase producer prices.	Supported	Unsupported
Hypothesis 10: the increase in food price inflation will increase producer prices.	Unsupported	Unsupported
Hypothesis 11: the increase in agricultural imports will reduce producer prices.	Unsupported	Unsupported
Hypothesis 12: the increase in population growth will increase producer prices.	Supported	Unsupported
Hypothesis 13: the increase in human capital will increase producer prices.	Supported	Supported
Hypothesis 14: the increase in information globalization will increase producer prices.	Supported	Supported

Source: Authors identification, 2024

Table 4: Supported or unsupported the hypothesis of this study.

Determinant factors of agricultural production in developing and developed countries

The use of NIT has a U-shaped relationship. When used appropriately, NIT has a positive effect on GPI, but it will have the opposite effect when NIT is used excessively (Qiu et al., 2022). NIT helps the process of forming chlorophyll and plant photosynthesis, resulting in increasing GPI in developing countries (Gholizadeh et al., 2017). The opposite condition occurs in developed countries where excessive NIT has increased environmental damage, soil acidity, biodiversity loss, and reduced its use efficiency, causing a decrease in GPI (Ding et al., 2022). In addition, developed countries have low NIT efficiency, or agricultural sectors utilize excessive fertilizer to achieve the same amount of output (Rudinskaya and Náglová, 2021). Hence, many developed countries have long switched to utilizing manure (MAN), which has been shown to boost GPI.

The addition of MAN improves soil organic matter, nutrient absorption, and water retention capacity. The positive influence of MAN on crop productivity is especially noticeable during dry seasons with low rainfall. The change in orientation of the use of NIT to MAN in developed countries is also due to a growing awareness of increasing sustainable agriculture, curbing soil nitrogen depletion, lowering GHG emissions, maintaining plant yield, and improving human and soil health (Gholkar et al., 2022). This action was also taken by developing countries, although it resulted in a drop in GPI. This is very typical because utilizing MAN initially lowers the GPI and gradually raises it.

The use of the next production factor, pesticides (PES), has proven effective in both developed and developing countries in reducing crop yield loss and quality decline by controlling insect pests, weeds, and diseases. Hence, PES use rose 56% and 38% in the United States (US) and Australia, respectively, between 2009 and 2016. Developing countries have used PES since the Green Revolution and continue to play an important part in current food, vegetable, and fruit production (Maino et al., 2023).

Total employment (EMP) has a negative correlation with GPI in both developing and developed countries. There are numerous child laborers and precarious labors in agriculture, which reduces the agricultural system's efficiency due to low skills (Behrendt et al., 2021). This makes agriculture unattractive since it cannot provide a decent income for labors. As a result, EMP is shifting from agriculture to industry and services as well as mobilization from villages to cities. The remaining agricultural labor has a limited ability to absorb knowledge and innovation spillovers (Usman et al., 2021). This suggests that agriculture does not require more EMP, but rather specialized EMP and mechanization to increase GPI.

The use of agricultural machinery (MAC) has

been shown to increase GPI in both developing and developed countries. Each region's governance is vigorously supporting the use of MAC and artificial intelligence to alleviate labor shortages, save labor costs, boost production efficiency, and improve agricultural production speed. Furthermore, this process increases the agricultural added value of each worker as well as the profits of production factors, promotes economic complexity, and strengthens economic ties between agriculture and the industrial sector (Liu and Wang, 2022). Even during the Covid-19 pandemic and lockdown, the decline in agricultural production can be reduced because of the use of agricultural mechanization (Zhang et al., 2020). Based on that, the government even provided MAC assistance and subsidies to make this program successful (Zaman et al., 2022).

Aside from production factors, increasing GPI can be accomplished through the provision of infrastructure, particularly irrigation (IRRI). IRRI in developing countries has much increased productivity and land values. (Phu, 2023; Usman et al., 2021). The use of advanced irrigation technologies such as drip irrigation is also an effective way to reduce soil salinity in the root zone and increase crop yields (Du et al., 2023). Hence, many developing countries prioritize policies for developing irrigation networks. For example, the Vietnamese government has built a vast irrigation infrastructure and waived irrigation fees for farmers to reduce rural poverty and improve the public image of the government (Phu, 2023). Meanwhile, developed countries use more wastewater that has been reprocessed utilizing artificial wetlands, waste stabilization ponds, membrane bioreactors, vermi-biofiltration, and land treatment technologies for the elimination of chemical and biological contaminants (Biswas et al., 2021). Hence, IRRI causes a decline in GPI in developed countries.

Temperature (TEMP) is the only explanatory variable that does not affect GPI. Although it differs from many other research, this can be explained for a variety of reasons, the most important of which are mitigation and adaptation to climate change. Recent discoveries have made researchers aware of multiple methods for mitigating the effects of drought disasters. The methods are based on forecasting future drought features several months or even seasons in advance. The outcomes of this method are used to make decisions in water resource management (Wang et al., 2023). In practice, climate change mitigation methods such as boosting the resilience of agricultural production practices, increasing human adaptation, and building project-based early warning systems for weather reports are being implemented (Omotoso et al., 2023). Farmers also implement climate change adaptations such as crop rotation, boosting agricultural inputs, modifying crop sowing dates, engaging in off-farm activities, expanding cropland areas, and raising more livestock to preserve GPI stability (He et al., 2023).

Determinant factors of agricultural producer price in developing and developed countries

Increased GPI benefits both developed and developing countries' producer prices (PPI). The GPI is not only used to meet domestic needs but also international demand. Many countries are now able to participate in the global agricultural food chain. This integration encourages each country to diversify its exports (Yakovenko et al., 2018). Many countries are also trying to enhance the commodity structure of agricultural exports and boost the export share of high value-added processed and food products (Pohlová et al., 2018). This is what raises PPI and provides many benefits for agricultural business participants and the food industry's sustainable growth (Yakovenko et al., 2018).

Another factor that influences PPI is agricultural imports (IMP). PPI was increased by IMP in this study. This is contrary to trade theory, which holds that imports cause a fall in the price of domestic products and keep producer prices to a minimum. The difference in results is caused by the fact that many countries pay subsidies to producers while importing products. Subsidies are widely used because they are thought to safeguard producers' ability to reach decent prices, boost production efficiency, and modernize agriculture (Rudinskaya and Náglová, 2018). In addition, economic openness has boosted product competitiveness, resulting in higher product quality (Shao et al., 2022). This can also be seen from the fact that agricultural value-added (AVA), which is a representation of product quality, has a positive relationship with PPI, especially in developing countries. AVA is critical for increasing the farmers' prices and export diversification in developing countries (Sanida et al., 2016). For example, boosting AVA in Brazil was critical for rising PPI (Hagel et al., 2019). Logically, increasing AVA will improve product quality and provide farmers with a decent price.

The relationship between food prices (FCPI) and PPI in this study is asymmetric. This means that the increase in FCPI is not transmitted to producers, resulting in a drop in PPI. The strong influence of consumer prices on PPI formation occurs in many developed countries. In Lithuania, for example, consumer prices have a greater short- and medium-run impact on producer prices than vice versa (Živkov et al., 2023). This occurs frequently in agriculture because many business participants conceal price information and in imperfect pure market conditions (Nugroho, 2021). Furthermore, when the FCPI rises quickly or is on an upward trend, the government will emphasize it by limiting the PPI. The government should also postpone moderate monetary policy easing until the FCPI cycle has stabilized or is in a decreasing phase (Shaoping and Xiaotao, 2014).

Population growth in developing countries raises the demand for food products. In these circumstances, producers have the opportunity to increase prices to meet market demand (Pindyck and Rubinfeld, 2013). In contrast, population growth in developed countries lowers PPI. Meanwhile, Behrendt et al. (2021) show that the role of skill and education development can be relied upon in increasing the efficiency of production and marketing systems. Increasing human capital helps agricultural participants to think rationally, resulting in higher producer prices, more efficient product creation, and better response to market demand. Producers can also quickly comprehend and utilize new agricultural technologies (Effendy et al., 2022).

Impacts of information globalization on agricultural producer price in developing and developed countries

Information globalization (IGI) can increase PPI in developed and developing countries The massive spread of IGI has resulted in increased access and transfer of agricultural knowledge. IGI has a significant positive influence on rural household income. IGI also lowers information costs and incentivizes farmers to engage in product markets (Leng, 2022). Information to identify pests and diseases, pesticide use, and appropriate production techniques is now delivered more quickly as IGI develops. Because of this, farmers can raise their selling prices since they can communicate directly with customers and create product compatibility with consumer needs (quality, health, and safety standards) (Krone et al., 2014). Farmers can also reduce the possibility of asymmetric information in the agricultural market, shorten the marketing chain to reduce marketing costs, enhance pricing transparency, boost farmers' bargaining power, and reduce crop losses as perishable products are sold more quickly (Nugroho, 2021).

The development of IGI also enables the agricultural industry to examine the extent and distribution of drought, as well as vegetation cover and soil temperature trends, and the impact of climate change. This allows them to devise measures to mitigate climate change, maintain agricultural output stability, and raise producer prices (Alimbekova and Walker, 2022).

Despite its promising impact, IGI development still faces several challenges. First, there is a lack of literacy and skills among farmers using IGI technology, especially in developing countries. Only young, educated and high-income farmers are familiar with modern information technology (Subejo et al., 2019). Second, there is a lack of information infrastructure. This is evident in underdeveloped technologies, low levels of internet adoption, and disparities in urban and rural growth. This issue stems from a limitation of infrastructure development funds (Leng, 2022).

Conclusion

This study uses two-stage least squares to determine the impact of information globalization on agricultural producer prices in developing and developed countries. The first stage of analysis shows that pesticides and farm machinery increase agricultural production in developing and developed countries, while employment in agriculture, forestry and fishing has the opposite effect. Meanwhile, nutrient nitrogen, manure, and irrigation have differing effects on agricultural production in the two areas. The second stage of analysis shows that agricultural producer prices in developing and developed countries will rise when agricultural production, agricultural import, and human capital increase. Agricultural value added, food consumer price inflation, and population growth have varying impacts on agricultural producer prices. Meanwhile, the main variable investigated in this study, information globalization, has been proven to increase agricultural producer prices in both developing and developed countries.

This study contributes to the application of innovation adoption theory in agriculture. The application of globalization information in agriculture provides benefits for increasing agricultural prices. According to the findings

of this study, several steps are required to increase agricultural producer prices, including 1. increasing public access to the internet (information globalization) by providing infrastructure and valid information; 2. increasing agricultural market participant's ability to use modern tools and process information; 3. increasing agricultural production by increasing quantity and efficiency of agricultural inputs use, especially pesticides and agricultural machinery; and 4. creating a more open agricultural business environment, especially the entry of imported products to increase the efficiency of agricultural businesses.

The main limitation of this study is that it looks at information globalization progress at a macro level. Meanwhile, many barriers to information technology adoption and innovation in the micro sector, make information globalization difficult to implement. Based on this, we recommend that future studies examine farmers' adoption of information technology in a broad geographic area, rather than just one country. Another limitation is that it does not account for subsidies. Even though subsidies have a considerable impact on agricultural producer prices. As a result, we recommend that future studies include subsidies as a variable influencing agricultural producer prices.

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Appendix

Developing Countries			Developed Countries	
1. Argentina	24. Honduras	47. Paraguay	1. Australia	24. Switzerland
2. Bangladesh	25. Hungary	48. Peru	2. Austria	25. United Kingdom
3. Belize	26. India	49. Philippines	3. Canada	26. United States of America
4. Benin	27. Indonesia	50. Poland	4. Cyprus	
5. Bolivia	28. Iran	51. Qatar	5. Czech Republic	
6. Botswana	29. Iraq	52. Romania	6. Denmark	
7. Brazil	30. Jamaica	53. Russia	7. Finland	
8. Burkina Faso	31. Jordan	54. Saudi Arabia	8. France	
9. Cambodia	32. Kenya	55. Senegal	9. Germany	
10. Cameroon	33. Lao PDR	56. South Africa	10. Greece	
11. Chile	34. Madagascar	57. Sri Lanka	11. Israel	
12. China	35. Malaysia	58. Tanzania	12. Italy	
13. Colombia	36. Mali	59. Thailand	13. Japan	
14. Democratic Republic of the Congo	37. Mauritius	60. Togo	14. Republic of Korea	
15. Costa Rica	38. Mexico	61. Trinidad and Tobago	15. Latvia	
16. Dominican Republic	39. Mozambique	62. Tunisia	16. Lithuania	
17. Ecuador	40. Myanmar	63. Turkiye	17. Malta	
18. Egypt	41. Nepal	64. Uruguay	18. Netherlands	
19. El Salvador	42. Nicaragua	65. Vietnam	19. New Zealand	
20. Ethiopia	43. Niger	66. Zimbabwe	20. Norway	
21. Fiji	44. Nigeria	65. Vietnam	21. Portugal	
22. Gambia	45. Pakistan	66. Zimbabwe	22. Spain	
23. Ghana	46. Panama		23. Sweden	

Source: Authors identification, 2024

Table A1: List of developing and developed countries.

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Economic Assessment of Small-Scale Mountain Dairy Farms by Using Accounting Data: Evidence from an Italian Case Study

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Abstract

Dairy mountain farms are economically disadvantaged due to small farm sizes and high production costs. This situation was exacerbated firstly by the opening of the market linked to the abolition of milk quotas; secondly by the rising prices due to the energy crisis due to covid 19 and the war in Ukraine. However, these farms are important for the preservation of traditional landscapes, the economy of these areas and the offered ecosystem services, especially when they are managed extensively. The objective of this research is to understand if mountain dairy farms are economically sustainable and competitive through the analysis of a case study. The economic analysis takes into account the production cost of milk, profitability, and some economic indicators using accounting data. The results show that the farm profitability is decreasing, and the costs are unsustainable. As a consequence, more efficient policy support is needed to overcome this crisis.

Keywords

Dairy farms, mountain areas, Appennines, economic analysis, sustainability, case study.

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Introduction

The European dairy sector has undergone many changes over the last decade, which led to a radical transformation. One of them is the removal of milk quotas in 2015. This event brought an increase in volatility in milk prices (Milk Market Observatory, 2023) and induced a change in European farmers' strategies, forcing them to rely on their adaptive and transformative capabilities (Jongeneel and Gonzalez-Martinez, 2022). This transition created the need for farmers to reform their existing management strategies and brought to gradual process of intensification of dairy production, with increased production and the concentration of livestock in larger holdings located in more profitable regions to the detriment of disadvantaged areas such as mountains (MacDonald et al., 2000; Tasser et al., 2007; Groeneveld et al., 2016; Dervillé et al., 2017; Berton et al., 2020).

These changes in the socioeconomic scenario can have dramatic and immediate effects on the mountain system, causing both economic and environmental problems (Bernués et al., 2011).

According to ISTAT data, in Italy mountain areas represent approximately 35% of the territory (ISTAT, 2020). In these areas, agricultural and livestock activities have a significant importance and, very often, are the only ones capable of guaranteeing the permanence of the populations and avoiding situations of extreme marginalization (European Parliament, 2013).

In particular, mountain dairy farms represent one of the primary sources of livelihood in these areas and are fundamental to the maintenance of the landscape and cultural rural heritage (Plieninger et al., 2006; Battaglini et al., 2014; Dervillé et al., 2017; Morales et al., 2019). Indeed, they are usually small-scale and low-intensity family farming systems, characterized by the use of a particularly high share of permanent grassland for hay production and pasturing (Pinter and Kirner, 2014; Kühl et al., 2020).

The use of pasture makes those farms an important source of ecosystem services and allows them to achieve more sustainable environmental performances when compared to the lowland farms (Bernués et al., 2011; Marini et al., 2011; Verduna et al., 2020). For this reason, the preservation

of small family farms is one of the key factors in the sustainability of agropastoral systems (Corsi, 2006; Aldanondo Ochoa et al., 2007; Aubert et al., 2009; Cavicchioli et al., 2015). The social system of mountain areas itself is suffering a profound impact which puts the cultural heritage of local populations and social sustainability for future generations at risk. For the Italian dairy sector, mountain livestock farming is the basis of dairy production that is unique in terms of history, production characterization and quality (Sturaro et al., 2013).

However, these farms are endangered by the marginal conditions they face which make their economic situation particularly difficult (Pinter and Kirner, 2014; Staffolani et al., 2023). From the literature, it emerges that mountain dairy farming has higher production costs compared to dairy farms located in plain areas (European Commission, 2008; European Parliament, 2013; Lips, 2014). This is related to higher fixed costs, due to a lower quantity of milk produced and the impact of the pasture rental on the farm costs (Kühl et al., 2020; Verduna et al., 2020).

Compounding the situation, from the second half of 2021 and subsequently in 2022, there has been a sharp increase in the variable cost, in particular of energy and feed (CREA, 2022) due to the increase in global energy demand due to the reopening of the markets after covid 19, and then to the war in Ukraine (European Commission, 2022).

To cope with this difficult situation, the European Union provides financial support for the maintenance of agriculture in the mountains (European Parliament, 2018). However, as Kühl et al. (2020) affirm, low-input farms are often dependent on subsidies and without financial aid, their income could be negative.

In this context, the aim of this research is to analyse the economic sustainability and competitiveness of small-scale mountain dairy farms. In detail, the economic analysis of a case study is conducted to compute the production cost of milk and the profitability. Moreover, to explain the dairy farm's efficiency the Income Over Feed Costs (IOFC) performance indicator is calculated. The analysis will be conducted following a cost analysis methodology. To increase the robustness of the results, a direct comparison between the case study's data and the national data from the Italian Livestock Products Market Observatory (SMEA, 2023) is carried out. In detail, the analysis of national production costs and profitability of bovine milk is carried out using the data collected by CREA-PB (Council for Research in Agriculture and the Analysis of Agricultural Economy - Policies and Bio-economy) within the FADN (Farm Accountancy Data Network).

The document is organized as follows: section 2 provides the dataset and method; section 3 presents and discusses the main results; finally, the conclusions and some policy implications are detailed in section 4.

Material and method

Case study and data collection

In this research, we focused on a case study.

The investigated dairy farm is located in the Marche Region (Central Italy) in the mountain area of the Apennines of central Italy (Figure 1). In the Marche Region, at the time of the analysis, there are only 88 dairy cattle farms, for this reason it represents one of the Italian regions with the smallest number of farms (Anagrafe Nazionale Zootecnica, 2024). However, 65% of the farms in this region are located in mountain areas. The average size of these farms is 60 dairy cows per farm, and they produce 68% of the milk in the entire region. For these reasons, mountain dairy farming is of particular importance for this area.

The case study farm was chosen because its average size conforms to the characteristics of the farms in its region and for its particular characteristics (presence of farm dairy and quality logos) which make it an interesting example for evaluating the sustainability of this type of farm.

The farm is family-run with the help of permanent employees. In 2022, an average of 120 animals were raised within the farm, of which 60 cows, of the “Italian Red Spotted” cattle breed, characterized by a dual attitude and marked rusticity. Breeding, in 2022, was carried out on pasture in the summer and in cubicles in the winter.

The feed and fodder are partly self-produced and partly purchased from local farms. In particular, the farm has access to a total of 87 ha of which 20 ha are occupied by forest, 60 ha are intended for grassland pasture and 7 ha are arable land.

The farm is characterized by the use of precision technologies for milking (automatic milking system DE LAVAL) that improve the efficiency of management.

Source: our elaboration

Figure 1: Geographical setting and picture of the study dairy farm.

Moreover, from the point of view of quality, the farm produces high-quality milk that complies with the quality parameters set by the regional system "Qualità Marche" (QM) (L.R. 23/2003) and is certified with the European "Mountain Product" label (Commission Delegated Regulation (EU) 665/2014).

Finally, it should be noted that part of the milk production, equal to 41%, is destined for sale to the local cooperative, while the remaining part is directly worked in the dairy farm for the processing and marketing of dairy products. For the purposes of this analysis, only the revenue and cost aspects of milk production will be presented, taking into account the higher price of milk processed in the farm dairy.

During the period under analysis, substantial changes were observed in the structural characteristics of the case study, as can be seen in Table 1.

	2019	2020	2021	2022
TAA (ha)	33	33	33	87
UAA (ha)	13	13	13	67
Total work units	2	2	3	3
Family work units	1	1	1	1
Number of cattle	105	120	120	120
Dairy cows	52	60	60	60
LU	79.2	84	84	84
Milk produced (t)	367	432	436	445
Yield (t/cow)	7.05	7.20	7.27	7.41

Source: our elaboration

Table 1: Evolution of the structural characteristics of the farm by reference year.

This first change occurred in the period 2019/2020 with the increase in the yearly average number of cattle, from 105 to 120, and cows, from 52 to 60, which led to an increase in the quantities of milk produced, from 367 t to 445 t, with an average annual production of 7.41 t of milk per cow in 2022.

After the increase in the number of cattle on the farm, there was an increase in the number of working units, with the recruitment of a new permanent worker. Finally, in 2022, the farm increased the usable agricultural area (UAA) available by renting new land mainly used for grassland/pasture. In fact, before 2022 the farm used grazing exclusively for dry cows, while starting from this year it has extended the practice to the entire herd.

The collection of information and data took place through a series of direct interviews with the owner of the dairy farm.

Economic assessment method

In order to analyse the costs of production of milk and the profitability of the case study, this research follows a cost accounting analysis.

In particular, the cost items were classified on the basis of the actual monetary transition. Explicit costs were therefore identified, i.e. monetary transitions in favour of the subject who supplied the specific production factor (e.g., payment to the fodder seller), and implicit costs, i.e. costs not originating from monetary outlays (e.g., depreciation) (Gregori, 2021).

In this classification, explicit costs are represented by all the factors purchased by the farm through the market, and which therefore require monetary transitions, while implicit costs are the costs linked to the factors supplied by the farm itself, for which their remuneration does not require of monetary transitions. These were therefore estimated. For this reason, the costs of the case study were collected based on the expenses actually incurred by the farm obtained from the analysis of the invoices received. Furthermore, some indirect cost items (such as depreciation) were calculated by the authors.

This methodology was chosen to identify total costs and total revenues in order to calculate the profitability of the dairy farm.

All production costs incurred are attributed to the main product, i.e. milk, as the farm under analysis is specialized in the production of this product, and the technical and economic choices are made based on bovine livestock production, with a crop combination oriented to obtain fodder and cereals intended for reuse in livestock farming. Furthermore, most of the other products sold, which on average account for less than a fifth of revenues, are largely co-products, such as meat, obtained in the same production process as milk, the cost of which is inseparable from this unless of complex and random estimates.

In detail, cost items are collected in eight groups of inputs and expressed in €/100 kg of milk produced:

- the first group of factors is related to the cost of purchased feed, represented by fodder and hay purchased.
- The second group includes the feed production costs, represented by the cultivation costs and the mechanization costs.
- The third group, called "livestock cost", comprises three categories of costs: veterinary and pharmaceutical products, energy expenditures, and other expenditures.
- The fourth group comprises the general expenses of the livestock farm and the cost of use of the land, composed of the rents and the value attributed to the landed capital of the property.
- The fifth group includes the depreciation of buildings, machinery and livestock.
- The sixth group is related to labour costs, where both family work and employees' wages are included.
- The seventh group consists of interest.
- The last group of costs consists of taxes on production. In the case study analysed it is specified that the tax item was not taken into consideration because the farm had an exemption for the payment of taxes due to the damages suffered as a result of an earthquake that hit the area in which it is located in 2016 (Camera.it, 2022).

The total revenue, also expressed per 100 kg of milk, derives from the sum of the value of the milk produced with the animal sales, the Common Agricultural Policy (CAP) payment, and the production rewards. In particular, among the CAP payments were considered:

- first pillar payments for practices beneficial to the environment and basic payments.
- Second Pillar payment linked to animal welfare practices, and reimbursement for disadvantaged areas.

In this analysis, was considered a period of four years (2019-2022).

Finally, to explain the dairy farm's efficiency the IOFC performance indicator are used.

This key index, proposed by Pratt and White (1930), is an indirect indicator of profitability of dairy farms and it is widely used to compare production performance in dairy farms (Hansen et al., 2005; Wolf, 2010; Atzori et al., 2013; Bellingeri et al., 2020). It expresses what remains to the farm of the revenue from milk sold after paying the total feed costs (Campiotti, 2021). Is expressed by Equation 1:

$$IOFC = (Revenues\ from\ milk - Total\ feed\ cost)/ N°\ of\ cow \quad (1)$$

Where the Revenue corresponds to the milk sales and total feed cost is the sum of the feed purchased and the feed produced.

To increase the robustness of the calculated costs, the empirical results are compared to the data from the farm accountancy data network (FADN) provided by the Italian Livestock Products Market Observatory (SMEA, 2023).

The comparison is made with the average data of farms from the Apennines of central Italy, operating in conditions similar to those in the case study.

Results and discussion

In this section, the results obtained by the case study farm will be presented. These data will then be used to make a parallel with the average data related to milk production in the Apennine area, where the case study farm is located.

Case study results

Table 2 shows the cost of producing milk on the case study farm, split by cost items. The period considered is a four-year term from 2019 to 2022.

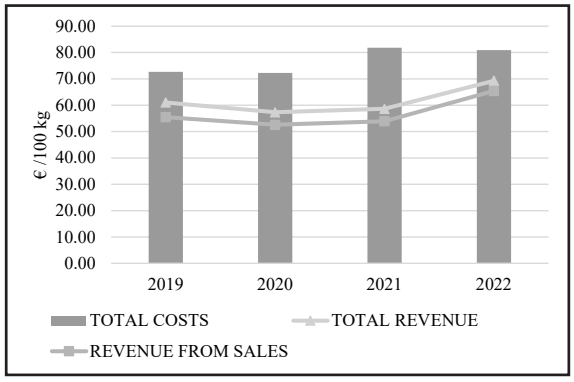
The first result that emerges from Table 2 is that the farm has no profit margins in the years under

€/100 kg	2019	2020	2021	2022
Feed purchased	34.72	34.29	40.1	36.76
feed	30.34	26.22	28.64	25.29
fodder	4.38	8.08	11.46	11.47
Feed production costs	2.52	1.83	2.19	7.1
crop expenditure	0.33	0.3	0.11	4.23
mechanization costs	2.19	1.53	2.09	2.88
Livestock costs	6.63	10.04	7.37	8.12
veterinary and pharmaceutical products	3.37	3.15	1.76	1.59
energy	1.41	1.21	2.11	4.2
other expenditure	1.85	5.69	3.5	2.33
General and land expenditure	4.98	2.07	2.97	6.9
overheads	4.98	2.07	2.97	6.05
land use	0	0	0	0.85
Depreciation	10.2	8.66	9.11	8.42
buildings	6.5	5.52	5.4	4.28
machinery	1.34	1.14	1.07	0.93
livestock	2.36	2	2.64	3.21
Maintenance quotas	3.74	6.74	7.74	3.17
buildings	2.76	1.46	2.5	1.3
machinery	0.98	5.28	5.24	1.88
Labour cost	7.44	7.98	10.51	10
family work	3.32	3.55	3.13	2.85
family social security contributions	0.29	0.32	0.25	0.25
paid employment	3.83	4.1	7.13	6.91
Interest on agricultural capital	2.44	0.67	1.79	0.43
Taxes (VAT)	0	0	0	0
TOTAL COSTS	**72.68**	**72.29**	**81.78**	**80.9**
Product value (milk)	51.26	49.82	49.54	58.39
Sale of animals	4.25	2.74	4.4	7.04
REVENUE FROM SALES	**55.5**	**52.57**	**53.94**	**65.43**
Milk quality rewards	0.88	0.83	0.73	0.7
CAP payment	4.68	3.94	3.96	3.16
TOTAL REVENUE	**61.06**	**57.33**	**58.63**	**69.29**
Loss or Profit (Margin) from sales	**-17.18**	**-19.72**	**-27.84**	**-15.47**
Loss or Profit (Margin)	**-11.62**	**-14.95**	**-23.15**	**-11.61**

Source: our elaboration on farm data

Table 2: Revenues and costs for milk production in the case study farm from 2019 to 2022 (euro/100 kg).

analysis. The margin is negative even if the CAP payments and the premiums obtained for high-quality production are considered. Furthermore, the loss worsens in the three-year period 2019/2021 and then eases in 2022 (Figure 2).

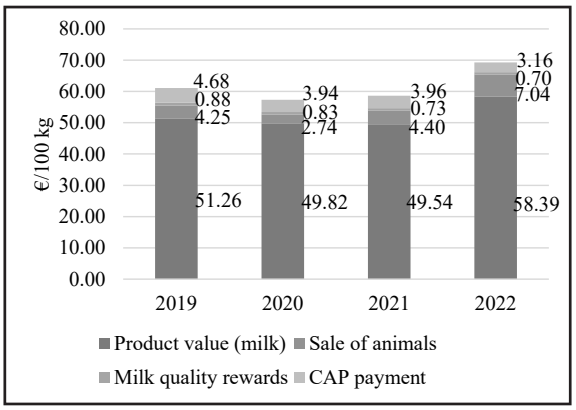


Source: our elaboration on farm data

Figure 2: Comparison between total costs, sales revenue and total revenue (euro/100 kg) from 2019 to 2022.

In particular, considering the analysis of total revenues, a fluctuating trend is observed over the years under analysis. This trend is linked to the main cost item, Product value (milk), which suffers from market price fluctuations. It is interesting to underline that the average annual value of milk recognized on the farm is higher than that recorded at a national level (Milk Market Observatory, 2024). This difference could be linked to the qualitative properties presented by the milk produced in the mountains and to the application of quality labels by the case study farm.

Revenues linked to premiums for the quality of milk produced and contributions obtained from the first pillar of the CAP are of little impact, on average around €4.7/100 kg, equal to 8% of total revenues. Despite the farm has access to numerous payments linked to the second pillar, such as payments for disadvantaged areas and good animal welfare practices (Figure 3; Table 2).

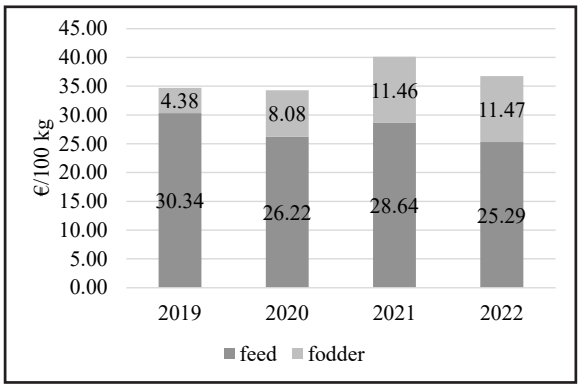


Source: our elaboration on farm data

Figure 3: Farm revenues (euro/100 kg) from 2019 to 2022.

While, analysing the production costs, from Table 2, it is notable that the main cost item is the feed purchased; this cost rise from 34.29 €/ 100 kg in 2020 to 40.10 €/ 100 kg in 2021, with a variation of +16.9%. The cost decreases in 2022 to 36.76 €/100 kg, with a variation of – 8.3% compared to 2021.

The increase in this cost item in the years is due mainly to the fodder, which, as it is observed in Figure 4, it is increased progressively, with a particular increment of +41% in 2021.

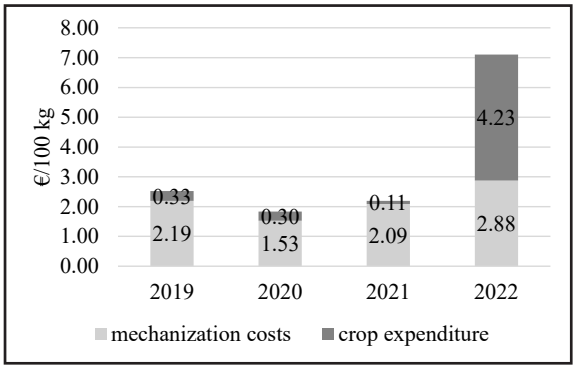


Source: our elaboration on farm data

Figure 4: Trend of the costs for the feed purchased (euro/100 kg) from 2019 to 2022.

The increase in the farm's cost of feed purchased could be linked to several factors. In particular, in 2019 the farm joined the "Mountain Product" label introducing a different production strategy. Adherence to this label requires the farm to essentially use feed and fodder produced in mountain areas, with a portion of the annual diet not produced in the aforementioned areas, expressed as a percentage of dry matter, not exceeding 40%. As a result, the farm has increased the incidence of purchasing local feed and fodder, produced in mountain areas, which however have higher costs than other suppliers. In parallel with this change in management, the increase in the incidence of costs could also be linked to the change in the economic aspects of the market, due to the pandemic and the Ukrainian conflict.

To confirm this, the data show a sharp increase in the item "feed production costs" in 2022, where the farm spent 224% more than in 2021 (Figure 5), to ensure self-sufficiency.



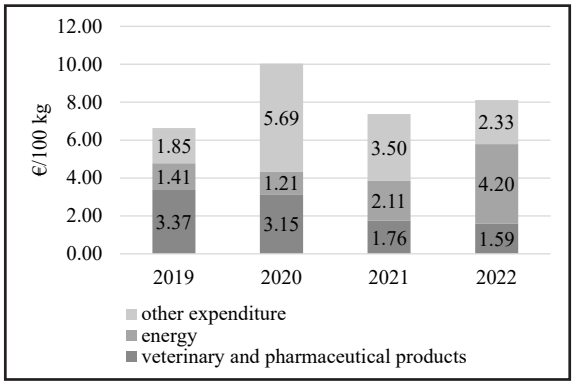
Source: our elaboration on farm data

Figure 5: Trend of the feed production costs (euro/100 kg) from 2019 to 2022.

The effect of the increase in costs for the feed purchased is also reflected in the "general and land expenditure", increased by the land use costs for the pasture.

The greater incidence of the costs of purchased feed and the lower impact of both the costs of produced feed and general and land expenditure during years 2019/2022 are an indication of the fact that the case study farm relied more on the purchase of feed off-farm than on self-production and use of pastures. However, following the cost increases, the farm has progressively changed the applied policy by increasing self-production costs and obtaining greater possibilities for grazing, as observed in 2022. Despite the change in management, the farm has not managed to cope with the high costs for purchased feed, remaining in a loss-making situation.

Also interesting is the trend of the "livestock costs", with particular reference to the energy item, which has a variation of +99% in the range 2021/2022 (Figure 6). The peak observed in livestock costs in 2020 is linked to extraordinary maintenance carried out in the farm for the renewal of the stable.



Source: our elaboration on farm data

Figure 6: Trend of the livestock costs (euro/100 kg) from 2019 to 2022.

Finally, the depreciation quotas show fluctuations during the years under analysis, but overall their incidence reduces between 2019 and 2022. This is linked to the end of some quotas on buildings and machinery. However, there was an increase in livestock quotas following the expansion of the herd (Table 1, Table 2). In parallel with the end of depreciation quotas, there has been an increase in maintenance quotas, in particular for machinery and tools.

Lastly, as a result of the increase in the number of fixed work units, labour costs rose by +31% between 2020 and 2021.

Lastly, Table 3 shows the results from the key performance indicator.

Year	IOFC (€/cow)
2019	989
2020	987
2021	527
2022	1039

Source: our elaboration on farm data

Table 3: Key farm indicator analysis of average Nord-Centre Apennines dairy farms and case study.

The IOFC in the case study remains slightly below the threshold levels indicated in the literature in all the years under analysis (1200 €/cow) (Campiotti, 2021). IOFC remains stable between 2019 and 2020, and then decreases significantly in 2021, due of the peak cost of nutrition. The value of €527/cow recorded in 2021, in fact, indicates a very low margin for the farm to cover all other production expenses and denotes a serious crisis condition. The 2022 increase, is not linked to a reduction in costs but to an increase in sales revenue due to an exceptionally high price of milk. For this reason, if the farm were to continue to bear these costs and the price of milk were to fall, it would find itself in a critical condition.

Comparison with the average data of farms from the Apennines of central Italy

In order to compare the case study with the mountain's geographical context, Table 4 refers to data on the North-Centre Apennine Mountains.

The average data from the Apennine mountains of central Italy show that, unlike the case study, on average the farms showed a positive margin in 2019, which then became negative in the three-year period 2020/2022. However, this margin is

	2019	2020	2021	2022
Number of cows	45.1	39.1	39.4	40
Milk produced (t/cow)	4.87	5.04	5.03	5.02
€/100 kg				
Feed purchased	17.08	11.05	12.93	17.16
fodder	14.77	9.77	11.57	15.22
hay	2.31	1.28	1.37	1.94
Feed production costs	5.58	6.91	7.35	8.67
Livestock costs	3.26	3.1	3.29	4.45
General and land expenditure	8.35	8.78	8.86	8.8
Depreciation	4.34	6.89	7.38	8.15
Labour cost	18.6	20.97	21.01	21.53
Interest	1.53	4.18	4.2	4.33
Taxes	0.15	0.35	0.39	0.46
TOTAL COSTS	**58.89**	**62.23**	**65.42**	**73.56**
Product value	54.79	49.54	54.41	65.45
Total rewards	7.9	6.87	6.85	6.77
TOTAL REVENUE	**62.69**	**56.41**	**61.26**	**72.23**
Loss or Profit (Margin)	**3.79**	**-5.82**	**-4.16**	**-1.33**

Source: our elaboration on SMEA, 2019, 2021, 2022, 2023

Table 4. Average revenues and costs for milk production in North-Centre Apennine Mountains from 2019 to 2022 (euro/100 kg).

positive if all CAP payments and other rewards are considered. In fact, if only sales revenues are considered, in line with the case study, the margin is negative. Even in the average data, the fluctuations in the price of milk are significant, following the same trend observed for the case study. Finally, it is important to underline that the losses detected in the case study are more critical than those observed on average.

This difference in the margin is linked to the fact that the average data presents higher total revenues than those of the case study, both in terms of the value of sales and the prizes obtained.

Furthermore, the case study also has higher production costs than the average data.

The main difference in the cost items is linked to the costs for purchasing feed. These are decidedly higher in the case study than in the average farms. This is linked to the widespread use of off-farm feed on the case study farm. However, compared to the case study, in the average data there are higher costs both for self-production and for the use of land, used by farms mainly for grazing. It can therefore be stated that on average the farms in the mountain areas practice more grazing and self-production of feed compared to the case study farm.

It is underlined that, despite the incidence of purchased food being lower, even on average there is an attempt to contain the latter which has led to an increase both in the costs for self-production and in the costs for the use of land. In fact, the costs for purchased food increased in the average data by +33%, due to the increase in both fodder (+31%) and hay (+42%). At the same time, self-production costs increased in the period 2019/2022 by +55%, while land use costs increased by +5%.

The values linked to depreciation are also very different between the case study and the mountain average. The case study farm, in fact, differs from the national average due to the presence of technological systems (milking robot). At the same time, the use of robotics in the farm allows it to face lower labour costs than average. In fact, if in 2022 the average labour costs in the mountain area were €21.53/100 kg, in the case study farm these amounted to half, or €10/100 kg. This is of particular relevance, if we consider the average number of cows present on the farm. In the mountain average the average

number of cows is around 40 compared to 60 in the case study, therefore the case study manages to spend half on labour costs while managing a greater number of animals.

Lastly, even from the average data we see an increase in total production costs, with a different trend than that seen in the case study. In fact, in the case study the increase is concentrated in the two-year period 2020/2021 and the costs stabilize in 2022, while in the average data the increase is progressive between the years under analysis.

Conclusion

Mountain dairy farms are crucial for the preservation of rural mountain communities because they represent an important source of income both directly, for the production of food, and indirectly for the preservation of cultural traditions and tourism. Moreover, these farms are also crucial from an environmental point of view, as they represent an environmentally sustainable animal production system and provide numerous ecosystem services. However strong market changes have made the survival of these farms very difficult.

The analysis shows that the average revenue of dairy farms in the Apennine mountains has increased, thanks to the particular market conditions which have led to high farm-gate milk prices and to the price premium which is awarded to mountain milk for its quality, certified by the mountain product label and local certifications.

However, revenues are not sufficient to offset total production costs. In fact, production costs, and in particular overheads, are very high in mountain dairy farms, making production at a loss. In addition, increases in feed purchase costs and production costs have aggravated the situation by further increasing pressure on these farms. For this reason, mountain dairy farms are not only less competitive than lowland farms but are not economically sustainable.

The case study chosen for this analysis is not representative of all the farms located in the Italian mountain area, however it provides us with a specific snapshot of a territorial reality and interesting ideas on how it might be possible to improve the situation of these farms.

First of all, a serious problem in the mountain farms of central Italy is labour costs, in the case study these are reduced thanks to the introduction of the milking robot. This allows the farmer to dedicate himself to other tasks and reduces the need for manpower in the stable. Furthermore, this technology also allows the farmer to monitor the health of the herd and the quality of production, thus optimizing other expenditure items and increasing the possible rewards linked to quality and animal welfare.

Secondly, the case study farm transforms part of the milk produced in the farm's dairy, in this analysis these costs have not been considered, however it is important to underline that overall the transformation phase allows the farm to obtain positive margins and invest in the renewal of both equipment and premises to remain competitive with farms located in more advantaged areas. It turns out that a possible solution for farms located in mountain areas could be the diversification of production through transformation.

Lastly, the farm adheres to quality brands which allow it to obtain higher premium prices compared to farms located in more advantageous areas. Joining these labels could therefore be a further opportunity for mountain farms.

It is clear that the funding provided by the European Union is crucial to the survival of these farms, but it is not enough. From a political point of view, it would be necessary to increase the funding for these farms to enable them to overcome the current crisis, allowing also to make investments for innovation.

The main limitation of this research is the presence of only one case study, taking into account the difficulty of collecting data, future research could extend the sample of farms analysed. Furthermore, it could be interesting to compare the differences between farms that purchase feed and farms that practice mainly self-production. Finally, future research could carry out cost-benefit analyses on the transformation phase into a dairy.

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Assessing Indonesian Nutmeg Commodity Trade Competitiveness and Developing Sustainable Strategies in the Global Market

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Abstract

Nutmeg encounters challenges in productivity, quality, climate change, Covid-19 disruptions, and stagflation, requiring efforts to enhance competitiveness and meet global market demands. This study aims to analyze Indonesian nutmeg trade performance, assess competitive advantage, and formulate essential strategies to increase its competitiveness. Using comprehensive mixed quantitative and qualitative analysis, methods include export-import market share analysis, CAGR, import dependency ratio, import-to-export ratio, RCA, RSCA, RTA, and SWOT/QSPM analysis. The data obtained from in-depth interviews with key stakeholders was used for formulating strategies enhancing nutmeg's competitiveness. The findings underscore Indonesia's significant dominance in the global nutmeg market, with a considerable 61.6% market share but its export growth rate for nutmeg was less than the import annual growth. The competitiveness indicators demonstrated a robust comparative advantage of Indonesian nutmeg trade in the global market, especially for products categorized as "nutmeg, neither crushed nor ground" and "nutmeg, crushed or ground". Indonesian also has comparative advantage among other exporter countries. Crucial strategies of internal and external perspectives, such as expanding markets, improving nutmeg quality and productivity through improving farmer capacity, technological adoption, and good agricultural practices are necessary to take into account Indonesia's nutmeg competitiveness in global markets.

Keywords

Trade performance, competitiveness, comparative advantage, nutmeg.

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Introduction

Nutmeg (*Myristica fragrans* Houtt.) is a tropical fruit obtained from a perennial essential spice tree originating from the Moluccas Islands in the eastern part of the Republic of Indonesia. It has been cultivated in various regions, including the western side of Indonesia and other countries (Sasikumar, 2021). From pre-colonial to modern society, Nutmeg has played a significant economic role throughout history. Since the 1700s, it has become an attracting values power of spice that has pulled traders all over the world to bring the goods recognized as green gold from the Moluccas exported to other continents as profit resources (Pakpahan et al., 2020; Barjiyah and Margana, 2022). The primary economic

utilization of Nutmeg is as one of the spice trade commodities for food, beverage, health medicines, cosmetic, perfume, and toiletries industries. Nutmeg is one of the most popular spices of world-culinary food and beverage flavors and a decent ingredient in such as curry, soup, instant seasonings mix powder, confectionery, bakery products, syrup, and drinks (Ananingsih et al., 2022; Kabak and Dobson, 2017; Farisi and Rasyid, 2022). Peer-reviewed studies and clinical experiments have investigated the potential functions of nutmeg essential oil, revealing its hepatoprotective, antimalarial, anticonvulsant, antiparasitic, nematocidal, and pesticidal activities (Ashokkumar et al., 2022; Vangalapati et al., 2022). Nutmeg offers numerous health benefits in traditional herb treatments, such as in Ayurvedic medicine, including stomachic, carminative, aphrodisiac, and anti-inflammatory properties (Agaus and Agaus, 2019). Nutmeg is also a potential source of functional properties due to its high antioxidant, antiviral, antibacterial, and antifungal activities (Astuty and Sukmawaty, 2022; Adibuduge and Senevirathne, 2023).

In the global market, nutmeg is a prominent species cultivated in developing countries and exported to developed countries to supply industrial consumption, retail, and catering sectors (Gordon, 2020). In 2022, the trade value of global spices was calculated at about 65,377,049 thousand dollars, and the export was dominated by products such as coffee, tea, mate, pepper, vanilla, cinnamon, clove, and nutmeg. The world exported value of nutmeg was estimated at 897,297 thousand dollars or 1.3% of world traded spices with the exporting countries, namely, Indonesia, India, Srilanka, Netherlands, and German (ITC, 2023). Nutmeg was recognized globally in the HS 09 – coffee, tea, mate, and spices category. For more detail within six digits of harmonized system, nutmeg is categorized into four types of products: (1) HS 09081- nutmeg, neither crushed nor ground; (2) HS 090812 - nutmeg, crushed or ground; (3) HS 090821 - mace, neither crushed nor ground; (4) HS 090822 - mace, crushed or ground.

Nutmeg has become a crucial agricultural product for sustainable agriculture, forest, and farmers' welfare. From the domestic socio-economic and biophysical perspective, nutmeg cultivation has been essential to Indonesian farmers and their communities. In 2021, the total nutmeg production was 39,577 tons, produced from 254,699 ha, of which 99.8 % was cultivated by 268.569 smallholder farmers (DG Estates, 2022). It makes Indonesia the biggest nutmeg country producer and exporter. Indonesia holds the first market share globally, with a share of 62% and an export value of around 183,280 thousand dollars in 2021 (ITC, 2022). The ten export country destinations were China, India, Vietnam, Netherlands, Germany, the US, Japan, Pakistan, Bangladesh, and Italy (MoA, 2022). Additionally, tropical agriculture-climatic suitability becomes the primary endowment factor in nutmeg plantations and development in Indonesia (Leatemia et al., 2017). Nutmeg plantations can be developed under the central agroforestry system because they can be cultivated in the rural area and forest edge to gain sustainable farmers' income and preserve carbon stock in the forest (Tjokrodiningrat et al., 2016; Mardiatmoko et al., 2019). However, the Indonesian nutmeg plantation still faces some challenges, such as relatively low productivity, 454 kg/ha, due to the lack of technological adoption, farmers' knowledge related to good agricultural practices and processing technology, which will determine the product quality, capital support, and market information (Muhammad and Neka, 2019). Another critical issue was that the quality of exported nutmeg did not meet international standard requirements, which led to the export rejection by imported countries and got a lower price than Grenada and India (Lawalata, 2019; Hafif, 2021). Moreover, the climate change challenge affects the nutmeg plantation growth, productivity, and quality; finally, it could impact the socio-economic of farmers and society (Anripa et al., 2023). All these factors can determine nutmeg's dynamic competitiveness and comparative advantage in the global market. Purba et al. (2021) have analyzed performance and competitiveness of nutmeg of Indonesia merely in destined export market periode 2014-2018 using RCA and Export Product Dynamic (EPD) based on data export without considering import growth and dependency ratio. According to Pakpahan et al. (2020), there are still ample opportunities for nutmeg development in Indonesia, especially for maintaining global competitiveness, increasing farmers' welfare, and meeting the quality standards demand. Therefore, it is needed a further research for assesing market share, competitive and comparative advantage comprehensively in global market.

On the other hand, the Covid-19 pandemic has impacted to agricultural supply chain economy disruption, exported products, including spices

business chain in terms of lack of traceability, safety and quality concerns, supply chain logistics bottleneck, and require rapid assessment technologies (Peter et al., 2021; Lin and Zhang, 2020). Spices were categorized as intrinsically highly vulnerable rate food disrupted by the supply chain (Ruth, 2020). Therefore, each stakeholder needs new survival strategies, such as improving market regulation, farmers' capacity, and building supply chain resilience (Benedek et al., 2022). Moreover, some worries and predictions about Indonesian conditions face stagnant economic growth and stagflation (Ilyas, 2022). Furthermore, the conflict condition within European fertilizer exported countries might impact increasing agricultural input production. Several developing countries that depend on chemical fertilizer, such as Indonesia, possibly have a negative impact on increasing food prices and agricultural production inputs (FAO, 2022). For those reasons, Government arranged the recovery programs through the development and improvement of agricultural products, especially in efforts to fulfill basic food needs and maintain the competitiveness of agricultural export products. One of the crucial concerns to be addressed is increasing product competitiveness in order to be able to compete in market dynamics and consumer demand, especially in the global market, as well as nutmeg as exported commodity.

Competitiveness is the ability to produce goods and services that meet international consumers' requirements while maintaining high and sustainable levels of income or the ability of product-producing countries to generate high income and employment opportunities while remaining open to external competition. Countries with high competitiveness have technological capabilities to produce innovative finished products (Filo, 2007). Given the circumstances characterized by the consequences of the medical emergency triggered by the COVID-19 virus and the concurrent geopolitical and energy crises, adopting an alternative perspective when considering competitiveness is a necessity (Vîrjan et al., 2023).

Product competitiveness is a multidimensional concept, where a product is expected to meet market conditions and specific consumer needs, including quality, technical aspects, economics, aesthetic characteristics, and its usability (Ozerova et al., 2019). One of the primary methods to enhance the competitiveness of agricultural product trading in the face of global uncertainties is by broadening our engagement with the international market (Zhou and Tong, 2022). This approach aims to boost agricultural production and trade, effectively addressing the challenges posed by uncertain factors during a global crisis. Competitiveness can also be interpreted as the capacity of producers to face the challenges of international market competition and maintain or increase their export value and market share (Kaleka and Morgan, 2017).

Therefore, nutmeg's comparative and competitive advantage analysis in the global market is crucial for understanding the current position, identifying market competition, and pursuing strategy development. This measurement analysis would be the basis of commodity development in the global market. Therefore, the study focused on nutmeg's net exports and imports, competitiveness, market share, strength, emerging opportunities, weaknesses, and threats.

This study aimed to analyze the current situation of Indonesian nutmeg trade in the global market, measure the competitive and comparative advantage, and analyze the dynamics of strategic commodity competitiveness performance for stakeholders to support increased competitiveness of nutmeg business. These findings and discussions are expected to give beneficial insight and lessons learned among producers and importers countries to the global nutmeg and mace trade and its development.

Materials and methods

The research approach used in this study includes a quantitative analysis and a qualitative descriptive approach. To accomplish the objectives of this research, firstly, the current status and trade performance of Indonesian nutmeg commodities in the global market were calculated using the export-import market share analysis, Compound Average Growth Rate (CAGR), the import dependency ratio, Import to export ratio, Trade Specialization Index (TSI). Second, for analyzing the competitiveness, we also used quantitative methods such as revealed comparative advantage (RCA), revealed symmetric comparative advantage (RSCA), and relative trade advantage (RTA). Third, the qualitative data from in-depth interviews with the representatives of exporters, policymakers, and commodity experts were analyzed using SWOT and QSPM to formulate the essential

strategies to develop the competitiveness resilience of Indonesian nutmeg trade in the global market.

The stages of the study conducted for this research include (1) Identification of the data requirement and resources needed to explore the current status of trade performance and competitiveness; (2) Collection of data of export-import through the ITC- International Trade Center, UN-Comtrade statistics, the Indonesian Statistics Agency (BPS), and data from the Ministry of Agriculture; (3) Calculating the trade performance and competitiveness indicators of nutmeg commodities; (4) Investigation of qualitative data through depth interview related to qualitative data.

The concept theory of revealed comparative export commodity advantage was first initiated by Liesner (1958), but popularized as the Balassa index by Balassa (1965) to measure the country's strengths and weaknesses of export sectors. Some primary econometrical analyses of comparative advantage are the Revealed Comparative Advantage (RCA), Revealed Symmetric Comparative Advantage (RSCA), and Relative Trade Advantage (RTA). Researchers have used these tools to analyze the competitiveness of commodities in specific markets. For instance, Rahardjo et al. (2020) analyzed Indonesian coffee competitiveness in the international market, and Ariesha et al. (2019) researched pepper's competitiveness in the ASEAN market. The RCA approach has also been used to analyze the export competitiveness of European countries' agricultural products on the global market. Some EU-15 countries have higher agricultural product competitiveness values and have a longer duration than other EU-12 countries. The Netherlands, France, and Spain are the three most prosperous countries in the export competitiveness of agricultural products (Bojnec and Ferto, 2015). RCA has also been used to analyze the competitiveness of Hungary's strategic agricultural products in the European market with the result that the country has a comparative advantage in animal and meat products compared to other agricultural products (Fertö and Hubbard, 2003). Likewise, in measuring the competitiveness of agricultural commodities in several ASEAN countries in the ASEAN market (Hoang, 2020). The simplification of the RCA formula of competitiveness measurement is Revealed Symmetric Comparative Advantage (RSCA). The RSCA has been carried out for several export agricultural commodities in India (Lakra et al., 2014; Narayan and Bhattacharya, 2019). The RCA and RSCA approaches are often complemented by the relative trade advantage (RTA) method initially introduced by Scott and Vollrath (1992), which has ever been conducted to assess milk competitiveness within European countries (Simo et al., 2016), analyzing the competitiveness of Viet Nam's agricultural competitive advantage in global market (Van Hoang et al., 2017), assessing European agro-food trade competitiveness (Bojnec and Ferto, 2012), and measuring the competitiveness of dried products of Turkey (Erdem, 2020).

This econometric analysis has determined the focus and scope: 1) The calculation of nutmeg exports and imports data was based on HS code 0908-Nutmeg, Mace, and Cardamom and its specific breakdown codes. While the 6-digit HS data specifically for Nutmeg consists of HS090811: nutmeg neither crushed nor ground; HS 090812: nutmeg, crushed or ground, and HS 090821: mace neither crushed nor ground; and HS 090822: mace, crushed or ground. The Nutmeg is a light brown to dark brown from the seed of the nutmeg fruit. At the same time, mace is the cover net of nutmeg seed aril with yellowish to dark red. After drying, the color changes into light yellow, tan, and orange. For technical consideration, the other writing of nutmeg types were only presented in the code of Harmonized System (HS); 2) The calculated data of the research were from 2012 to 2022, which were yearly time series; 3) In calculating RCA, RSCA, and RTA the data cluster of relative comparison based on spices commodities include HS 09: coffee, tea, mate, and spice.

Data analysis

To answer the first problem, we elaborated several analytical tools commonly used to analyze the performance of foreign trade of products, including the Compound Average Growth Rate (CAGR), Trade Specialization Index (TSI), and Import Dependency Ratio (IDR), Those indices were used to analyze the current development, position stages, and dependency indicator of product traded in the global market. Specifically, International Trade Specialization Index (TSI) can describe the relative position of a country that tends to become an exporting or an importing country for an agricultural sector commodity traded on the international market.

Compound Average Growth Rate (CAGR) of nutmeg export or import

$$CAGR = \left(\frac{V_{final}}{V_{begin}}\right)^{1/t} - 1 \quad (1)$$

$CAGR$ = compound annual growth rate of export or import

V_{begin} = starting value

V_{final} = the end value

t = number of years

Trade Specialization Index (TSI)

$$TSI = \frac{X_i - M_i}{X_i + M_i} \quad (2)$$

TSI = trade specialization index,

X_i = the value of Indonesia's commodity exports of Nutmeg in the year *i*,

M_i = the value of Indonesian commodity imports of Nutmeg in the year *i*

Interpretation of index value, if:

-1 to -0.5: The commodity is categorized as an imported product with very low competitiveness.

-0.4 s/d 0.0: This commodity is categorized as being in the import substitution stage in world trade.

0.1 s/d 0.5: means that the commodity is categorized as being in the starting expansion of exports in world trade.

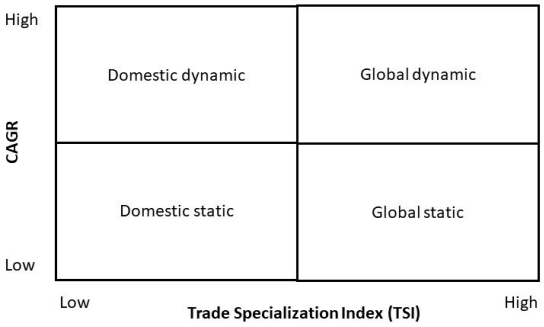
0.6 to 1.0: means that the commodity is in the category of maturity stage in world trade, so the product has strong competitiveness.

Import dependency ratio (IDR)

This approach explains a country's dependence on imports of certain commodities. The IDR calculation does not include stock changes because the size of imported and domestic production stocks is often unknown. In other words, if a country can meet domestic consumption based on its fulfillment, the IDR will be zero (0%). The IDR value can be calculated using the following formula:

$$IDR = \frac{Nutmeg's\ Import}{(Domestic\ production + Import - Export} x\ 100 \quad (3)$$

By understanding the results of CAGR and TSI (the positive value), the type of exported competitive commodity can be described in a 2 x 2 matrix with net trade growth in one axis and TSI in another. The commodities classified as dynamic products are the commodities that have a higher value of growth than the average of world growth and trade specialization index. On the other hand, the positive value of TSI > 0 means that the traded commodity was categorized as export-oriented, while the low value of TSI < 0 means that it is an imported product for the domestic home market. Domestic static products neither fast-grow nor are specialized. Four different types of commodities competitiveness can be figured as in Figure 1.



Source: Adapted from Fetscherin et al. (2012)

Figure 1: Type of competitive export commodities.

Revealed Comparative Advantage (RCA) and Revealed Symmetric Comparative Advantage (RSCA)

Revealed Comparative Advantage (RCA) or Comparative Advantage Index is one of the essential measurement tools in determining the competitiveness of products produced by a country that is marketed in a particular market. Balassa (1965) stated that the RCA index measures a particular commodity export relative to the total export category and compares them to the other product category performance. This Comparative advantage index helps formulate international trade policies for a product and even some products exported to foreign markets. Furthermore, this RCA index can be used as a guide for each country to determine which sector or commodity choices can generate additional foreign exchange because they have a superiority in competitiveness. Laursen (2015) proposed a refining symmetric index from RCA since the RCA result cannot be compared on both sides. The Revealed Symmetric Comparative Advantage (RSCA) approach was used to rationalize the deficiencies in the RCA index. The concept of RSCA brings a significant simplicity in interpreting the meaning of competitiveness, which is the range of RCSA coefficients. The RCA and RSCA formulas can be adjusted formula as follows:

$$RCA\ Index = \left(\frac{X_{ij}/X_{wj}}{X_{iw}/X_w}\right) \quad (4)$$

$$RSCA = \frac{(RCA - 1)}{(RCA + 1)}$$

RCA = revealed comparative advantage

$RSCA$ = revealed symmetric comparative advantage

X_{ij} = export value of nutmeg-type commodity from Indonesia

X_{wj} = the total value of the country's spices exports

X_{iw} = export value of nutmeg commodity from the world

X_{w} = the total value of world spices exports

The commodity is competitive if the RCA indicators value > 0 or RSCA > 0. The commodity has no competitive advantage if the RCA indicators value < 0 or RSCA < 0. If the RCA indicator value = 0, the commodity has neither a competitive advantage nor a disadvantage.

Relative Trade Advantage (RTA)

The RCA and RSCA approaches have the limitation of ignoring the importance of export-import demand and its growth. Therefore, a more in-depth analysis was conducted using the RTA index, calculated based on the difference between the Relative Export Advantage (RXA) and the Relative Import Advantage (RMA). The mapping visualization of index changes is calculated based on the RTA value (Bojnec and Fertő, 2012). Scott and Vollrath (1992) formulated the econometrical analysis of RTA as follow:

$$RTA_{ij} = RTX_{ij} - RMA_{ij} \quad (5)$$

$$RXA_{ij} = (X_{ij}/X_{it})/(X_{nj}/X_{nt})$$

$$RMA_{ij} = (M_{ij}/M_{it})/(M_{nj}/M_{nt})$$

RTA = Relative Trade Advantage

RXA = Relative Export Advantage

X_{ij} = the nutmeg export "*i*" from country "*j*"

X_{it} = total of the nutmeg export "i" to the global market except for the country "j."

X_{nj} = total of export of spice commodities (HS 09) except the nutmeg into a particular country

X_{nt} = total of all export of spice commodity (HS 09) except nutmeg in the global market except particular country

RMA = Relative Import Advantage

M_{ij} = import of nutmeg "i" from country "*j*"

M_{it} = total of nutmeg import "*i*" from all countries except country "*j*"

M_{nj} = total of all imported spice commodities (HS 09) except the commodity "*i*" from country "*j*."

M_{nt} = total of all imported spice commodities (HS 09) except the commodity "i" from all countries except country "j."

If RTA > 0 and RXA >1, it indicates the commodity has a competitiveness

If RTA <0 and RMA >1, it indicates the commodity has no competitiveness

SWOT dan QSPM analysis

SWOT (Strength, Weakness, Opportunity, and Threat) and QSPM (Quantitative Strategic Planning Matrix) analysis are the analytical framework approach to determine decent strategies (Abdolshah et al., 2017). The advanced strategies in increasing the competitive advantage of strategic nutmeg commodity can be identified by conducting analysis using followed approaches, namely identifying SWOT analysis for each factor, calculating the IFE (Internal Factor Evaluation), EFE (External Factor Evaluation) matric, and conducting the QSPM method (David et al., 2017). SWOT analysis consists of strengths and weaknesses originating from the country's internal competitiveness and opportunities and threats originating from the environment it faces. SWOT analysis is a historical technique to make a qualitative insight into the strategic situation of a commodity's competitiveness (Benzaghta et al., 2021; Gurel, 2017). In contrast, the QSPM is an analytical tool used in decision-making that can assist researchers in evaluating various strategic alternatives objectively, which are based on internal and external factors that have been identified. The QSPM matrix helps evaluate and determine the best strategy most suitable for the internal and external environment. The strategy alternative with the most significant total value obtained in the QSPM matrix can be considered the relevance strategy (Putri et al., 2014).

This analysis is based on in-depth interviews with experts in the particular nutmeg field area, such as champion farmers, local traders, exporters, and government officers, especially the provincial government and the Indonesian Ministry of Agriculture (MoA). The data cleaning process, extracting and processing data analysis, visualization, and interpretation of data were using computer-assisted Qualitative Data Analysis (QDA) software, Nvivo12.

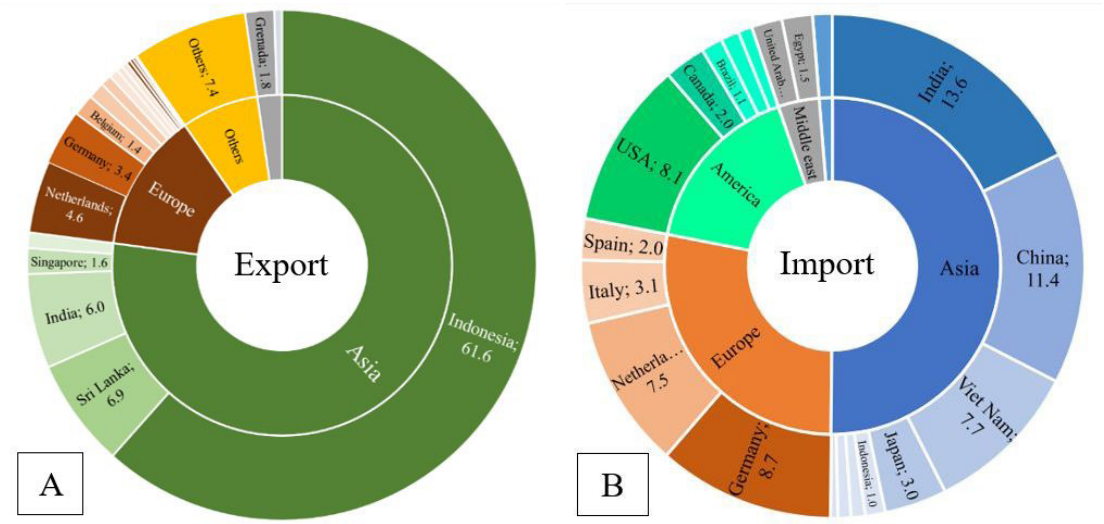
Results and discussion

Indonesian nutmeg trade performance

As a nutmeg exporting country, Indonesia ranks first in the global market share at 61.6% with an export value of around 185,763 thousand dollars from total global export of 301,674 thousand dollars in 2022. For more detail, Figure 2 shows the market share of export and import of nutmeg in global trade. The destinations of Indonesia's exports were China, Vietnam, Japan, German, Italy, the USA, and the Netherlands. In the global market, the nutmeg exporters countries were dominated by Asian countries, such as Indonesia, Sri Lanka, and India. On the contrary, Importers' countries are slightly more evenly distributed all over continents, not only focused on the market in Asian countries but also trading into American, Europe, and Middle East countries. However, some European countries such as the Netherlands and Germany have roles as re-exporter. They were the intermediary countries that imported nutmeg from producing countries for domestic need and resold it to final export destination countries with or without further processing. Netherland nutmeg importing value was about 23,003 thousand dollars, consisting of 20% of nutmeg neither crushed nor ground (HS 090811), 44% of the nutmeg crushed or ground (HS 090812), 10% of mace neither crushed nor ground (HS 090821), and 26% of mace crushed or ground (HS 090822). Those kinds of nutmeg were used for its domestic consumption and re-export to the global market. The re-exporting value of the Netherlands was about 13,836 thousand dollars, more than half of its export value. Likewise, Germany imported Nutmeg mainly from Indonesia, Grenada, Sri Lanka, and India. About 79 % of imported value was used for domestic needs, and 21 % was traded to be re-exported to neighboring European countries.

As the leading exporter of nutmeg in the global market, Indonesia still became an importer country. The Indonesian export value of nutmeg continues to increase significantly with a Compound Average Growth Rate (CAGR) for 2012-2022 of 3.27%, but it also accompanied import incline over the past few years with a growth CAGR of 27.85% (Table 1). CAGR export means the annual growth rate based on the geometric progression ratio over 2012-2022. The Indonesian annual export growth of nutmeg was less than the average world export growth, 11.8% annually.

Unprocessed nutmeg dominates the exports in the form of dried whole nutmeg seed and mace (fuli). Most imported-nutmeg was in terms of processed and derivated products such as nutmeg powder from other countries. However, the trade analysis of Indonesian nutmeg shows that nutmeg is an essential exported commodity, indicating that 70.8% of domestic production was exported to other countries. This trade is confirmed by the value of the import dependency ratio in 2021, and 2022 were only 1.06 and 3.92 %, respectively. The ratio of imports to imports is still relatively low, with only 1.66% of the total exports of Nutmeg in 2022. This percentage shows the ability to meet domestic consumption.



Source: Own calculation based on ITC-statistic and UN-Comtrade, 2023

Figure 2: Market share percentage of nutmeg exporters countries (A) and importers countries (B) on the global market 2022.

The import dependency ratio (IDR) also declares the value of imports compared to total production plus the difference between exports and imports. The TSI (Trade Specialization Index) was conducted to validate as an export commodity. The TSI value of Indonesian nutmeg from 2011 to 2021 is 0.96-0.99 (Table 1). These values show that the commodity is categorized as an exported product in the maturity stage.

Based on the growth and TSI value, Indonesian nutmeg was categorized as a global static competitiveness commodity in the global market. The value of the trade specialization index (0.9) was high, but the CAGR value (3.27%) was less than the average annual world growth (11.8%). It means that the nutmeg market focuses on global trade and market specialization. However, from 2012-2022, the spices commodities had an average annual growth rate of 13.46%. The relative growth of the Nutmeg to spices market was classified in the dynamic trade. Nutmeg's global static matrix zone indicated that the export growth was lower than other spices commodities. It is the chance to compete or expand the market share based on the growth rate.

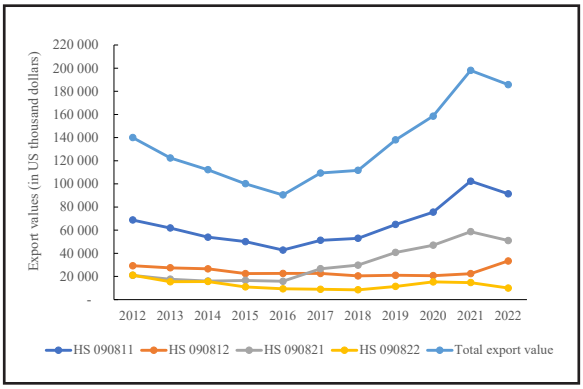
On the other hand, the growth rate of imports should be a concern for the government to control it. Both the rate of import and export can be seen in Table 1. It can be initiated by transforming raw nutmeg into semi-processed or processed products, adding more added value to substitute imports. In the future, it is hoped that Indonesia, as a nutmeg-producing and exporting country, will not rely on the export of nutmeg of neither crushed nor ground but instead on their derivates products which have a higher value.

Indonesia's exports of nutmeg are dominated by Indonesia's neither crush nor ground nutmeg exports (HS 090811) then, followed by 090821 (mace, neither crushed nor ground), HS 090812 (Nutmeg, crushed or ground), and HS 090822 (mace, crushed or ground), as can be seen in Figure 3. In one decade, the total export value of nutmeg had increased from about 140 million dollars to more than 180 million dollars. Even though they had decreased export value from 2012 to 2016, the export trend rose again until 2021. Since 2017, the export value of mace HS090821 has overtaken the export value of nutmeg HS090812. The significant increase in the export of all kinds of nutmegs in 2020-2021 was driven by the high market demand due to covid-19 pandemic health awareness. After that time, the exported nutmeg declined. This condition was related to covid-19 relaxation, which determined the market demand, and the global economy was stagflation. In contrast, the export of HS 090812 nutmeg, crushed or ground, increased from 22.4 million dollars to 33.3 million dollars. It indicated the initiation of exported processed products. Likewise, the export of HS 090821 mace was neither crushed nor ground, which was double the export value in one decade. In nutmeg agribusiness, farmers and exporters begin sorting mace as an exported valuable commodity and do not prefer to sell it as crushed or ground.

Year	Production Quantity (ton)	Production (US Dollar thousand)	Import Values (US Dollar thousand)	IDR (%)	Export Values (US Dollar thousand)	RIE (%)	TSI index
2012	25,321	189,290	815	1.63	140,018	0.58	0.99
2013	28,167	184,774	1,736	2.71	122,372	1.42	0.97
2014	32,729	178,210	626	0.94	112,248	0.56	0.99
2015	33,711	156,319	948	1.66	100,141	0.95	0.98
2016	33,305	161,330	1,091	1.52	90,469	1.21	0.98
2017	32,842	145,818	930	2.49	109,353	0.85	0.98
2018	44,100	201,549	2,237	2.43	111,698	2.00	0.96
2019	40,689	252,679	2,051	1.76	138,024	1.49	0.97
2020	38,150	293,729	1,388	1.02	158,520	0.88	0.98
2021	39,577	294,304	1,031	1.06	198,114	0.52	0.99
2022	39,955*	261,306*	3,085	3.92	185,763	1.66	0.97
CAGR Export		3.27					
CAGR Import		27.85					

Note: * estimation value calculated by Indonesian Ministry of Agriculture (MoA).
Source: own calculation based on MoA, BPS-Statistic Indonesia, and dan UN Comtrade (2023)

Table 1: Indonesian nutmeg production, export-import, IDR (Import Dependency Ratio), RIE (Ratio Import to Export), and Trade Specialization Index (TSI).



Source: Own calculation based on ITC-statistic and UN-Comtrade, 2023

Figure 3: Export value of four kinds of nutmegs HS 090811 (nutmeg, neither crushed nor ground), HS 090812 (nutmeg, crushed or ground), HS 090821 (mace, neither crushed nor ground), and HS 090822 (mace, crushed or ground).

Comparative and competitive advantage

The RCA and RSCA indices are measuring tools for determining the competitiveness of a country's commodities relative to category commodities marketed in specific market areas. High RCA and RSCA values indicate not merely a commodity's competitiveness and market share but also the competitiveness of nutmeg commodities against similar commodities in a country. The results of the calculation of the RCA of the nutmeg trade were transformed and presented into RSCA values. Among the exporter countries, Indonesia has the highest value of the RSCA index, with the RSCA index 2022 and average values of 0.91 and 0.86, respectively, as shown in Table 2. RCA indicators value > 0 or RSCA > 0 means nutmeg commodities have a competitive advantage. It can be said that Indonesian Nutmeg was a more competitive advantage and specialized commodity than other spice commodities in the category of HS 09 coffee, tea, maté, and spices in the global market. Even though the change index value did not increase (0.0%) in ten years and was relatively stagnant. Of the ten top exporter countries, only five exporters have a positive value of RSCA, namely Indonesia, the Netherlands, Sri Lanka, India, and Germany in 2022. Interestingly, Netherlands and Germany are not nutmeg producer countries, but they have a competitive advantage in nutmeg trade relative to their spice commodities in the global market.

All nutmeg products have a positive competitive advantage in the global spices market, as presented in Table 3. All types of Nutmeg were essential and specialized for Indonesian export. Even though the export values were still focused on HS 090811 and HS 090821, the mean values of RSCA in one decade were almost the same. From Change Index (2023/2012), the increased competitiveness advantage of the product HS 090811 and 090812 were 6.67 %and 7.97 %, respectively. Conversely, Change Indices were relatively constant on HS090821 and HS 090822 products. They were

No	Exporters	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Mean	CI (%)
1	Indonesia	0.86	0.82	0.84	0.81	0.82	0.85	0.88	0.89	0.89	0.90	0.91	0.86	0.00
2	Netherlands	0.76	0.70	0.60	0.65	0.65	0.59	0.49	0.46	0.38	0.37	0.47	0.56	-0.26
3	Sri Lanka	0.36	0.46	0.52	0.44	0.45	0.49	0.54	0.62	0.52	0.45	0.42	0.48	0.33
4	India	0.58	0.50	0.56	0.61	0.68	0.57	0.51	0.35	0.45	0.46	0.31	0.51	-0.12
5	Germany	0.19	0.28	0.30	0.26	0.34	0.24	0.25	0.05	0.02	0.11	0.19	0.20	0.05
6	France	0.27	0.29	0.35	0.18	0.29	0.12	0.16	0.02	-0.13	-0.23	-0.32	0.09	-0.67
7	Grenada	0.00	0.11	0.19	0.19	0.21	0.07	0.13	0.08	0.00	-0.13	-0.12	0.07	∞
8	Italy	0.34	0.14	0.16	-0.14	-0.11	-0.13	-0.16	-0.24	-0.23	-0.18	-0.17	-0.07	-1.21
9	USA	-0.19	-0.18	-0.22	-0.12	-0.23	-0.20	-0.26	-0.35	-0.34	-0.36	-0.34	-0.25	0.32
10	Belgium	0.05	-0.16	-0.17	-0.25	-0.24	-0.41	-0.52	-0.44	-0.41	-0.31	-0.22	-0.28	-6.60

Source: Own calculation based on export-import nutmeg global trade, UN-Comtrade, and ITC statistics

Table 2: RSCA, mean value, and Change Index of all kinds Nutmeg of ten exporting countries in 2012-2022.

Type of nutmeg	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Mean	CI (%)
HS 090811	0.87	0.82	0.84	0.82	0.82	0.85	0.89	0.90	0.90	0.92	0.93	0.87	6.67
HS 090812	0.79	0.75	0.79	0.73	0.78	0.78	0.81	0.81	0.78	0.79	0.85	0.79	7.97
HS 090821	0.87	0.87	0.89	0.85	0.86	0.87	0.89	0.87	0.88	0.88	0.87	0.87	0.06
HS 090822	0.87	0.87	0.89	0.85	0.86	0.87	0.89	0.87	0.88	0.88	0.87	0.87	0.06

Source: Own calculation based on export-import nutmeg global trade, UN-Comtrade, and ITC statistics

Table 2: RSCA, mean value, and Change Index of all kinds Nutmeg of ten exporting countries in 2012-2022.

according to their export values of mace that were less than the export value of Nutmeg (HS 090811). Exporters in Indonesia can expand HS 090821 and HS 090822 to compete in the existing market or find new prospectus-importing countries.

Relative Trade Advantage (RTA)

The RTA, RXA, RMA, and CI analysis show that Grenada, Indonesia, and Sri Lanka were the only exporting countries with RTA> 1, RXA>1, and CI positive values. It can be said they have a competitive advantage relative to their spices export in the global market. Those values can be seen in Table 4. Grenada owned the highest values. The Relative Trade Advantage (RTA) trend was also significant, reaching 939.15% from 2012-2022. Its value exceeded Indonesia's RTA Change Index (102%) and Sri Lanka's (41.08%). Grenada is a progressive newcomer exporting country, now holding a 1.8% world export market share in 2022. This value is much smaller than Indonesia's market share (61.6%) and Sri Lanka's (6.9%). However, the rapid growth of Grenada's production and export can open up the possibility that Grenada could overtake Sri Lanka and India in the next ten years. On the other hand, the exporters' countries that were not producer countries, such as Netherlands, France, and USA, even though they have positive RTA values, the trend value was negative. It means they have a declining trend competitive disadvantage of nutmeg in the global spices market.

All types of Indonesian nutmeg products are categorized with competitive advantage indicated by their RTA value > 0 and RXA>RMA value. It can be seen in Table 5. In the breakdown value of nutmeg commodities, the nutmeg products HS 090811, nutmeg neither crushed nor ground, has the highest value of RTA average, but it has

Country	Indicators	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Mean	CI (%)
Indonesia	RXA	29.48	17.73	21.29	16.15	17.69	22.92	33.63	38.22	39.70	49.13	60.26	31.47	104.41
	RMA	0.42	2.08	0.61	1.23	0.79	0.65	0.99	1.34	1.06	0.63	1.42	1.02	238.10
	RTA	29.07	15.66	20.69	14.92	16.91	22.27	32.64	36.88	38.65	48.49	58.84	30.46	102.41
Sri Lanka	RXA	1.85	1.86	2.02	1.92	2.00	1.74	2.24	2.77	2.02	1.81	2.61	2.08	41.08
	RMA	0	0.43	0.37	0	0.07	0.08	0	0	0.25	0	0	0.20	20.00
	RTA	1.85	1.42	1.66	1.92	1.93	1.65	2.24	2.76	1.77	1.81	2.61	1.97	41.08
India	RXA	2.37	2.10	2.59	2.58	3.06	2.25	1.74	1.02	1.19	1.26	1.01	1.92	-57.38
	RMA	0	4.69	4.35	3.65	2.76	4.93	6.76	10.43	6.86	10.43	27.78	8.26	27.77
	RTA	2.37	-2.59	-1.76	-1.07	0.30	-2.68	-5.02	-9.41	-5.67	-9.18	-26.77	-5.59	-1229.54
Netherlands	RXA	8.54	6.66	4.32	5.21	5.31	4.23	3.15	2.86	2.35	2.26	2.91	4.35	-65.93
	RMA	5.75	4.97	3.11	3.34	2.67	2.28	1.76	2.10	2.01	2.20	2.53	2.97	-56.00
	RTA	2.79	1.70	1.21	1.87	2.64	1.95	1.39	0.76	0.35	0.06	0.38	1.37	-86.38
Germany	RXA	0.57	0.54	0.53	0.54	0.60	0.53	0.56	0.46	0.53	0.48	0.55	0.54	-3.51
	RMA	1.35	1.52	1.02	0.81	0.78	0.78	0.81	0.93	0.95	0.94	0.91	0.98	-32.59
	RTA	-0.78	-0.99	-0.49	-0.27	-0.18	-0.25	-0.25	-0.47	-0.42	-0.46	-0.36	-0.45	-53.85
Italy	RXA	1.98	1.07	1.06	0.62	0.60	0.53	0.46	0.36	0.35	0.34	0.39	0.71	-80.30
	RMA	1.29	1.23	1.07	0.69	0.60	0.65	0.48	0.53	0.64	0.75	0.72	0.79	-44.19
	RTA	0.68	-0.16	-0.01	-0.07	0.00	-0.12	-0.02	-0.17	-0.28	-0.40	-0.33	-0.08	-148.53
France	RXA	2.44	1.10	1.03	0.81	0.76	0.48	0.46	0.29	0.25	0.22	0.33	0.74	-86.48
	RMA	0.78	0.59	0.53	0.51	0.42	0.36	0.28	0.31	0.34	0.41	0.53	0.46	-32.05
	RTA	1.65	0.51	0.50	0.30	0.34	0.12	0.18	-0.02	-0.09	-0.19	-0.20	0.28	-112.12
Grenada	RXA	20.87	21.00	195.00	207.00	219.00	222.00	225.00	196.00	183.00	168.00	217.00	170.35	939.77
	RMA	0	0	0.43	0	0	0	0	0.33	0	0	0	0.38	0
	RTA	20.87	21.15	194.83	207.26	218.61	221.86	225.48	195.57	183.48	168.20	216.87	170.38	939.15
USA	RXA	0.60	0.47	0.45	0.46	0.44	0.48	0.40	0.33	0.40	0.41	0.46	0.45	-23.33
	RMA	0.66	0.52	0.45	0.42	0.37	0.32	0.31	0.32	0.39	0.48	0.41	0.42	-37.88
	RTA	-0.07	-0.05	-0.01	0.04	0.07	0.16	0.09	0.01	0.01	-0.07	0.05	0.02	-171.43
Belgium	RXA	0.48	0.56	0.63	0.46	0.53	0.51	0.46	0.60	0.69	0.72	0.56	0.56	16.67
	RMA	1.34	1.02	1.12	0.81	0.90	0.87	0.76	0.79	1.00	1.17	0.76	0.96	-43.28
	RTA	-0.85	-0.46	-0.49	-0.35	-0.36	-0.36	-0.29	-0.19	-0.31	-0.45	-0.20	-0.39	-76.47

Source: Own calculation based on export-import nutmeg global trade, UN-Comtrade, and ITC statistics

Table 4: RXA, RMA, RTA values, Means, and Change Index (CI) of all nutmeg of top ten exporting countries in the global market.

Type of nutmeg commodities	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Mean	CI (%)
HS 090811													
RXA	13.98	8.68	9.91	7.90	8.16	10.41	15.31	17.13	17.97	23.87	28.09	14.67	100.9
RMA	0.29	1.66	0.54	1.08	0.49	0.34	0.12	0.85	0.49	0.40	0.66	0.63	127.6
RTA	13.69	7.02	9.37	6.82	7.67	10.07	15.19	16.28	17.48	23.47	27.43	14.04	100.4
HS 090812													
RXA	5.74	3.73	4.74	3.46	4.20	4.48	5.72	5.32	4.69	4.91	9.74	5.16	69.7
RMA	0.12	0.45	0.17	0.19	0.67	0.58	1.35	0.65	0.60	0.13	0.59	0.50	391.7
RTA	5.62	3.28	4.57	3.26	3.54	3.90	4.37	4.67	4.09	4.78	9.16	4.66	63.0
HS 090821													
RXA	4.11	2.39	2.85	2.55	2.94	5.27	8.32	10.32	10.69	12.87	14.91	7.02	262.8
RMA	0.00	0.04	0.01	0.38	0.00	0.00	0.00	0.18	0.02	0.00	0.06	0.06	6.0
RTA	4.11	2.35	2.84	2.17	2.94	5.27	8.32	10.14	10.67	12.87	14.85	6.96	261.2
HS 090822													
RXA	4.13	2.10	2.78	1.69	1.73	1.76	2.37	2.88	3.48	3.22	2.92	2.64	-29.3
RMA	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.01	0.02	0.01	1.0
RTA	4.13	2.10	2.78	1.69	1.70	1.76	2.37	2.88	3.45	3.21	2.90	2.63	-29.8

Source: Own calculation based on export-import nutmeg global trade, UN-Comtrade, and ITC statistics

Table 5: RXA, RMA, RTA, mean values, and Change Index (CI) of all kinds of Nutmeg of Indonesian trade in the global market.

a change index lower than the type of product HS 090821, mace neither crushed nor ground. The highest value of CI was at HS 090821, mace neither crushed nor ground, reaching 261.1%. The trend RTA value of all nutmeg is increasing, except RTA's HS 090822, which has decreased by about 29.3%. The product HS 090822 was still exported without further processing, and only a small amount was exported in powder. The RMA values in each commodity type are relatively low and less than each RXA value. Despite the relatively low value, the RMA value of each product tends to incline year by year. This is what needs to be considered to maintain its level of competitiveness in the future.

SWOT and QSPM analysis

Some essential findings from the depth interview with the primary actors in the nutmeg sectors reveal that the Indonesian nutmeg trade has strengths, weaknesses, opportunities, and threats, as presented in Table 6. It has strengths from internal factors, such as agro-climatic endowment factors, availability of cultivation technologies, workforce, and genetic nutmeg biodiversity. While the weaknesses are that nutmeg takes a long time to start fruiting, has low farmers' knowledge, is small-scale farming, and needs input support. On the other hand, there are some opportunities as the external factors such as the emerging market of derivative products, growth of importing countries, and increasing demand for spices in the global market. However, it faces some challenges threats, namely increasing competitors' production, climate change, high quality of market demand, and global market security. In the internal factor based on IFE analysis (Table 7), the essential two findings should be accentuated that Indonesian nutmeg has some innovations in the nursery supported by the Ministry of Agriculture in nutmeg centers, seed grafting technology, superior varieties, and the downstream research support; and comparative advantage in terms of agro-climatic endowment. In the EFE analysis, two key factors should rely on market growth opportunity and the awareness of other producing competitors. This is consistent with Anggrasari and Saputro (2022), that Indonesia is the fourth-largest exporter of spices in the world. Indonesia continues to be the leader in terms of area and productivity, especially for cinnamon, cloves, and nutmeg.

INTERNAL FACTORS / EXSTERNAL FACTORS	*Strengths*	*Weakness*
	S1: Agro-climate suitability and ease of cultivation as forest plants and non-timber conservation	W1: The annual plant that takes 3-5 years to start bearing fruit
	S2: Availability of innovations in nursery cultivation, grafting technology, superior varieties, downstream research support	W2: The level of knowledge of farmers related to cultivation, harvesting, and post-harvest technology is relatively low
	S3: The number of demographic bonus workers in the labor sector	W3: Small farming businesses, not yet centralized, and low productivity
	S4: The genetic resources and commodities of Indonesia's nutmeg are well-known to the world	W4: Less input support, Nutmeg does not get subsidized fertilizer
Opportunities	"SO Strategies"	"WO Strategies"
O1: Market growth of nutmeg, spices, and derivative products that open the development of value-added products such as essential oils and cosmetic raw materials from nutmeg	SO1: Preparing domestic production in order to take a positive growth of the nutmeg market by Increasing national production through rejuvenating unproductive nutmeg and preparing seeds using grafting technology	WO1: Accelerate fruit production with grafting technology to increase national production and meet market share growth opportunities
O2: New markets of importing countries	SO2: Efficiency of supply chain lines and costs to destination countries and direct harbor port in east Indonesia	WO2: Increasing farmer knowledge through training, technical guidance, and assistance to increase production and productivity, quality, and create value-added products
O3: Efficiency of supply chain lines and costs to destination countries based on technological developments	SO3: Developing value-added derivative products and scaling up new nutmeg-based businesses, such as essential oil and cosmetic raw materials from nutmeg	WO3: Strengthen farmers' community base for creating more added-value products
O4: Positive growth trend CAGR of 6.5% from 2020 to 2027 for the world spice market	SO 4: Growing new agri-preneurs or exporters to create new markets, especially export destination countries	WO4: The need for fertilizer subsidies or the manufacture of nutmeg fertilizer which is cheaper to reduce production costs, and the need for ports in development centers for cost efficiency
Threats	"ST Strategies"	"WT Strategies"
T1: Competitors for nutmeg producers from other countries, such as Grenada, India, and Sri Lanka, are increasing their market share	ST1: Trying to increase the market share by growing a new exporter and new importing countries	WT1: Encouraging farmers to adopt SOP and GAP to increase the production quality of products
T2: Challenges of climate change on production and productivity	ST2: Anticipate the use of technologies through climate change mitigation and adaptation strategies	WT2: Maintain the quality of nutmeg and keep the market from switching to competitors
T3: EU green product regulations related to free aflatoxin and deforestation	ST3: Try to comply with the green nutmeg quality and standard by adopting technologies in farmers and processors	WT3: Improving farmers' knowledge about mitigation and adapting strategy to climate change
T4: Global market security and stagflation conditions	ST4: Developing a sustainable nutmeg plantation program that is economically, socially, and environmentally feasible	WT4: Paying attention not to destroying the forest and being environmentally friendly

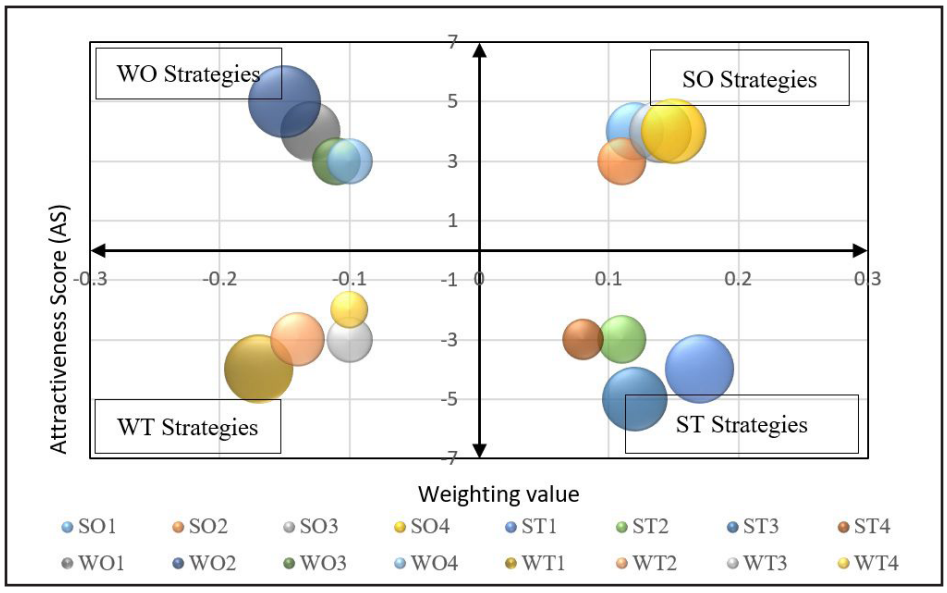
Source: Own authors' analysis considering the experts' opinion

Table 6: SWOT analysis matrix of Indonesian nutmeg competitiveness

No	Internal Key Factors	Weight	Modus Rating	Score	External Key Factor	Weight	Modus Rating	Score
	Strengths	Ai	Bi = 1,2,3,4,5	AixBi	*Opportunities*	Ci	Di = 1,2,3,4,5	C1xD1
1	S1	0.14	4	0.56	O1	0.2	4	0.8
2	S2	0.16	5	0.8	O2	0.13	3	0.39
3	S3	0.12	3	0.36	O3	0.09	4	0.36
4	S4	0.1	3	0.3	O4	0.11	3	0.33
		0.52		2.02		0.53		1.88
	Weakness				*Threats*			
1	W1	0.15	4	0.6	T1	0.17	3	0.51
2	W2	0.16	3	0.48	T2	0.12	3	0.36
3	W3	0.1	3	0.3	T3	0.1	3	0.3
4	W4	0.07	2	0.14	T4	0.08	3	0.24
		0.48		1.52		0.47		1.41
	Total	1		3.54		1		3.29

Source: Own authors' calculation based on the experts' view

Table 7: Internal Factor Evaluation (IFE), and External Factor Evaluation (EFE) matrix.



Source: Own authors' graphical creation

Figure 4: Focus strategies nutmeg competitiveness based on the QSPM analysis graph of key factors strategies.

The QSPM results prioritize strategies to improve nutmeg competitiveness in the global market in four quadrants, SO, WO, ST, and WT (Figure 4 above). For the SO strategies, trade should focus on expanding the market to other importing countries, and the ST strategies address producing good quality nutmeg as international standard demand. For WO strategies, it needs to increase farmers' knowledge to increase production and productivity and create value-added products. The WT strategies prioritize encouraging farmers to adopt SOP and GAP of Nutmeg, which finally increase domestic production and quality of nutmeg products. Overall, to increase nutmeg competitiveness in the global market, Indonesia should give attention to market expansion to importing countries, either new or existing countries, and focus on producing good quality and high productivity through increasing farmers' knowledge in adopting good agricultural practices.

Conclusion

The current trade situation of Indonesian nutmeg reveals still a robust performance, with Indonesia maintaining a strong role in the global market. Majority nutmeg was exported globally. Despite its leading position as the primary exporter of nutmeg, Indonesian nutmeg still face the significant challenges include the low of growth rate of exports (3.27%), exported unprocessed and imported derivative product, and high nutmeg imports growth (27.85%). The Trade Specialization Index categorized this commodity as a gobal static competitiveness commodity of exported product in the maturity stage that need to focus on market specialization, which can be developed through maintaining and increasing quality standard, and the innovation strategy to process nutmeg into added value product which can replace import demand dan initate sell it to global market.

From the competitiveness indicators of nutmeg trade, it can be concluded that Indonesian nutmeg has been more competitive advantage and specialized commodity than other spice commodities in the category of HS 09 coffee, tea, maté, and spices in the global market, especially still focused on the type of nutmeg HS 090811 and HS 090812. It is a big chance to increase the export rate in HS 090821 and HS 090822 both current or new market. Comparatively, Indonesia has been the highest positif value of RSCA (mean = 0.86 and CI = 0%) among ten top exporter countries. It show obviously that Indonesian as a nutmeg producer still hold comparative advantage by holding the higher market share of nutmeg export than the others. However, Grenada has been a newcomer allert in global market initiating to export nutmeg focus within decade with relative advantage (RTA value) higher than Indonesia. Fortunately, it only has market share 1.8%, much less than Indonesian market share 61.6%. Meanwhile, based on type of nutmeg, all RTA values are more significant than zero, indicating they have a competitive advantage relative to spice in the global market. Likewise, their trend, all CI tend to increase except the type of nutmeg HS 090822 mace, crushed or ground that has negative change.

Some crucial strategies (external and internal) were proposed for increasing nutmeg competitiveness in the global market. On the external side, Indonesian's trade should give attention to market expansion and export growth for running a static to dynamic global market both targeting new importing countries and existing countries. In internal factors, farmers should concentrate on producing good quality and high productivity nutmeg by increasing farmers' capacity and knowledge, adopting technologies, and practicing good agricultural practices. In addition, Indonesia's government and all domestic actors must make extra efforts to maintain and increase Nutmeg's competitiveness both from internal and external aspects.

The limitation of study was the research only focus in macro and global perseptive based on the analyzed data. This research could not able to explore detail about the comparative advantage and competitive of each country producer in term of cost of production of nutmeg, transcation cost and value chain in each country. Meanwhile, for enhancing Indonesian nutmeg competitiveness, further research about supply and value chain analysis from farm to export market in multi-layer actors could be proposed, so it could be benefit for the stakeholders taking a comprehensive decision.

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Juxtaposing Gender Differentials in Credit Assessment of Farmers in Nigeria: A Hybridized Credit-Scoring Approach

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Abstract

Using data from 360 smallholder farmers in Southeast Nigeria, the study creates the architecture for a new farmer's hybrid credit rating system used in classifying farmers who applied for microfinance loans based on their creditworthiness. We discovered new evidence that the hybridized credit scoring algorithm demonstrated unprecedented concordance in assessing the financial viability of farmers along gender lines. The discriminant analysis, in particular, closely aligned with the credit score model, with 34.4% and 46.7% of male and female farmers grouped as creditworthy, reflecting the model's estimates of 33.3% and 45.5%, indicating gaps of 12.3% and 12.2%, respectively, to the advantage of the female farmers. Our findings further suggest that annual income, marital status, and farm size strongly influence the separation between creditworthy and non-creditworthy farmers. While age, loan term, and a history of defaults had a negative impact on discrimination, in light of the findings, we recommend a collaboration between authorities, financial institutions, and extension workers in offering tailored trainings to both male and female farmers, assisting them in meeting up-to-date credit prerequisites, adopting modified farming techniques, and improving their general preparedness to be accepted for loans in this changing credit evaluation landscape so as to bridge the disparity and promote financial inclusion for farmers irrespective of gender affiliations.

Keywords

Agricultural finance, credits scoring, discriminant analysis, smallholder farmers, microfinance lending, gender.

Ukoha, I. I., Osuji, M., Uhuegbulem, I. J., Ibekwe, C., and Ibeagwa, O. (2024) "Juxtaposing Gender Differentials in Credit Assessment of Farmers in Nigeria: A Hybridized Credit-Scoring Approach", *AGRIS on-line Papers in Economics and Informatics*, Vol. 16, No. 3, pp. 139-153. ISSN 1804-1930. DOI 10.7160/aol.2024.160310.

Introduction

With nearly 206,000,000 inhabitants, Nigeria is Africa's most populous nation and the seventh-most populated nation globally (World Bank, 2021). For the Nigerian population, agribusiness offers the best opportunity for jobs, revenues, and food supplies. The cultivation of crops, raising animals, woodlands, and fisheries make up the bulk of the agricultural sector (Adewale et al., 2022). Availability of credit to agribusiness is particularly warranted when farmers have limited capital, inadequately structured rural financial systems, and access to suitable farmstead technologies whose appropriation is restricted by a lack of farm assets (Ukoha et al., 2020). According to the International Monetary Fund (2005), microfinance institutions (MFIs) exist to provide lending services to the underprivileged and extremely disadvantaged, especially in agrarian areas, as a more comprehensive evaluation of access adequacy includes evaluating the regulatory environment for MFIs.

In Nigeria, where agriculture is a significant sector, microfinance banks often extend credit to farmers and agricultural enterprises. It is critical to ascertain if lenders use prejudicial approaches to lending when evaluating the loan creditworthiness of smallholder farmers in light of the reported inequalities in access to bank-related products between farmers of both genders. A fundamental concern confronting the financial services sector is determining bad loan applicants, given that ongoing credit delivery to uncreditworthy consumers may generate grave issues in the years to come through escalating bank capital losses, reduced bank earnings, and insolvency (CBN, 2014).

According to the Economic Commission for Latin America and the Caribbean (2019), policymakers

have recognized financial autonomy for women in agriculture as a crucial development objective. Hitherto, in the conventional loan market, there has been a gender gap in financial access, regardless of the reality that women possess greater creditworthiness and less risky preferences (Morsy, El-Shal, and Woldemichael 2019). This is because of a number of factors, such as job prospects, legal restrictions, social customs, and restricted access to agricultural credit (Chen et al., 2020; Paglia et al., 2014; Eckel et al., 2015; Moro et al., 2017).

In Nigeria, there are some occasions where clients know loan employees through personal contacts or through acquaintances, which may influence their evaluation capacities. There is a chance that female borrowers who applied for credit will face more obstacles than their male counterparts when trying to secure funding (De Andrés, Gimeno, and De Cabo, 2021). Possible causes of this include prejudice rooted in preferences that paint female borrowers as less competent and effective; issues relating to data that depend on the choice of whether to grant credit based on the average qualities of the group (statistical prejudice); or the prevalence of implicit biases (embedded bias). Female farmers would undoubtedly have more difficult financing access in any of these scenarios, which would have a severe negative impact on the Nigerian agricultural sector. Any possible malfunction in the financing medium for farmers, as well as any impediment or prejudice impeding the loan assessment process, might have a detrimental impact on the agricultural development of any nation.

To successfully appraise and predict small-holder farmer creditworthiness, it is vital to respect its complexities. Creditworthiness assessments are crucial in order to reduce defaults in financial institutions as well as determine whether to award credit and the amount that should be charged for that credit (Ofonyelu et al., 2013). Inadequate evaluation of borrowers' qualities makes it difficult for the financial institution to properly safeguard itself in the event of default outcomes since it determines the risks and default probability of prospective borrowers, which is a criterion that must be followed before credit is issued.

There are numerous publications on credit scores or credit evaluation for businesses (including MFBs), with the majority of them already commercialized. Among the foremost pertinent articles on worker credit scores, one puts forward an institutional reliability assessment technique using fuzzy rough sets. This suggested rule-driven technique was implemented to forecast farmers' financial standing and utilized with real bank data from 2044 agriculturalists across China for use in farm loan decision-making (Bai et al., 2019). Several studies have examined the determinants of creditworthiness and the potential gender differences in these factors. For instance, Agarwal et al. (2010) explored the impact of income, employment status, and educational attainment on creditworthiness. They found that gender differences in these factors significantly influenced creditworthiness outcomes, with women often facing disadvantageous conditions. Wilson et al. (2007) explored the role of gender norms and expectations in loan decisions. They found that traditional gender roles and stereotypes affected loan officers' perceptions of creditworthiness, leading to potential disparities. A large historical loan sample of the same credit type is classified into two types: positive loans and poor loans. The combination of clients' qualities distinguishing "acceptable" from undesirable credits generates a rating (or likelihood) that can be used as an assessment of the likelihood of default rating for every incoming loan whenever creditors determine whether or not to provide the loans or not (Limsombunchai et al., 2005).

Several studies have found that women have more constraints in agricultural production than men, resulting in decreased accessibility to and more competitive rates for loans, supplies, and technologies (Guétat-Bernard, 2014; Asadullah and Kambhampati, 2021; Beuchelt, 2016).

Financial services for smallholder farmers in developing countries are crucially provided by banks; however, gender disparities persist in accessing credit and financial services, affecting women disproportionately (Malhotra and Schuler, 2002; Kabeer, 2005; Kabeer, 2012). Sana and Shailja (2019) investigated the gender gaps in entrepreneurial activities and capitalization of small and medium enterprises. They were of the opinion that gaps in entrepreneurial activities could be a result of differences in financial, economic, and socio-cultural variables influencing the entrepreneur’s business environment.

Notwithstanding these noteworthy research inputs, there is still a substantial study vacuum, as we couldn’t find a study that analyzed and compared the gender-related differences in credit assessments for smallholder farmers by banks. The current study aims to fill this gap by juxtaposing the gender gaps in credit assessments among Southeast Nigerian smallholder farmers who applied for microfinance bank credit using

a new hybridized credit scoring model specifically designed for smallholder farmers. In doing so, it seeks to further contribute to existing literature by classifying male and female farmers into creditworthy and non-creditworthy smallholder farmers using the CSMSF and discriminant analysis. Another important contribution of this study is that it empirically analyzed the gender gaps in credit assessments of male and female smallholder farmers.

Gender gaps in loan evaluations of Nigerian farmers by microfinance institutions hold important ramifications for the country's agricultural progress and SDG achievement. Adeosun and Owolabi (2021), Enakhe, and Tamuno (2021) affirmed that Nigeria is beleaguered by destitution, an insufficient food supply, and disparities in gender. These challenges are interconnected and can be alleviated by providing farmers with equal opportunities for agricultural financing. Gender prejudices in loan evaluations limit women's ability to use farm resources, thereby reducing crop yields and prolonging impoverishment. Nigeria's advancement in achieving the SDGs, particularly Goals 1 (no poverty) and 2 (zero hunger), is highly reliant on agricultural growth (Henry, 2022; Egberi, 2023). Hence, addressing disparities in gender assessment by financial institutions, particularly microfinance banks in Nigeria, could empower female farmers, raise revenues, and improve agricultural output, thereby connecting to Goals 5 (gender equality) and 10 (reducing inequalities) and supporting sustainable development.

This study focuses on gender differences in credit risk assessment among microfinance bank beneficiaries in Nigeria. In this regard, we juxtaposed a gender analysis in credit assessments of smallholder farmers by microfinance banks in south-east Nigeria using a hybridized farm credit scoring algorithm that incorporates the credit scoring model for smallholder farmers (CSMSF) and the discriminant analysis to shed light on the creditworthiness of male and female farmers, empirically ascertain the gender gaps in credit evaluation and assessment of male and female smallholder farmers, and also ascertain the efficacy of the hybridized credit scoring model specifically designed for smallholder farmers, thereby providing vital information for microfinance banks, agricultural policy makers, and stakeholder farmers. These results would help address gender-based credit gaps in farmer credit assessment so as to improve the level of final inclusion in the Nigerian agricultural sector.

Materials and methods

Study area

The geopolitical zone of south-east Nigeria was used as the research area. The south-east zone is made up of five states: Anambra, Abia, Enugu, Imo, and Ebonyi. With 169 microfinance banks in total, the south-east zone has the second-highest concentration of them in the nation, accounting for 19.4% of the total of these: 8 in Ebonyi, 23 in Enugu, 25 in Abia, 38 in Imo, and 75 in Anambra (Ukoha et al., 2020). This study adopted a multistage sample procedure. Firstly, Imo and Enugu States were purposefully chosen because they had a high percentage of female smallholder farmers and numerous microfinance institutions. Secondly, ten microfinance banks from each state (Imo and Enugu) were purposively selected due to their lending activities to smallholder farmers. From Enugu State: Lapo MFB, Umuchinemere MFB, Ifeanyichukwu MFB, Kenechukwu MFB, Nsukka MFB, Oha MFB, Aris MFB, Coal Camp MFB, Good Shepard MFB, and Isu-ozu MFB; from Imo State: All Workers MFB, Lapo MFB, Oche MFB, Osina MFB, Merit MFB, Ogbe-Ahiara MFB, Chikum MFB, Vantage MFB, Amaifeke MFB, and Orsu MFB. Thirdly, 18 loan applicants, consisting of nine male and nine female applicants, were randomly selected from a list of 30 loan applicants provided by each of the banks listed above, making a total of 360 respondents, comprising 180 male and 180 female applicants (180 farmers from Enugu State and 180 farmers from Imo State). There were three major reasons for our choice of the study location. First, the zealous economic activity; second, because the majority of the population are Igbos, who are largely recognized for their agricultural practices, independence, and commercial abilities, there is a substantial level of societal uniformity in the area; and lastly, there is a scarcity of empirical applications of credit scoring and credit risk assessments by microfinance banks in south-eastern Nigeria.

Methods of data analysis

Two stages of analysis were performed on the data. Firstly, a credit scoring model for smallholder farmers (CSMSF) was developed. This CSMSF is basically done by attaching weights to key variables used in accessing the eligibility of loan applicants by most banks so as to derive credit scores, which were further classified into four categories based on risk classes. The key variables

that were used in this research were selected from a pre-survey of MFBs in Southeast Nigeria from the Development Finance Office of the CBN, Imo State. This study specifically assessed the eligibility of loan applicants who applied for and are yet to receive credit.

For the purpose of this research, the classification of farmers into creditworthy and non-creditworthy applicants acted as a pre-classifier, which was used in the second stage (discriminant function analysis). The second stage was done by making use of the preclassifiers from the first stage in the discriminant analysis (DA). The discriminant analysis was used in creditworthiness analysis (Onyenuchaya and Ukoha, 2007) (Table 1).

FACTORS	SCORE	MINIMUM SCORE	MAXIMUM SCORE
ACCOUNT OFFICER			
Yes	20		20
No	10	10	
FARM OWNERSHIP			
Owns a farm	20		20
Rents a farm	10	10	
EDUCATIONAL LEVEL			
Tertiary	40		40
Secondary	30		
Primary	20		
Vocational	10		
No formal education	0	0	
PROXIMITY TO MFB			
Yes	20		20
No	10	10	
MARITAL STATUS			
Married	30		30
Single/divorced/widowed	10	10	
OFF FARM INCOME			
Yes	10		10
No	0	0	
AGE			
20-30	40		40
31-40	30		
41-50	20		
51-60	10	10	
HOUSEHOLD SIZE			
1-3	30		30
4-5	20		
> 6	10	10	
FARMING EXPERIENCE (YEARS)			
13 and above	50		50
10-12	40		
7-9	30		
4-6	20		
1-3	10		
0	0	0	
LOAN TENURE			
3 months	30		30
6 months	20		
9 months	10		
1 year	0	0	
FARM INCOME (ANNUAL) (NAIRA '000)			
Above 90	50		50
71-90	40		
51-70	30		
31-50	20		
X.30	10	10	
DEFAULT HISTORY (MONTHS)			
90 days default	0	0	
60 days default	10		
30 days default	20		
None	30		30
LOAN FROM OTHER BANKS			
Yes	0	0	
No	10		30
RELATIONSHIP (YEARS)			
Above 8	50		50
07.VIII	40		
05.VI	30		
03.IV	20		
01.II	10		
0	0	0	
FARM SIZE (HECTARES)			
4 and above	50		50
03.IV	40		
02.III	30		
01.II	20		
Less than one ha	10	10	
ACCOUNT HOLDER			
YES	10		10
NO	0	0	
OVERALL TOTAL		**80**	**510**

Source: Data from a field survey, 2022

Table 1: Credit Scoring Model for Smallholder Farmers (CSMSF).

The socio-demographic factors were used to measure the credit risk levels of loan applicants. The CSMSF factors each have a number of qualities and corresponding scores, which were developed using 16 different variables, while the credit scores ranged from 80 to 510. This was further transformed into a credit score on a scale of 1–100.

Mathematically, 25% of a scale of 80 to 510 is 107.5 + 80 = 187.5.

50% = 215+80 = 295

75% = 322.5+80 = 402.5

100% = 430+80 = 510

Therefore, if a farmer's credit scores fall between 80 and 187.5 (on a scale of 80 to 510), he automatically falls between 1 and 25 (on a scale of 1 to 100); similarly, if he/she falls between 187.6 and 295, he/she automatically falls between 26 and 50; if he/she falls between 295.1 and 402.5, he/she automatically falls between 51 and 75; and if he/she scores between 402.6 and 510, he automatically scores between 76 and 100 on a scale of 1 to 100 (Table 2).

For this framework, 51% is the qualifying score. Applicants with scores of 51% and above were categorized as creditworthy farmers, while applicants with less than 51% were not qualified for a loan and were categorized as non-creditworthy farmers.

The discriminant analytical model classified the farmers by the same set of variables used in the CSMSF, which were used as independent variables, into two mutually exclusive categories. Applicants with a total credit score above 50% were categorized as creditworthy farmers, while applicants with a score of 50% or less were categorized as not creditworthy farmers. In the discriminant analysis, the following variables are used: age, gender, educational level, farmer's locative situation, proximity to the bank, marital status, off-farm income, farming experience, credit history, monthly income, loans from other banks, relationship with the bank, farm size, loan tenure, household size, and account holder. According to Onyenucheya and Ukoha (2007), the model is expressed as follows:

$$D_i = b_o + b_1 z_{1i} + b_2 z_{2i} \ldots + b_n z_{ni} + e_i \quad (1)$$

z_i is derived from the formula, $x_{ij} - x$

Where;

z_i = the discriminant score of the ith Farmer

D_i = the total discriminant score

x_{ij} = the i^{th} distinct-value of the j^{th} regressor.

b_{ij} = the j^{th} variables discriminant coefficient

x = standard deviation of the independent variable.

e_i = error term

Let z_i, the discriminant score for each individual, be a function of the regressors. Therefore,

$$z_i = b_o + b_1 x_1 + b_2 x_2 \ldots + b_n x_n \quad (2)$$

The classification process is as outlined below;

When

$z_i = z_{crt}$ classify the applicant (i) as creditworthy,

$z_i < z_{crt}$ classify the individual (i) as non-creditworthy

Classification boundary is the locus of the point where;

$$b_o + b_1 x_1 + b_2 x_2 \ldots + b_n x_n = z_{crt} \quad (3)$$

Variables	Explanations/Unit
Dependent variable	
z_i	The discriminant score of the ith Farmer
Independent variables	
Age (x_1)	Years
Accessibility to Account Officer (x_2)	A dummy = (1) should the account officer interact with the farmer more than four times a year; (0) otherwise
Educational Level (x_3)	Number of years spent in school.
Farm ownership (x_4)	A dummy variable equals to (1) if the farmer Owns a farm and (0) otherwise
Proximity To Bank (x_5)	The distance in kilometers between farmers location and the MFBs
Marital Status (x_6)	Dummy = (1) if the farmer Married; (0) Otherwise
Annual Off-Farm Income (x_7)	Non-farming activities in Naira received by the farmer annually
Farming Experience (x_8)	Years.
default History (x_9)	Duration of the farmers' previous defaults in months.
Annual Farm Income (x_{10})	Naira
Loans From Other Banks(x_{11})	Dummy = (1) should the applicant have a credit running in another bank; (0) if he has not.
Relationship with Bank (x_{12})	Number of years a farmer has operated MFB account. Measured in years
Farm Size (x_{13})	Hectares
Loan Tenure (x_{14})	Tenure of the loan years.
Household Size (x_{15})	Number of people using the same catering setup with the applicant.
Account Holder (x_{16})	Dummy = (1) should the applicant have an account with the bank; (0) Otherwise.

CREDIT SCORE (Scale of 80 to 510)	CREDIT SCORE (Scale of 1 to 100)	QUALITY	RISK CLASS
402.6- 510	76-100	Excellent	A
295.1-402.5	51-75	Good	B
187.6-295	26-50	Average	C
80-187.5	1-25	Below Average	D

Source: Data from a field survey, 2022

Table 2: Credit risk class derived from the credit scores.

The credit scoring model and the discriminant function analysis is applied for male and female farmer loan applicants separately.

Results and discussion

Creditworthiness along gender lines as determined by the credit scoring methodology

Table 3 presents the distribution of the credit-worthiness of smallholder farmers by gender as derived from the credit scoring model.

As indicated in Table 3, most of the male loan applicants (66.7%) were not creditworthy, while only 33.3% of them were creditworthy in the study area. The same scenario was observed among the female loan applicants, where most (54.4%) of them were not creditworthy while a few (45.5%) were, indicating a gap of 12.2% in credit assessment along gender lines. For the entire group of respondents, 60.6% of applicants were not creditworthy, while 39.4% were creditworthy. The result, however, indicates that there were more creditworthy female loan applicants than males in the study area. This suggests that female loan applicants were more qualified and prepared to obtain loans than their male counterparts. This is on account of being more creditworthy. This result contrasts with existing literature. According to Zainuddin and Yasin (2020), traditional financial institutions, as well as government-funded initiatives, frequently focus on male customers. This could be due to their perceived creditworthiness. Our findings point to a notable departure from popular opinion and a considerable gender gap in creditworthiness in favour of female smallholder farmers.

Comparison of the creditworthiness of smallholder farmers by gender

Table 4 presents the z-test result of the significance difference in the creditworthiness (using credit score) of smallholder farmers along gender lines.

As shown in Table 4, we observed a significant difference in the average credit scores of the male and female loan applicants in the study area (Z = -3.704) at the 1% level of significance, while the mean credit scores of the male and female respondents in the study area were 63.857 and 71.892 respectively, suggesting that female loan applicants were more creditworthy than their male counterparts. The results above shows that the assessment of farmers credit applications was precisely and accurately evaluated. It shows statistical proof either in favour of or against the economic theory that the creditworthiness of male and female smallholder farmers differs meaningfully. The difference which is seen from the results above in from the average credit scores in this instance is not likely to be the product of chance, according to the significant Z-test result (-3.704 at the 1% level of significance).

Credit risk class as derived from the credit scores of smallholder farmers by gender

The distribution of the credit risk class derived from the credit scores of smallholder farmers by gender is presented in Table 5. The credit risk class shows the classification of the probability of default on a debt by a borrower and guides the decision-making process for granting loans.

Creditworthiness of farmers	Male		Female		Pooled	
	Freq.	%	Freq.	%	Freq.	%
Creditworthy farmers	60	33.3	82	45.5	142	39.4
None Creditworthy farmers	120	66.7	98	54.4	218	60.6
Total	180	100.0	180	100.0	360	100.0

Source: Data from a field survey, 2022

Table 3: Distribution of the creditworthiness of smallholder farmers by gender.

Sample	Mean	N	Standard Deviation	Standard Error	Df	Z-test
Creditworthy Male farmers	63.857	60	14.644	1.891		-3.704***
Creditworthy Female farmers	71.892	82	19.002	2.098		
Difference	-8.035		18.296	2.169	140	

Source: Data from a field survey, 2022

Table 4: Test of significance difference in the creditworthiness (using credit score) of smallholder farmers by gender.

Credit Score	Quality	Risk Class	Male		Female		Pooled	
			Freq.	%	Freq.	%	Freq.	%
76-100	Excellent	A	2	1.1	2	1.1	4	1.1
51-75	Good	B	58	32.2	80	44.4	138	38.3
26-50	Average	C	116	64.4	98	54.4	214	59.4
0-25	Below Average	D	4	2.2	-	-	4	1.1
Total			180	100.0	180	100.0	360	100.0

Source: Data from a field survey, 2022

Table 5: Credit risk class as derived from the credit scores.

The majority of male loan applicants as well as female loan applicants are classified as risk class C, indicating average borrower quality. Only a small percentage (1.1%) of applicants are exceptionally qualified for loans. This makes it difficult for most farmers to obtain loans, especially those rated as average or below average in creditworthiness. Overall, only a fraction of applicants (33.3% of males, 45.5% of females, and 39.4% of all farmers) are considered good-risk borrowers, making it riskier to grant loans to the majority. This has implications for debt financing in the farming sector in the study area.

Discriminant analysis of the determinants of the creditworthiness of smallholder farmers by gender

Having classified the creditworthiness of the loan applicants using the credit score model, we further employ the discriminant analysis technique to classify the loan applicants based on creditworthiness. This serves to complement the reliability of the results of the creditworthiness of the farmers done using the CSMSF approach.

Diagnostic tests

Box's test of equality of covariance matrices

The outcome of Box's test of equality of covariance matrices, used in examining the homogeneity both within and between the two sets of dependent variables, is shown in Table 6.

Parameters	Male	Female	Pooled
Box's M	207.617	259.605	334.655
F-value	1.359	1.729	2.074
Sig.	1.000	1.000	1.000

Source: Data from a field survey, 2022

Table 6: Box's test of equality of covariance matrices.

As shown in Table 6, Box's M statistic was 207.617 and the F-value of 1.359 was not statistically significant, an indication that the covariance matrix is homogenous and the individuals in the group contribute equally to the discriminant model (Field, 2009; Hair et al., 2019). For the female smallholder farmers, the Box's M statistic was 259.605 and the F-value of 1.729 was not statistically significant, an indication that the covariance matrix is also homogenous. According to the finding, the data sets utilized for the discriminant analysis did not deviate from normality, making it possible to classify the creditworthiness of farmers based on gender with confidence.

Eigen values of the canonical discriminant functions

The summary of the canonical discriminant functions indicating the eigenvalue and the canonical correlation is presented in Table 7.

Parameters	Male	Female	Pooled
Eigenvalue	1.915[a]	1.898[a]	1.244[a]
% of total variance	100.0	100.0	100.0
Cumulative %	100.0	100.0	100.0
Canonical Correlation	0.891	0.809	0.745

Note: [a] Canonical discriminant function is significant at $P < 0.05$.

Source: Data from a field survey, 2022

Table 7: Eigen values of the canonical discriminant functions.

From the Table 7 above, the eigen values shows evidence of the effectiveness of discriminant functions (Thomas, 1992; Bartkowiak and Zimroz, 2013; Benyamin et al., 2019). For the male smallholder farmers, higher engin values (1.915) suggests better information about the effectiveness of the dependent variable. The canonical correlation value (0.891) indicates a strong relationship between creditworthiness and the discriminant score for males. For females, the eigenvalue (1.898) explains a significant share of the variance, and the canonical correlation value (0.809) shows a sturdy relationship. For the pooled

group of farmers, the eigenvalue (1.244) explains a significant variance, and the canonical correlation value (0.745) indicates a strong relationship. These results suggest a reliable classification of farmers based on creditworthiness and unprejudiced interpretations.

Wilk's Lambda Ratio of unexplained total variance of discriminant scores

Table 8 shows the ratio not explicated by the entire variance of Wilk's Lambda statistics discriminant scores. Wilk's lambda quantifies how successfully each function classifies groups.

Parameters	Male	Female	Pooled
Wilks' Lambda	0.452	0.345	0.446
Chi-square	109.820	180.897	281.689
Df	16	16	17
Sig.	0.000	0.000	0.000

Source: Data from a field survey, 2022

Table 8: Wilk's Lambda ratio for the total unexplained variation in discriminant scores.

A variable's potential for discriminating between groups is measured using the Wilks' lambda. Lower values suggest higher effectiveness in discriminating among groups (Pednekar and Tung, 2017). For male smallholder farmers, Wilks' Lambda was 0.452, indicating 45.2% of variance unexplained by differences among the groups. The chi-square test was significant at the 1% threshold, suggesting better than chance discrimination. For female farmers, Wilks' Lambda was 0.345, showing greater discriminatory ability, implying that 34.5% of the overall variation in the discriminant scores is unexplained by differences among the groups. The pooled model had a Wilks' Lambda of 0.446, also indicating good discrimination. The chi-square test was significant, suggesting an effective separation of creditworthy and non-creditworthy farmers. Table 8 indicates the female model as the best, followed by pooled and male models.

The Canonical discriminant function of coefficients

Table 9 provides the canonical discriminatory function coefficients for the male, female, and pooled respondents.

Variables	Male	Female	Pooled
Age of respondent	-1.029	-1.036	-2.034
Marital status	0.145	0.283	1.233
Household size	1.011	1.049	1.036
Farming experience	1.066	2.083	0.969
Annual income	2.034	2.780	1.992
Off farm income	1.020	0.000	0.459
Membership of cooperative society	-0.462	-0.132	-0.279
Location situation	-0.018	0.423	0.283
Farm size	1.134	1.162	1.139
Educational qualification	0.973	1.310	0.966
Proximity to Bank	0.486	0.586	0.334
Access to account officer	0.923	0.859	0.489
Loan duration (Months)	-1.098	-1.114	-2.113
Banking relationship	0.407	0.787	0.617
Default duration (months)	-0.806	-1.047	-1.083
Loans in other banks	-0.101	-0.599	-0.213
Gender of respondent	-	-	-1.052
(Constant)	-1.657	-3.490	-2.483

Source: Data from a field survey, 2022

Table 9: Canonical discriminant function coefficients for the male, female and pooled loan applicants.

The canonical discriminant function coefficients help to show the variables that contributed significantly to discrimination between two groups (Sajobi et al., 2020). For the male respondents, the results presented in Table 9 showed that the important variables for the z-score value in discriminating the male respondents into creditworthy and non-creditworthy farmers were mostly annual income, with a canonical discriminant function coefficient value of (2.034). Annual income played a very vital role in the discrimination of smallholder male farmers into creditworthy and non-creditworthy groups, alongside the farm size of the farmer (1.134), off-farm income (1.020), level of education (0.973), and accessibility of farmers to their account officers (0.923). Annual income reflects how financial institutions rate financial performance; in addition, off-farm income reflects the importance of income diversification; education also underscores the importance of financial literacy and information on the part of the farmer; and accessibility to an account officer translates to guidance from financial institutions on terms and conditions.

However, annual income (2.780), farming experience (2.083), educational qualification (1.310), and farm size (1.162) were important

in discriminating female respondents between groups. This translates to the female farmers financial performance, farming experience, level of training, exposure, and financial literacy, and finally the farmers scale of operation. This shows the complex nature of the credit evaluation process, as several conditions need to be met before credit is extended to an applicant.

Average group discrimination function values

The result of the distribution of the respondents by average group discrimination function values is presented in Table 10 below.

Parameters	Male	Female	Pooled
Non-Creditworthy	-0.684	-1.282	-0.916
Creditworthy	1.323	1.465	1.351
Z-score	0.639	0.183	0.435

Source: Data from a field survey, 2022

Table 10: Average group discrimination function values.

Unstandardized canonical discriminant functions assessed using the group mean

The average group discrimination function values were used to determine whether creditworthiness existed between the farmers. Table 10 displays the mean separation function performances for each category of farmers. This is the same as finding the difference between the function values of the creditworthy farmers and those of the non-creditworthy farmers. Whenever the z-score value exceeds the z-value of each group of farmers, loans are granted to applicants based on their creditworthiness, or vice versa. From the results in Table 10 above, the z-scores of the male, female, and entire (pooled) farmers were 0.639, 0.183, and 0.435, respectively. This implies that loans are granted to applicants based on their creditworthiness. This suggests that not all the farmers received the loan they applied for due to their creditworthiness.

Discriminant analysis classification success results of farmers' creditworthiness

The discriminant analysis classification success result of the creditworthiness of farmers along gender line is obtainable in Table 11.

The Table 11 shows the practical results of using the discriminant model. In the cases utilized to develop the male farmer's model, the model estimated creditworthiness with 82.2% and 88.7% accuracy for the non-creditworthy and creditworthy farmers, respectively. The total correct classification success rate for 180 male loan applicants is recorded as 84.4%. This indicates that the model is mostly accurate. The discriminant analysis success result shows that 62 out of 180 (34.4%) male smallholder farmers who applied for loans are creditworthy based on their socioeconomic characteristics, which is similar to the result of 33.3% derived using the credit score model approach.

Similarly, for the female farmers, the model estimated creditworthiness with 90.6% (87 out of 96) and 88.1% (74 out of 84) accuracy for the non-creditworthy and creditworthy farmers, respectively. The total correct classification success rate for 180 female loan applicants is recorded as 89.4%. The discriminant analysis success result shows that 84 out of 180 (46.7%) female smallholder farmers who applied for loans are creditworthy based on their socioeconomic characteristics, which is similar to the result of 45.5% derived using the credit score model approach.

From the results in the Table 11, 34.4 percent of the male farmers were creditworthy, while

Discriminant Analysis		Male farmers Estimated Group				Female farmers Estimated Group				Pooled farmers Estimated Group			
		Non-Creditworthy	Creditworthy	Total	Accuracy %	Non-Creditworthy	Creditworthy	Total	Accuracy %	Non-Creditworthy	Creditworthy	Total	Accuracy %
Observed Group	Non-Creditworthy	97 (82.2)	21 (17.8)	118 (100.0)	82.2	87 (90.6)	9 (9.4)	96 (100.0)	90.6	184 (86.0)	30 (14.0)	214 (100.)	86.0
	Creditworthy	7 (11.3)	55 (88.7)	62 (100.0)	88.7	10 (11.9)	74 (88.1)	84 (100.0)	88.1	17 (11.6)	129 (88.4)	146 (100.0)	88.4
	Total	104	76	180	84.4	97	83	180	89.4	194	166	360	86.9

Source: Data from a field survey, 2022

Table 11: Discriminant analysis classification success results[abc].

[a] 84.4% of original grouped cases for the male farmers were correctly classified.
[b] 89.4% of original grouped cases for the female farmers were correctly classified.
[c] 86.9% of original grouped cases for the pooled farmers were correctly classified.

46.7 percent of the female farmers were creditworthy, indicating a gap of 12.3% in credit assessment along gender lines.

Summary statistics of sample description

Socioeconomic characteristics of the smallholder farmers by gender (Loan Applicants)

The socioeconomic characteristics of the smallholder farmers by gender that applied for credit in the study area are presented in the Table 12.

The result shows that the average age of male and female respondents was 36 and 34 years, respectively. When pooled together we had a mean age of 35 years. However, the female farmers were seen to be in a more youthful age bracket than their male counterparts. This indicates a very close variation in age profile along gender lines. Implying a youthful population of farmers who would be enterprising and inclined to take loans for productive purposes or for expansion of existing operations. This close age variation of farmers along gender lines underscores the need to design customized loan products and standard assessments of farmers creditworthiness for male and female farmers.

Majority of both male and female respondents (about 67% and 63 %) were married. This implies that both the male and female respondents were settled and should therefore be better positioned to undertake their economic activities profitably responsibly. Ominikari, Onumadu and Nnamerenwa (2017) posited that being married can confer some level of stability to an individual in a household and can put them in a better position to practice their occupation more profitable for the business sustenance and for solving family needs. The results show a close variation in percentage difference of the majority of farmers who are married. This could imply that the gap in marital status of farmers along gender lines may not influence a difference in credit assessment by banks as the lending institutions should maintain uniformity in credit assessments for farmers irrespective of gender differences.

The result also shows that most of the respondents (35.6% of males and 33.3% of females) had primary education. However, 85.6% and 83.9% of the male and female respondents had formal education. This result suggests that a large number of the respondents were educated and therefore

Variables	Male smallholder farmers		Female smallholder farmers		Male and female pooled together	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Age of Farmers (years)						
Average	35.8		33.9		34.6	
Farmers marital status						
Single	50	27.8	55	30.6	105	29.1
Married	120	66.7	113	62.8	233	64.8
Divorced	7	3.9	7	3.9	14	3.9
Widowed	3	1.7	5	2.7	8	2.2
Educational Level						
No formal education	26	14.4	29	16.1	55	15.3
Primary	64	35.6	60	33.3	124	34.4
Secondary	49	27.2	47	26.1	96	26.7
Tertiary	41	22.8	44	24.5	85	23.6
Farming Experience (years)						
Average	7.83		8.22	8.03		
Farm size (ha)						
Average	1.58		1.17		1.37	
Extension Agents						
Yes	106	60.6	109	58.9	215	59.7
No	74	39.4	71	41.1	145	40.3
N	180	100.0	180	100.0	360	100.0

Source: Computed by the researcher from field survey data 2022

Table 12: Socioeconomic characteristics of the smallholder farmers by gender (Loan borrowers).

understood the requirements for accessing credit from the bank. Education is a virtue that is required for a successful business operation; thus, these educated respondents have acquired relevant skills that would be useful in operating their own firms and know how to utilize loans to enhance their business performance. Nnamerenwa et al. (2017) posited that education serves as an important criterion for loan approval and thus gives an edge to any individual with educational qualification over another with no educational qualification.

In addition, the farming experience for male, female and pooled smallholder farmers in the study area were 7.88, 8.22 and 8.03 respectively. The results suggest that most of the smallholder farmers in the study area had some level experience into the business of farming to know how to allocate financial resources for farm expansion. According to Nwaru (2004) expansion in farm business is dependent on the years of farming experience. Lender would prefer to extend credit facilities and loans to experienced farmers (Nnamerenwa et al., 2017). The average farm size is 1.58 ha for males, 1.17 ha for females, and 1.37 ha for all respondents. This implies that the respondents had small farm sizes. According to UNCTAD Commodities and development report (2015) and Chiaka, et al (2022) the average farm size for smallholder farmers in Nigeria is 2.0 hectares and indicates that most respondents were actually smallholder farmers. This implies that male farmers are at an advantage over their female counterparts as farm size could translate to higher revenue generation which could help in loan repayment.

The result further shows that 61% of males, 59% of females, and 60% of all respondents visited agricultural extension agents in the study area. The small-gap percentage of male and female smallholder farmers who visited extension agents shows a fairly identical assignment and suggests similarity in extension information. It would be advisable for financial institutions. Agricultural extension programs tend to advance their level of financial literacy and keep farmers at an advantage when evaluated by microfinance banks.

Conclusions

The objective of this research is to juxtapose the gender differentials in credit assessment by microfinance banks in southeast Nigeria using a hybridized credit scoring approach. Secondly, we analyzed the factors influencing the creditworthiness of smallholder farmers along gender lines, and finally, we presented the summary of the sample description for male and female smallholder farmers in the study area. Several outcomes were attained. One outcome indicated that 34.4% and 46.7% of male and female farmers were identified as creditworthy based on our credit assessment of MFBs farmer applicants, indicating a gap of 12.3% in the assessment of farmers' financial standing using the discriminant analysis, while the CSMSF showed that 33.3% and 45.5% of male and female farmers were grouped as creditworthy based on the credit assessment of MFBs farmer applicants, indicating a gap of 12.2% and an average 12.25% gender discrepancy (using the hybridized credit scoring approach). The gap points to extensive disparity on the basis of gender in credit evaluation, indicating that female farmers are more creditworthy than males, thereby marking a significant divergence from the previous narrative, which frequently portrays male farmers as more creditworthy. Reasons for the improved creditworthiness amongst smallholder female farmers could be as a result of the efficacy of variables used in credit assessment, which provided a penchant for abilities in which women were at an advantage, such as the non-availability of loans in other banks, better banking relationships, and a good previous credit record, among others. In addition, it could be as a result of the increasing level of accessibility to agricultural extension programs, which tends to advance their level of financial literacy and commercial savvy due to societal trends, the rising level of women in leadership positions, and improved educational accessibility.

Other results revealed that annual income, marital status, and farm size strongly influenced the separation between creditworthy and non-creditworthy farmers. While age, loan term, and a history of defaults had a negative impact on discrimination, as a result, suggestions for policy include boosting income diversity and improving gender equality in financing.

In addition, the summary of the sample description showed that the average age of male and female respondents was 36 and 34 years, the majority of both male and female respondents (about 67% and 63%) were married, the mean years of farming experience was 7.83 for males and 8.22 for females, the average farm size was 1.58 hectares for males

and 1.17 hectares for females, 85.6% and 83.9% of the male and female respondents had formal education, and 61% of males and 59% of females visited agricultural extension agents in the study area.

We therefore recommend a collaboration between authorities, financial institutions, and extension workers in offering tailored training to both male and female farmers, assisting them in meeting up-to-date credit prerequisites, adopting modified farming techniques, and improving their general preparedness to be accepted for loans in this changing credit evaluation landscape so as to bridge the disparity and promote financial inclusion for farmers irrespective of gender affiliations.

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