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The Effect of Monetary and Financial Policies on Iran's Food Security

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Abstract

Using appropriate policies to overcome food insecurity is one of the pillars of economic prosperity of countries. Economic decisions that change macroeconomic parameters can directly or indirectly affect food production and prices and affect food security. Therefore, achieving a clear understanding of how macroeconomic policies affect different dimensions of food security in the country can lead to providing solutions to improve the food security index. In this study, a framework of simultaneous equations is presented in order to investigate the relationship between monetary and financial policies with food production and prices in the country. In this regard, using the method of generalized moments, behavioral equations were estimated separately using the data of 1978-2018. The model was then implemented as a system of equations using the Gauss Seidel method. Different scenarios were simulated in this model to investigate the effects of changes in interest rates, money volume, and general government investment on various aspects of food security. The results indicated that government investment in the agriculture sector and public investment expenditures have a positive impact on food production through capital stock. Additionally, changes in interest rates have minimal effects on food production but significant negative effects on food prices. Overall, monetary policy decisions result in increased food prices alongside decreased food production due to the demand for money and private investment. Therefore, the implementation of these policies should be done more carefully in order to encourage farmers to increase production and therefore ensure food security for consumers.

Keywords: Food security, Generalized Moments method, Macro policies

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Introduction

Food security is one of the most important criteria for measuring the security, welfare and economic prosperity of countries (Anderson, 2001) and therefore, it is necessary to implement appropriate policies at all household, national and global levels in order to overcome food insecurity. Among the four main dimensions of food security, namely food availability, food access, food utilization and food sustainability (FAO,1998), the two dimensions of food availability and access are the main factors to ensure food security in each country (FAO,1998). In developing countries, food availability depends on a sufficient domestic production of food. In addition, most of these countries have a high population growth rate, and therefore a sustainable growth in food production that is greater than population growth is inevitable to achieve food security in them. On the other hand, access to food can be classified into physical access and economic access. Physical access requires the existence of sufficient market infrastructure, but economic access depends on the purchasing power of the household and therefore the income and price level of food. Considering the low growth of household income in developing countries, it can be concluded that economic access to food items is highly dependent on effective policies regarding food inflation control. The presence of high inflation in food prices can significantly hinder economic access to food. By considering the domestic production of food as the dimension of supply and access to food as the dimension of demand for food, it can be seen that both of these factors are significantly related to the price of food and in other words the gap between supply and demand in the competitive markets of food items (Anderson, 2001).

In Iran, in all medium-term development plans, ensuring food security is regarded as a primary responsibility of governments. Given its susceptibility to macroeconomic policies, governments have consistently sought to mitigate the rise in food prices through the implementation of various monetary and financial policies (Ghahramanzadeh *et al*., 2016). However, the issue that should be noted is that food security is a multidimensional issue and the various factors that affect it are varying at different international, national and household levels. At the national level factors such as economic growth (Bagherzadeh *et al*., 2016; Mehrabi Basharabadi & Mousavi Mohammadi, 2010; Ismaili, 2013), urbanization (Salem, 2016; Bagherzadeh *et al*., 2016), food prices (Pishbahar & Javdan, 2015; Bagherzadeh *et al*., 2016; Salem, 2016; Mohammadi, 2014), economic policies (Mehrabi Basharabadi & Ohadi, 2014; Ismaili, 2013), population (Ismaili, 2013) and at the household level factors such as household income (Bagheri *et al*., 2016; Tanhayi, 2015; Pakravan *et al*., 2015; Hosseini, *et al*, 2017, Sepahvand, 2014; Asgharian Dastnaei *et al*., 2013), the number of household members (Pakravan *et al*., 2015; Hosseini, *et al*, 2017), the literacy level of the head of the household (Pakravan *et al*., 2015; Hosseini, *et al*, 2017), food price index (Ghorbanian & Bakhshodeh, 2016, Mehrabi Basharabadi & Mousavi Mohammadi, 2010; Hakimi, 2015) and government policies (Hosseini, *et al*, 2017; Heidari *et al*., 2007; Sepahvand, 2014; Mehrabi Basharabadi & Mousavi Mohammadi, 2010; Hakimi, 2015) have been identified as effective factors in food security. Of course, other non-economic factors such as physical crises (climate change, drought, etc.) and phenomena such as war and embargo and global policies also affect food security.

In all the past studies, the role of the government's economic policies has been considered as a key and effective variable. This issue also has been emphasized in other abroad studies (Ramakrishna & Demeke, 2002; Bashir *et al*., 2013; Faradi & Wadood, 2010; Cock, 2013; Applanaidu, 2014; Gustafson, 2013; Dithmer & Abdulai, 2017). Different dimensions of the concept of food security are directly or indirectly affected by macro policies. What is important is the reliability of the impact of these policies on food security in order to understand the broad dimensions of

monetary and financial shocks.

The results of the study by Gahramanzadeh *et al*. (2016) showed that in the short term, the shock of food inflation has a positive and significant effect on food inflation. In the long term, the money volume shock has a positive and significant effect on food inflation and leads to an increase in food inflation by 0.0723. Azamzadeh Shurki & Khalilian (2010) showed that there is a long-term relationship between monetary policy variables and food price index, and food price index has a positive relationship with interest rate, liquidity and exchange rate. Therefore, the government should use monetary policies in order to control the price of food and ensure food security. Pish Bahar & Javadan (2015) also investigated the effect of monetary shocks on food prices in Iran and showed that in the long run, positive monetary shocks have a significant effect on food prices.

The increase in food prices in the country in recent years has raised major concerns regarding food policy because the price increase will have adverse effects on food security and household poverty. Therefore, on the one hand, the growth of domestic food production should be accelerated, and on the other hand, the economic access to food should be improved by controlling the growth of food prices. Considering the importance of food security at the national level, macroeconomic decisions that change macroeconomic parameters can directly or indirectly affect the rate of food production and inflation. Therefore, a clear understanding of how macroeconomic policies, including monetary and financial policies, affect different aspects of food security in the country can lead to providing solutions to improve the food security index. In this study, an attempt is made to simulate the effects of various shocks caused by the application of various economic policies on food security by providing a macro-framework for food policies at the national level.

Methodology

We investigated the impact of monetary and financial shocks on the availability and accessibility dimensions of food security. For both dimensions, affecting factors are estimated based on monetary, financial and other exogenous variables. All equations (1-11) of the model have been individually estimated using the generalized method of moments (GMM), which is considered superior to other methods in addressing econometric issues such as heteroskedasticity and non-linearity. Hausman's J statistic (1982) was used to test the validity of the over determined constraints in each equation. The LM serial correlation test, White's test for heterogeneity variance and F test for overall significance have been calculated. F test statistics along with standard error and adjusted R2 have been used as a test to check the goodness of fit of each of the estimated equations. After estimating the equations individually, all the equations, including the unions, are put together and the model is solved as a system of equations. All estimates were made in STATA 12 software. Following are details about model structure, variables and data.

Model Structure

In this model, food availability is assumed to obtain through domestic production, stocks and imports. So, food supply (Y_t^{FP}) is considered as a function of domestic production. On the other hand, the price of food is the most important factor in determining access to food in developing countries such as Iran. Therefore, the second equation considered in this study is food price (P_t^{FD}). These two equations are related to macroeconomic policy instruments through a system of simultaneous equations framework. It is assumed that there are two sectors in the economy: the agricultural sector and the non-agricultural sector in which non-food products are considered as exogenous. The production of the agricultural sector is also divided into two parts: food (Y_t^{FP}) and non-food (Y_t^{NF}):

(1) $$Y_t^{FP} = Y_t^{FP} + Y_t^{NF}$$

Food sector production depends on factors such as capital (K_t), labor (L_t) and other inputs such as chemical fertilizer consumption (F_t), and energy (E_t). The effects of credits granted to the agricultural sector (DC_t^A) and the total

population (N_t) have also been examined in the model. Therefore, the food production function is defined as:

(2) $$Y_t^{FP} = Y^{FP}(K_t, L_t, E_t, F_t, DC_t, N_t)$$

Food prices (P^{FD}) are determined by demand and supply side variables. Demand-side factors that determine the quantity demanded of food items are food prices, money supply (M2), and per capita income (Y^P), and supply-side factors that affect the quantity supplied of food items are food prices, the amount of production (Y^{FP}) and inflation (π):

(3) $$Q_F^D = f(P^{FD}, M2, Y^P)$$
$$Q_F^S = f(P^{FD}, \pi, Y_t^{FP})$$

By equating the quantity demanded with the quantity supplied, the price of food is determined, so the equation of food price can be written as follows:

(4) $$Q_F^D = Q_F^S$$
$$P_t^{FD} = P^{FD}(M2, Y_t^{PC}, Y_t^{FP}, \pi_t)$$

Credits granted to the agriculture sector and the population are exogenously included in the model. The demand functions for labor, energy, and chemical fertilizers are included in the form of conditional demand functions obtained from minimizing the variable cost per level of the product in the following form (Applanaidu *et al*., 2014):

(5) $$E_t = E\,(K_t, P_t^{EN}, P_t^{Fr}, W_t, FP_t)$$
$$F_t = F\,(K_t, P_t^{EN}, P_t^{Fr}, W_t, FP_t)$$
$$L_t = L\,(K_t, P_t^{EN}, P_t^{Fr}, W_t, FP_t)$$

In the above functions, energy and fertilizer prices are considered exogenous, and the wage rate (W_t) for the agricultural sector is a function of the general level of prices (P_t), the agriculture sector value added (Y_t^A) and the unemployment rate (UR_t):

(6) $$W_t = W^A(P_t, Y_t^A, UR_t)$$

The capital stock in the agriculture sector is determined based on private and public investment:

(7) $$K_t^A = \left(\frac{I_t^{PA} - I_t^{GA}}{\delta + g^A}\right)$$

Where δ is the annual depreciation rate of fixed capital in the agriculture sector, $g^A$is the annual growth rate of production in the agriculture sector, I_t^{GA} is public investment and $I_t^{GA}$is private investment.

The role of financial policies in the model is applied through fixed investment in the agriculture sector. The government makes investment decisions with the aim of reach to a target growth rate in agriculture. Investment in the agricultural sector (such as investment in irrigation canals, dams and roads) directly affects production in the agriculture sector:

(8) $$I_t^{GA} = I^{GA}(R_t, Y_t^A, I_t^{GG})$$
$$I_t^{GG} = I^{GG}(R_t)$$

Determinants of private investment (I_t^{PA}) in the agriculture sector are public investment in the sector (I_t^{GA}), interest rate (R_t), credits (DC_t^A) and agricultural sector value added. So we have:

(9) $$I_t^{PA} = I^{PA}(R_t, Y_t^A, I_t^{GG}, I_t^{GA}, DC_t^A)$$

Total inflation in the economy significantly affects food price growth. (Y_t^{FC}), nominal money supply (M2), exchange rate (ER_t) and energy price (P_t^{EN}) are considered as determinants of the general level of prices in the economy. So, the function of the general price level (P_t) includes supply side and demand side variables and is determined as follows:

(10) $$P_t = P(M2, Y_t^{FC}, P_t^{EN}, ER_t)$$

Given the exogeneity of the exchange rate, it's imperative to account for the behavior of money supply, given its significance in response to monetary policies. In this model, money supply is equated to the demand for money in the economy. Consequently, the quantity of money is set equal to the demand for liquidity, which, in turn, relies on factors such as the nominal interest rate, total demand, and the overall price level in the economy. Interest rate, total demand and per capita income are also exogenously included in the model:

(11) $$M2_t = m2(r_t, P_t, Y_t,)$$

Data used in the estimation of the model (equations 1 to 11) are from 1978 to 2018. We used the deflated time series data for energy demand, money supply, wage rate and exchange rate, gathered from the Central Bank of Iran and adjusted to the base year of 2013.

Results

Table 1 shows the diagnostic test statistics related to the estimation of 11 equations and 66 model coefficients. The results of Durbin-

Watson's test and White's test indicate the homogeneity variance and lack of autocorrelation in all the estimated equations. The probability values related to the J statistic are estimated to be greater than 0.1. This shows that the null hypothesis of normality conditions for accepted equations and therefore overspecification of all behavioral equations is confirmed. The values of R2 in most of the estimated equations are high. In addition, 50 coefficients out of 66 model coefficients, which include more than 75% of the estimated coefficients, are significant and all parameter estimates can be justified. Therefore, the validity of the estimated equations is established.

Table 2 shows the models estimation along with the explanatory variables related to each model, the effects of drought (D1) and war (D2) have also been included in the estimations. The results show that the effect of all the variables of the food production function is significant, except for the population and energy coefficients. Among the production inputs, labor force has a negative effect on food production. This shows that the agricultural sector is over-employed and any increase in the employment of labor will lead to a decrease in food production. The increase in population will lead to a decrease in food production because agricultural land will be converted into residential areas. The significant effect of agricultural sector credits on food production also shows the role of efficient distribution of agricultural projects in the development of the production of this sector.

Table 1- Results of diagnostic test statistics for behavioural equations

Dep. Var.	DW	R2 Stat.	F stat.	J Stat (p-value)	White Test (p-value)
Y_t^{FP}	2.11	0.94	402.6	0.95	0.860
F_t	1.98	0.76	253.8	0.52	0.550
L_t	1.89	0.8	420.9	0.79	0.830
W_t	2.00	0.83	344.6	0.85	0.901
I_t^{GA}	1.95	0.95	549.4	0.96	0.760
I_t^{GG}	1.84	0.96	623.5	0.86	0.910
I_t^{PA}	1.78	0.89	193.8	0.74	0.784
P_t	1.89	0.77	226.8	0.54	0.593
$M2_t$	2.09	0.89	498.7	0.66	0.695
P_t^{FD}	1.93	0.75	347.6	0.74	0.784
E_t	2.03	0.89	335.4	0.62	0.664

In the estimation of the food price function, the variables of food production, money supply and inflation rate were found to be significant and per capita income variable was insignificant. Money supply and inflation rate are directly related while food production has an inverse relationship with food balance. This shows that the food supply-demand gap is a key determinant of food prices in the country. Therefore, food production plays a key role in food security.

Fertilizer prices and agricultural wage rates do not affect energy demand, while energy prices negatively and significantly affect energy demand in the agricultural sector. Capital stock and food production have positive and significant effects on energy demand in the agricultural sector, which indicates that an increase in food production leads to the use of more energy by farmers and that an increase in the capital stock of the agricultural sector, such as machinery, increases the demand for energy. The wage rate plays a meaningless role in determining the demand for labor in the agricultural sector, because the supply of labor is greater than the demand for labor in this sector, and in fact there is a surplus of labor in this sector. Fertilizer price significantly and negatively affects labor demand, because an increase in the price of fertilizer has led to a decrease in the demand for chemical fertilizer consumption, which in turn reduces food

production. A reduction in food production results in a decrease in the wage rate. Furthermore, the price of energy significantly influences labor demand, with its positive sign indicating that energy serves as a substitute for labor in the agricultural sector. The positive and significant impact of food production on labor demand suggests that labor utilization as an input depends on production efficiency. Conversely, capital stock exerts a negative effect on labor demand, implying that the capital employed in the agricultural sector reduces the demand for labor. The price of energy and the wage rate directly affect the demand of chemical fertilizer in the agricultural sector. Food production and capital stock have no significant effect on fertilizer demand. Finally, the value added of agriculture and the unemployment rate are the determinants of the agricultural wage rate, while inflation has no significant effect.

Table 2- The results of estimating models

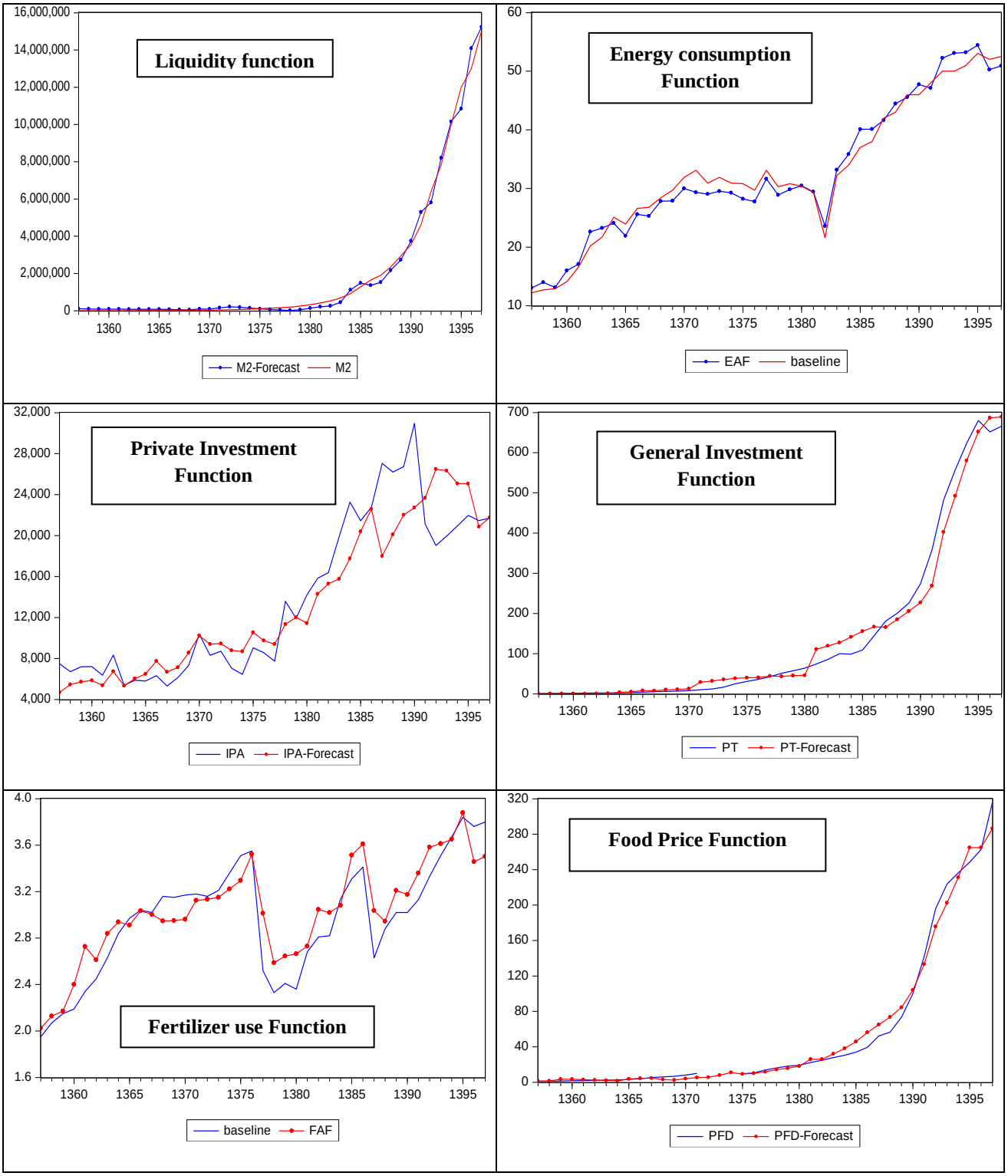
	P_t	$M2$	I_t^{PA}	I_t^{GA}	W_t	L_t	F_t	E_t	P_t^{FD}	FP_t
K_t	-	-	-	-	-	0.106	-0.5	0.21**	-	0.116**
L_t	-	-	-	-	-	-	-	-	-	-0.003**
E_t	-	-	-	-	-	-	-	-	-	0.001
F_t	-	-	-	-	-	-	-	-	-	0.08**
DC_t	-	-	0.42**	-	-	-	-	-	-	0.042**
N_t	-	-	-	-	-	-	-	-	-	-0.006
$M2$	0.502**	-	-	-	-	-	-	-	0.18**	-
Y_t^{PC}	-	-	-	-	-	-	-	-	-0.004	-
FP_t	-	-	-	-	-	0.22**	1.43	0.93**	-0.27**	-
π_t	-	-	-	-	-	-	-	-	0.68**	-
P_t^{EN}	0.47	-	-	-	-	0.63**	0.84*	-0.208*	-	-
P_t^{Fr}	-	-	-	-	-	-0.16**	-1.02**	-0.015	-	-
W_t	-	-	-	-	-	-0.11	0.05*	0.08	-	-
P_t	-	0.51**	-	-	1.82	-	-	-	-	-
Y_t^A	-	0.02	-0.33	0.22	0.052**	-	-	-	-	-
UR_t	-	-	-	-	0.26**	-	-	-	-	-
R_t	-	-0.62**	-0.05*	-0.47	-	-	-	-	-	-
I_t^{GG}	-	-	0.86**	0.53**	-	-	-	-	-	-
I_t^{GA}	-	-	0.19**	-	-	-	-	-	-	-
Y_t^{FC}	-0.28**	-	-	-	-	-	-	-	-	-
ER_t	0.03*	-	-	-	-	-	-	-	-	-
D1	-	-	-0.22	-	-	-	-	-0.52**	0.04	-0.105
D2	-	-	-	-	-0.04**	-	-	-	-	-0.11**
$Lag\ Dep_t$	-	2.43**	-	1.41**	0.172**	0.25**	-	-0.14**	0.71**	0.421**
Const	15.1*	-5.2**	9.24**	-0.4**	7.4*	-22.5*	-0.32**	11.8*	6.62**	12.5**

The effect of public investment of the government was recognized as direct and significant. This indicates that decisions regarding direct public investment in the agricultural sector should not be based on agricultural performance or production and available resources. However, public investment expenditures of the government are determined by public income and therefore, public income directly affects the decisions related to government investment in infrastructure development in this sector. Interest rates and agricultural production affect private investment in the agricultural sector. So, monetary policy decisions have a significant effect on private investment in the agricultural sector. Money demand is directly affected by the total demand and the general price level in the economy, while the interest rate negatively affects the money demand in the country's economy. And finally, money demand, exchange rate and energy prices have direct

effects, while total production has a negative effect on the general price level in the economy. After estimating the behavioral equations, all equations including unions were put together and the model was solved as a system of simultaneous equations using Gauss-Seidel iterative method to provide predicted values for years 1978 to 2018. The estimated Mean Absolute Percentage Error (MAPE) is given in Table 3. These statistics show that the values predicted by the model and the actual values are close to each other, because the values of this statistic are in an acceptable range. Also, the graphical predictions of the real and predicted values of the endogenous variables in Fig. 1 show that the real time values are well followed and therefore the validity of the model is established.

Table 3- The results of the prediction accuracy of models

Dep. Var.	Mean Absolute Percentage Error (MAPE)
E_t	0.042
F_t	0.034
L_t	0.052
W_t	0.056
I_t^{GA}	0.064
I_t^{GG}	0.057
I_t^{PA}	0.149
P_t	0.037
$M2_t$	0.044
P_t^{FD}	0.049
Y_t^{FP}	0.063


Liquidity function
M2-Forecast
M2
Energy consumption Function
EAF
baseline
Private Investment Function
IPA
IPA-Forecast
General Investment Function
PT
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Fertilizer use Function
baseline
FAF
Food Price Function
PFD
PFD-Forecast

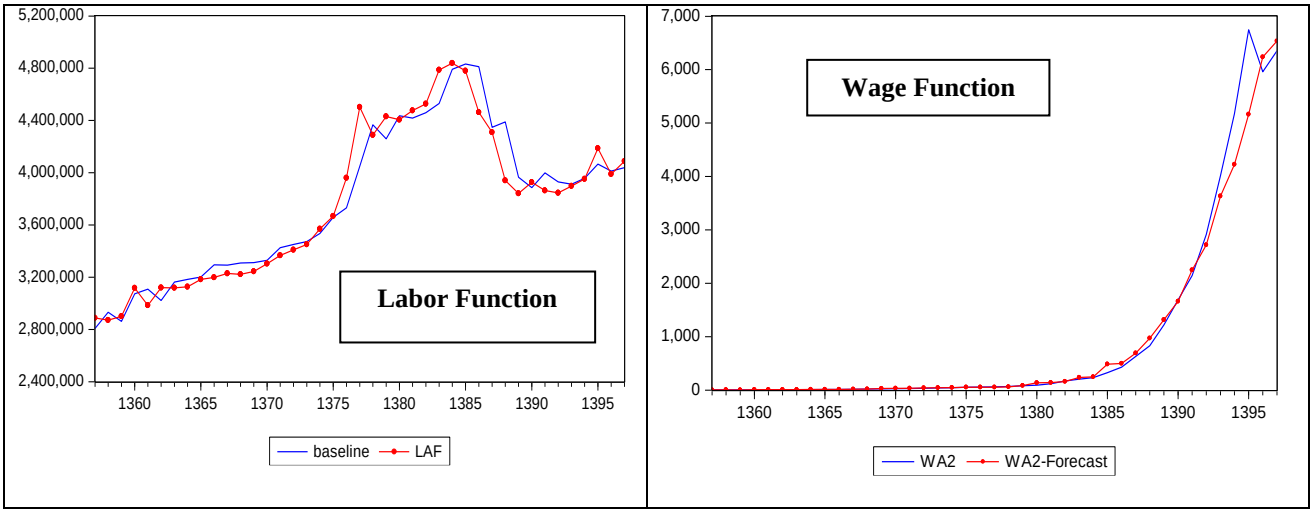

Figure 1- Comparison of in-sample prediction (dotted line) and real data (solid line)

Simulation

After establishing the validity of the estimated model, it can be utilized for simulation analysis to assess the impact of macro policy variables on food production and prices. This enables policymakers to gauge the potential effects of different policy interventions and make informed decisions regarding macroeconomic policies related to food security. What follows in this section is to examine the effect of changes in interest rates, liquidity volume and government investment expenditures during the period of 2019 to 2023. To this end, the above variables have been determined exogenously for a 5-year forecast horizon, and then the model has been run dynamically from 2019 to 2023. Changing the interest rate and the growth of the monetary base are among the conventional tools of monetary policy in countries. In this study, according to the trend of recent years in interest rate changes (weighted average interest rate of banking facilities to different sectors in terms of percentage), an interest rate increase scenario with an annual rate of 2% and an interest rate increase scenario in 2021 as an interest rate shock are considered. The continuation of the annual growth of 5% in liquidity has also been considered as another monetary policy.

Table 4- Changes in food production and price growth in different scenarios (%)

	FD_t	P_t^{FD}
Mean growth rate in base scenario	5.25	3.58
2% yearly increase in interest rate	-0.8	1.26
Interest rate shock in 2021	-0.105	0.59
5% increase in liquidity	-1.29	1.05
10% increase in public investment expenditure	1.53	-0.152

Table 4 shows the average growth rate of food production and price as two components of food availability and access to food in the discussion of food security and its percentage changes during the above scenarios. As can be seen, an increase in the interest rate reduces food production by 0.8% by reducing private investment in the agricultural sector. This decrease in investment and therefore food production will lead to an increase in the price of food, as mentioned in the studies of Pishbahar & Javidan (2015), Azamzadeh & Khalilian (2010) and Ghahramanzadeh *et al*. (2016). However, based on the second scenario, it can be concluded that an interest rate shock have a long and significant effect on the price and its increase will lead to an increase in the price of food due to the direct relationship with inflation. These results show that the monetary policies that are applied with the aim of

controlling food inflation have a small reducing effect on food production. These results can be related to the difference in the interest rate of facilities granted in the agricultural sector compared to other economic sectors, which causes the major effect of interest rate changes on food prices and inflation in the entire economy. A change in the volume of liquidity, which can be the result of any other economic policy in the economy, will lead to an increase in the price of food. It is predicted that the continued growth of liquidity in the studied period will lead to a 1.05% increase in food prices. This result is in agreement with the theory of the money supply and shows that the increase in the money supply has caused the increase in the price of food. However, by the application of appropriate policies, not only the growth rate of liquidity does not exceed its acceptable value, but also production decisions in the agricultural sector will not affect by external shocks.

Fiscal policies include increasing government revenue and public spending. Since the agricultural sector is exempt from taxes, tax policies will not have a significant effect on food production. Public expenditure includes current and capital expenditure, which investment expenditure plays an important role in the economy in terms of the role it will play in the formation of capital stock. In this section, a scenario of 10 per cent increase in public investment of the government is examined. In the implementation of this scenario, other investment variables are considered to be without change. The results of Table 4 show that the growth of public investment has a positive effect on food production and a negative effect on food inflation, so that a 10% increase in public investment by the government will lead to a 1.53% increase in food production and a 0.15% decrease in price. The positive effect is expected because the public investment of the government that used for the development of infrastructure that will lead to an increase in production in the agricultural sector. Therefore, this policy can be used to improve the availability of food in the country. These results are consistent with the findings of Mehrabi Beshrabadi & Mousavi (2010).

Conclusion

The recent rise in food inflation in the country has raised significant concerns regarding food security and household poverty. This trend underscores the urgency for effective measures to address the affordability and accessibility of food for all segments of the population. How macro decisions can help to improve the two main components of food security, i.e. food availability and access to food in the country, is an issue that has been addressed in the present study. In this regard, a framework of simultaneous equations has been presented to relate monetary and financial policies with food production and prices in the country. Using the GMM method, the behavioural equations were estimated separately using the data of 1978-2018 and then the model was implemented as a system of equations using the Gauss Seidel method. Then different scenarios were simulated to investigate the effect of changes in interest rates, money volume, and general government investment on food security dimensions. The simulation results showed that changes in interest rates have little effect on food production, but will have significant negative effects on food prices, and in general, monetary policy decisions can lead to an increase in food prices along with a decrease in food production. Therefore, the implementation of these policies should be done more carefully in order to obtain the maximum benefit in encouraging farmers to increase production and therefore ensure food security for consumers. This issue suggests that policies should be used to stabilize food prices and control the adverse effects of food price shocks on poor households. In addition, the government should also increase its expenditures for the development of public investment in order to develop agricultural infrastructure. This will lead to an increase in food production and a decrease in its price due to the reduction of the gap between supply and demand.

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مقاله پژوهشی

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اثر سیاست‌های پولی و مالی بر امنیت غذایی ایران

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چکیده

اجرای سیاست‌گذاری‌های مناسب به‌منظور غلبه بر عدم امنیت غذایی یکی از ارکان شکوفایی اقتصادی کشورها می‌باشد. تصمیمات اقتصادی که پارامترهای کلان اقتصاد را تغییر می‌دهد، می‌تواند به‌طور مستقیم یا غیرمستقیم بر تولید و قیمت مواد غذایی اثرگذار بوده و امنیت غذایی را تحت تأثیر قرار دهد. از این‌رو، دستیابی به درکی روشن از چگونگی تأثیر سیاست‌های کلان اقتصادی بر ابعاد مختلف امنیت غذایی در کشور می‌تواند به ارائه راهکارهایی برای بهبود شاخص امنیت غذایی بیانجامد. در این مطالعه یک چارچوب معادلات همزمان به‌منظور بررسی ارتباط سیاست‌های پولی و مالی با تولید و قیمت مواد غذایی در کشور ارائه شده است. در این خصوص با استفاده از روش گشتاورهای تعمیم یافته، معادلات رفتاری مربوطه به‌طور مجزا با بکارگیری اطلاعات سال‌های ۱۳۵۷-۱۳۹۷ برآورد شده و سپس مدل بصورت یک سیستم معادلات با بکارگیری روش گاوس سایدل اجرا شده است. در ادامه، شبیه‌سازی سناریوهای مختلف برای بررسی اثر تغییرات در نرخ بهره، حجم پول و سرمایه‌گذاری عمومی دولت بر ابعاد مختلف امنیت غذایی صورت گرفت. نتایج نشان داد، سرمایه‌گذاری دولتی در بخش کشاورزی و مخارج سرمایه‌گذاری عمومی دولت، بوسطه موجودی سرمایه، اثر مثبتی بر تولید غذا اعمال می‌کنند. همچنین تغییرات در نرخ بهره اثر کمی بر تولید غذا دارد اما اثرات منفی قابل ملاحظه‌ای بر قیمت مواد غذایی خواهد داشت و در مجموع، تصمیمات سیاست پولی منجر به افزایش در قیمت‌های غذایی همراه با کاهش در تولید غذا بواسطه تقاضا برای پول و سرمایه‌گذاری خصوصی می‌شود. لذا اجرای این سیاست‌ها باید با دقت بیشتری صورت گیرد تا حداکثر منفعت را برای تشویق کشاورزان به افزایش تولید و لذا تأمین امنیت غذایی برای مصرف‌کنندگان به دنبال داشته باشد.

واژه‌های کلیدی: ابعاد امنیت غذایی، روش گشتاورهای تعمیم یافته، سیاست‌های کلان

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Investigating the Factors Affecting Natural Disinvestment: A Panel Data Regression Approach

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Abstract

This study examined the correlation between economic growth and the impact on the environment, specifically focusing on the concept of environmental sustainability. The World Bank's Adjusted Net Savings (ANS) data is utilized in this study to gauge the strain on the environment, specifically through the measurement of natural disinvestment. This measurement encompasses the cumulative effects of carbon dioxide (CO_2) damage, as well as depletions in minerals, energy, and forest resources. This study uses panel data with respect to the endogeneity of explanatory variables to estimate the real effect of per capita income and the other variables on environmental pressure. In this regard, employing the panel Fixed-Effects Instrumental Variable (IV) methodology, the data from 213 countries have been used in the period from 1990 to 2018. Through regression analysis, it has been discovered that there is a direct correlation between income and the impact on the environment in developing nations. However, this relationship is notably more pronounced in low-income countries compared to high-income countries. Additionally, the study reveals that trade expansion contributes to an increase in environmental pressure across all groups of countries. An increase in the school enrolment rate can affect the environment in developed and high-income developing countries. Moreover, the variable effect of capital openness on environmental pressure was estimated to be positive for developed and high-income countries. However, this effect was found to be negative for low-income countries. Finally, the result showed that developing countries should improve their legal structure and also reduce the bureaucracy and complexity of the laws.

Keywords: Developing country, Economic growth, Environmental sustainability, Instrumental variables, Panel data

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Introduction

The traditional perspective prioritizing economic growth for human welfare has been challenged, particularly after the global economic crisis in 2008 (Aşıcı, 2012). According to neoclassical economic theory, economic growth is tied to the accumulation of physical capital. However, this narrow focus on capital accumulation overlooks other aspects of well-being, such as natural resources, human capital, quality of the environment, and leisure time. Merely increasing GDP per capita does not guarantee improved welfare (Siche *et al.*, 2008; Singh *et al.*, 2012; Slesnick, 2020). Some proponents of "degrowth" argue that human progress is possible without relying on continuous economic growth (Schneider *et al.*, 2010), but this perspective has faced criticism from other scientists (Jackson, 2009). On the other hand, advocates of the green economy believe that investments in sustainable sectors like energy and construction can create green jobs and transition away from carbon-based economies (Barbier, 2010).

In low-income and middle-income countries, natural resources often constitute a significant portion of their exports (Costantini & Mooni, 2007). Human demand has led to environmental degradation, especially since the mid-1970s, and the gap is widening (Ewing *et al.*, 2010). Statistics indicate that human activities account for over 95% of greenhouse gas emissions, intensifying climate change and drawing global attention to environmental degradation (Herwartz & Walle, 2014; EIA, 2018). The dissatisfaction with conventional development approaches during the global economic crisis has sparked interest in rational planning to achieve environmentally sustainable economic growth in low and middle-income countries (Schneider *et al.*, 2010). The ultimate goal is to achieve the highest standard of living in high-income countries while minimizing environmental pressure.

Numerous studies have explored the relationship between the environment and economic development, often using the Environmental Kuznets Curve (EKC) framework (Ehrhardt-Martinez *et al.*, 2002; Mazzanti & Zoboli, 2009; Boulatoff & Jenkins, 2010; Al-Mulali *et al.*, 2015; Özokcu & Özdemir, 2017; Yang *et al.*, 2017; Venevsky *et al.*, 2020). The EKC suggests an inverted U-shaped curve, indicating that economic growth and environmental quality initially have a negative relationship until a certain level of development is reached. Beyond that point, society strives for economic growth while improving environmental quality (Pao & Tsai, 2011; Ganda, 2019b). While some studies support the EKC hypothesis, there are critics who question the positive impact of economic growth on environmental quality.

Several steps have been considered for measuring the environmental impacts of economic activities through the development of environmental indicators and criteria in the context of conventional accounting. Indicators relating to income and the environment can be enumerated as Environmental Sustainability Index (ESI) (World Economic Forum, 2001) Environmental Performance Index (EPI) (Bohringer & Jochem, 2007; Balezentis *et al.*, 2016), Environmental Vulnerability Index (EVI) (Singh *et al.*, 2012; Sanchez *et al.*, 2018), Index of Sustainable Economic Welfare (ISEW), Centre for Environmental Strategy (CES), green net national product (United Nations Environment Programme (UNEP), 2000), Ecological Footprint (EF) (Weinzettel *et al.*, 2014; Aşıcı & Acar, 2015; Ahmad *et al.*, 2020; Destek & Sinha, 2020; Nathaniel & Khan, 2020), and Adjusted Net Savings (ANS) (Pardi *et al.*, 2015; Poltarykhin *et al.*, 2018; Larissa *et al.*, 2020; Roeland & de Soysa, 2021).

The relationship between income and environmental sustainability, EF and ANS, also called Genuine Savings, indices other than the listed indicators to measure quality of life is more appropriate to assess the potential damage caused by environmental problems (Singh *et*

al., 2012). The use of resources consumed, regardless of country of origin where the extraction is criticism of the EF. Since some consumers can displace the environmental consequences associated with their use of the trade, the EF index is inappropriate for this study. In contrast, using the ANS, the effect of income growth on the sustainability of the domestic environment can be seen (Aşıcı, 2012) Because this component represents a lack of the natural disinvestment component of ANS is characterized by combining three forms of capital physical, human, and natural.

The idea of ANS was formally introduced by the World Bank in 1992. ANS is defined as national net savings plus training costs, minus energy reduction, mineral reduction, net forest reduction, and damage from carbon dioxide pollution and particulate emissions (World Bank, 2020). The advantages of ANS compared to the conventional savings rate in terms of showing the real well-being of society have been proven in several studies (Gnègnè, 2009). The ANS is a reliable accounting method that can measure the depletion of natural resources and the impact of environmental damage on the economy with negligible error (Merko *et al.*, 2019; Larissa *et al.*, 2020; Fakher *et al.*, 2023). When ANS is negative, it may indicate that wealth is declining. Moreover, when the ANS is positive, it may indicate that wealth is growing (World Bank, 2020). ANS is a comprehensive indicator for measuring sustainable development from the perspective of savings as investment and accumulation of wealth. This economic dimension of sustainability shows that for a sustainable development path, an economy must maintain a positive ANS rate (Pardi *et al.*, 2015).

The study utilizes the ANS index as an indicator, encompassing data from 1990 to 2018 and covering 213 countries classified into developed countries, high-income developing countries, higher middle-income developing countries, lower middle-income developing countries, and low-income developing countries. To examine these relationships, a panel dataset is employed, and fixed-effects instrumental variable regression is utilized. By adopting an environmental sustainability perspective, this study aims to investigate the correlation between economic growth and the strain on the environment. The pressure on nature is evaluated using the natural disinvestment component of the ANS data from the World Bank, which incorporates measures such as energy, mineral, net forest depletion, and carbon dioxide damage. It is worth noting that this study specifically focuses on the domestic consequences of environmental issues and highlights the significance of utilizing the natural disinvestment components of the ANS index. Consequently, the advantage of this study over previous research lies in its comprehensive utilization of the ANS index and its consideration of the endogenous aspects of the economic growth variable across different countries.

Literature review

In recent decades, as environmental instability has increased, the assessment of the drivers of environmental indicators has expanded. In studies of the impact of trade on environmental pressures, researchers have used different proxies for trade in their models. Most researchers have used the degree of trade openness (the ratio of imports plus exports to GDP). Some authors use only exports as a proxy for trade. Some studies have also used the merchandise trade (GDP %) index (Khan *et al.*, 2021). For instance, Al-Mulali *et al.* (2015) within the framework of the EKC concept analyzed the effects of economic growth, energy consumption, political stability, the share of trade in GDP, and the rate of rural-urban migration on the ecological footprint as an indicator of environmental quality. In this study, the countries of the Middle East and North Africa were considered and the data of the studied variables during the period 1996 to 2012 were investigated. The results of this study showed that trade openness and political stability affect the ecological footprint.

In the existing literature, the rule of law index is also one of the variables that is always considered to be related to the quality of the environment. It is expected that by improving

the ability of countries to enforce the rule of law, the pressure on nature will decrease. However, it is important to note that the existence of laws and regulations does not necessarily guarantee their implementation (Muhammad & Long, 2021).The level of education in society is also one of the factors influencing the environment. According to the theory, as the average years of education increase and the number of students increases, the quality of the environment is likely to improve (Alam, 2010; Zafar *et al.*, 2020). There is a strong literature confirming the impact of democracy and good governance on environmental quality (Ali *et al.*, 2020). Indeed, with the improvement of democracy, we can hope for effective and appropriate implementation of government laws and regulations to achieve better environmental performance (Jahanger *et al.*, 2022). However, the effect of democracy on increasing CO2 emissions is positively estimated in the studies of Chou *et al.* (2020) and Adams & Nsiah (2019). Congleton *et al.* (1992) also showed that democracy has side effects, while autocracy has a positive effect on the environment in the long run.

The use of the ANS index as a criterion for measuring environmental pressure and assessing the factors influencing it has been explored in a number of studies. For example, Aşıcı (2012) examines the relationship between economic growth and environmental quality within the EKC concept by examining the effects of economic growth variables, population density, literacy level, trade liberalization, and political indicators on ANS as an indicator of pressure on nature in 213. The country paid during the period 1970 to 2008. In this study, the instrumental variables method of panel data was used to estimate the effects. The findings of the study showed that economic growth, trade liberalization, and political indicators of countries are factors affecting environmental pressures. Ganda (2019a) evaluated the impact of the variables GDP per capita, domestic credit to the private sector, and foreign direct investment on the ANS index for OECD countries. The results, using the method of GMM analysis, show that the Kuznets curve can be demonstrated for the years 2001 to 2012. In the study Roeland & de Soysa, (2021), the effect of per capita income (representing economic growth), democracy index, urban population, and population density on the ASN index for 170 countries during the years 1970-1970 was evaluated. The results showed that democracy and higher incomes reduce the chances of eco-friendly production and increase pollution and degradation of nature. Din *et al.* (2021) analyzed the relationship between sustainable development, ANS, financial development, economic growth, and resource rents using the panel least squares method for the emerging economies of South Asia during the years 1990-2020. The results showed that the index of sustainable development, financial development, and economic growth have a positive and significant effect on ANS. Fakher *et al.* (2023) also used the ANS as a proxy for environmental deterioration in order to assess the impact of renewable and non-renewable energy on this index.

The objective of this study is to conduct a thorough literature review to identify the key variables that contribute to the strain on the environment and assess their impact on the Adjusted Net Savings (ANS) index. An important aspect of this research is the careful selection of an appropriate estimation method that adequately addresses the issue of endogeneity associated with certain explanatory variables, such as real per capita income, which has often been overlooked in previous studies. Moreover, this study investigates the influence of various factors on the environment, examining each separately for different countries based on their level of development and income, building upon the findings of Aşıcı (2012) and Destek & Sinha, (2020). The primary aim is to explore the causal relationships between income and environmental pressure, with a specific focus on domestic environmental sustainability. While economic growth impacts the environment both domestically and globally, this study specifically concentrates on its repercussions within a country.

Methodology

The present study uses instrumental variable regression with panel data to check the relationship between log real income per capita and log real pressure on nature per capita. Pressure on nature in constant 2011 US$ is defined as a dependent variable which is the sum of CO_2 damage per capita (CDD), mineral depletion per capita (MD), energy depletion per capita (ED), and net forest depletion per capita (NFD) (Aşıcı, 2012).

$$PN = CDD + MD + ED + NFD \quad (1)$$

Pressure on nature is measured by the natural disinvestment component of the ANS data of the World Bank (World Bank, 2020). An analysis is performed on five groups of countries including developed countries, high-income developing countries, upper middle-income developing countries, lower middle-income developing countries, and lower-income developing countries which are based on World Bank classification. In our study, the extended model is used as follows (Aşıcı, 2012):

$$\log(PN_{it}) = \alpha + \beta_1 \log(G_{i,t-1}) + \beta_2 Log(POPDEN_{it}) + \beta_3 \log(EN_{it}) + \beta_4 \log(OPEN_{it}) + \beta_5 (RL_{it}) + \beta_6 (CO_{it}) + \beta_7 (DEMO_{it}) + u_i + \varepsilon_{it} \quad (2)$$

Where Log (PN_{it}) is natural logarithm real per capita pressure on nature, Log ($G_{i,t-1}$) is the lagged value of natural logarithm real income per capita (constant 2011 international dollars), Log ($POPDEN_{it}$) is natural logarithm population density (total population divided by land area (km^2), Log (EN_{it}) is natural logarithm school enrolment rate (secondary school enrollment rate, total), Log ($OPEN_{it}$) is s natural logarithm merchandise trade (GDP%), and RL_{it} is rule of law index, which captures perceptions of the quality of contract enforcement, property rights, police and courts, and the likelihood of crime and violence, as well as the extent to which agents trust and abide by the rules of society. The value of this index ranges from -2.5 to 2.5. Moreover, CO_{it} is the capital account openness index (the degree of capital account openness). It ranges from 2.5 (highly open) to -.83 (least open), and $DEMO_{it}$ is the democracy index (combined polity score, normalized from 0 to 1).

This equation is estimated separately for different groups of countries according to the classification. For this purpose, a panel regression analysis was used with 213 different countries between 1990 and 2018. Data on the variables are derived from the World Bank's World Development Indicators (WDI) database, the Worldwide Governance Indicators (WGI) and the Polity IV project database (PPD). Stata software was used to estimate the model.

In panel data econometrics, the initial step involves determining whether there is cross-sectional dependence or independence prior to conducting any tests. To assess cross-sectional dependence, Pesaran's (2004) CD test was employed. Moreover, in panel data models, it is necessary to check the stationarity of the variables before estimation. There are a variety of panel unit root tests, including Levin *et al.* (2002), Im *et al.* (2003), Fisher tests (Maddala & Wu 1999; Choi, 2001), and Hadri test (2000). Levin *et al.* (2002)'s panel unit root test assumes a homogeneous autoregressive coefficient for all members of the panel, whereas Im *et al.* (2003)'s test allows for a heterogeneous autoregressive coefficient. In other words, the former has a common unit root process and the latter has an individual unit root process. The results of Im *et al.* (2003)'s unit root test are misguided when the length of the time period is small for each section (Pierse & Shell, 1995). In our study, the stationarity of the variables is examined by Levin *et al.* (2002)'s test.

Consider the following simple econometric model, which will be the basis of our analysis:

$$y_{it} = \alpha + x'_{it}\beta + u_i + \varepsilon_{it} \quad (3)$$

In which Y_{it} is the dependent variable, X_{it} is the instrumental variable, ε_{it} is the traditional error of the country i in the period t, u_i is the individual or time-specific error (unobserved heterogeneity among countries or time periods), and α is the intercept.

There are different methods to estimate panel data. If there is no unobserved

heterogeneity among countries or time periods, the least-squares panel data method is used. Otherwise, there are different estimation methods based on heterogeneity with fixed or random effects. The fixed and random effects models are defined as (Park, 2011):

$$FE: Y_{it} = (\alpha + u_i) + X'_{it}\beta + \varepsilon_{it} \quad (4)$$
$$RE: Y_{it} = \alpha + X'_{it}\beta + (u_i + \varepsilon_{it})$$

The unobserved heterogeneity, which is the omitted variable, is a part of the intercept in the fixed effect model. In other words, the fixed effects model studies different intercepts of the countries or time periods. But, it is a part of the error term in the random effects model. There are two components of the error term, traditional error (ε_{it}) and specific error (u_i), in this model. Therefore, assumption $cov(X_{it},u_i)=0$ is necessary in the random effects model. Otherwise, the random effects estimators will be inconsistent. Also, the random effects model studies the difference in error variance (Park, 2011).

Endogeneity, which is one of the serious problems in patterns econometric, is defined as: $cov(X_{it}, \varepsilon_{it}) \neq 0$. It is a source of the inconsistency of the least-squares estimators (Baltagi, 2005). Thus, endogeneity is controlled by instrumental variables. Within the panel data framework, instrumental variables are necessary for preventing simultaneously. There are three methods to use instrumental variables: a) instrumental variables method (IV), b) the Hausman-Taylor method, and c) the Arellano-Bond (1991), which is first-differencing Generalized Method of Moments (GMM).

The Arellano-Bond method is used while the lagged value of the dependent variable is as an explanatory variable in the model. Time-invariant variables are estimated in the Hausman-Taylor method. There are two groups of variables in this method, time-variant and time-invariant variables. Also, some explanatory variables are correlated with the component of individual effects, and others are not correlated in this method. Therefore, IV method is used due to more restrictions in the Hausman-Taylor method (Cameron & Trivedi, 2009).

Individual fixed effects and the least-squares panel data methods are compared with F-test and fixed effects and random effects with the Hausman specification test. The Hausman specification test is defined as follows (Greene, 2008):

$$LM = (b_{fe} - b_{re})\hat{W}^{-1}(b_{fe} - b_{re}) \approx \chi^2(k) \quad (5)$$
$$\hat{W} = Var(b_{fe} - b_{re}) = Var(b_{fe}) - Var(b_{re})$$
$$H_0 : \text{cov}(\alpha_i, x_{it}) = 0$$

If the null hypothesis is refuted, the fixed effects model is then preferred. Otherwise, the random effects model is appropriate.

Results and Discussion

The estimation Pesaran's (2004) CD test results indicate indicate that the null hypothesis, which suggests no cross-sectional dependence at the one percent significance level for all variables and across the five groups of countries (Developed countries (G1), High-income developing countries (G2), Upper middle-income developing countries (G3), Lower middle-income developing countries (G4), Low-income developing countries (G5)), is rejected (Table 1). The list of the studied countries by different groups is provided in Appendix. Consequently, conventional tests and the first generation of unit root analysis cannot be applied in panel data analysis, necessitating the use of specialized tests that account for this cross-sectional dependence.

Due to the presence of cross-sectional dependence, the unit root of the Pesaran (2007) test, also known as the cross-sectional augmented IPS test, was used. As seen from Table 2, the result showed that all variables for all country groups were stationary (I(0)).

Table 1- Cross-sectional dependence test results (CD-test statistic)

Variabels	G1	G2	G3	G4	G5
$Log(G)_{-1}$	36.2***	8.62***	16.08***	4.39***	26.63***
Log(POPDEN)	152.02***	37.58***	21.58***	38.41***	89.82***
Log(EN)	21.13***	29.18***	5.02***	8.12***	17.32***
Log(OPEN)	63.19***	75.03***	125.12***	19.49***	87.03***
(RL)	2.35***	22.78***	9.92***	37.26***	4.28***
(CO)	7.82***	9.32***	52.55***	6.37***	18***
(DEMO)	11.09***	73.14***	48.25***	16.19***	88.71***

Note: *** indicates the p-value is less than 1%.
Source: Research findings

Table 2- Panel unit root test results

Variabels	G1	G2	G3	G4	G5
$Log(G)_{-1}$	-1.84**	-2.16***	-1.69*	-3.12***	-2.23***
Log(POPDEN)	-3.45***	-5.61***	-2.21***	-6.82***	-4.03***
Log(EN)	-2.15***	-2.89***	-2.15***	-3.02***	-2.15***
Log(OPEN)	-1.78**	-1.98***	-1.98***	-2.23***	-1.69*
(RL)	-4.52***	-6.05***	-3.81***	-3.62***	-4.92***
(CO)	-1.68*	-2.48***	-2.09***	-1.93***	-2.63***
(DEMO)	-5.64***	-8.02***	-5.03***	-6.88***	-3.48***

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels respectively.
Source: Research findings

Table 3- Panel cointegration test results

Variabels	G1	G2	G3	G4	G5
P_r	-4.58***	-7.23***	-11.02***	-14.51***	-21.08***
$P\alpha$	-9.28***	-6.47***	-6.42***	-7.2***	-5.13***
G_r	-5.15***	-15.31***	-8.74***	-8.24***	-4.37***
$G\alpha$	-15.65***	-4.62***	-4.24***	-6.08***	-3.81***

Note: *** indicates the p-value is less than 1%.
Source: Research findings

Table 4- F-Test and Hausman Specification Test

Classification of countries	F -statistic	Hausman specification statistic
Developed countries	278.4***	69.55***
High-income developing countries	27.51***	33.3***
Upper middle-income developing countries	189.79***	43.3***
Lower middle-income developing countries	375.76***	15.48**
Low-income developing countries	29.21***	22.71***

Note: ** and *** indicate significance at the 5%, and 1% levels respectively.
Source: Research findings

In this context, four sets of test statistics for five groups of countries are reported in Table 3. The results of Westerlund's (2007) cointegration test show that the non-cointegration hypothesis is rejected at the 1% level for all four statistics. Thus, the long-run steady-state relationship between the variables is confirmed.

The estimation was done by the instrumental variables method (IV) because the lagged value of the log real income per capita is an endogeneity variable (Aşıcı, 2012). Table 4 reports the results of the F and Hausman specification tests revealing that the fixed effects model is preferred to the pooled panel regression and random effects for all country groups.

Initially, robustness checks were conducted to validate the results. To investigate the effect of economic growth on the environment of the studied countries, the model was estimated using only the explanatory variable of real per capita income (Gi,t-1). The results of this analysis are presented in Table 5. Table 5 shows that economic growth has a positive and significant effect on pressure on nature. Then,

the model was estimated by countries based on the criteria of development and income (Table 6). Because it is rational to expect that the impact of income growth on the environment in high-income countries will be different from low- and middle-income countries (Aşıcı, 2012; Destek & Sinha, 2020). The results presented in Table 3 show that for low- and middle-income developing countries, economic growth increases the pressure on nature. However for high-income developing countries, this effect is not significant, and for developed countries, the effect of economic growth on the pressure on nature is negative and significant. Finally, the effect of economic growth on the pressure on nature was evaluated according to the criteria used in the ANS index (Table 7). The results of Table 4 showed that economic growth has a positive and significant effect on the three components of CO2 degradation, mineral, and energy depletion, but the effect of this variable on the component of net forest reduction is not statistically significant. The results of the diagnostic tests also show that the estimated linear model satisfies the conditions of data normality, absence of serial correlation and conditional heterogeneity (see Table 8).

In the estimated model, the probability of the Sargan test statistic is equal to 0.57, so the null hypothesis that there is no correlation between the instruments and the error terms cannot be rejected (see Table 9). Therefore, the results indicate the appropriate selection of the instrumental variables used in this model, as well as confirming their selection and validity.

Table 5- Robustness check: all of countries (balanced panel)

Variables	All of counteries
$Log(G)_{-1}$	0.82^{***}
α	-2.32^{***}

Source: Research findings

Table 6- Robustness check: different countries group

Variables	Developed	High-income developing	Upper middle-income developing	Lower middle-income developing	Low-income developing
$Log(G)_{-1}$	-0.03^{***}	1.46	2.11^{***}	3.08^{***}	3.23^{***}
α	10.83^{***}	8.26^{***}	-9.53^{***}	-16.21^{***}	-18.54^{***}

Source: Research findings

Table 7- Robustness check: components of pressure on nature

Variables	CDD	MD	ED	NFD
$Log(G)_{-1}$	0.63^{***}	0.38^{**}	0.49^{**}	0.08
α	-6.48^{***}	-7.56^{***}	-7.53^{***}	-12.38^{***}

Source: Research findings

Table 8- The results of diagnostic tests

Diagnostic tests	G1	G2	G3	G4	G5
JB test	0.386 (0.852)	3.44 (0.145)	0.983 (0.523)	2.18 (0.248)	4.12 (0.112)
LM test	0.582 (0.352)	0.780 (0.308)	1.52 (0.145)	1.89 (0.110)	0.653 (0.327)
ARCH test	0.418 (0.538)	1.28 (0.172)	0.765 (0.502)	2.93 (0.123)	1.15 (0.179)

1. The value in parenthesis is p values.
2. JB is Jarque–Bera normality test.
3. LM is Lagrange multiplier test for serial correlation.
4. ARCH is Heteroscedasticity test.

Source: Research findings

Table 9- Validity test of instrumental variables

Statistis	Prob
Sargan test (Chi2)=9.68	0.572

Source: Research findings

Finally, the results of the effect of all the explanatory variables on the ANS index by groups of different countries are presented in Table 10. This table reports the results of the fixed effects IV method and it should be noted that some variables were excluded due to time invariant. The results of the Wald test represents an appropriate estimation for all country groups.

The results indicate that the relationship between the income per capita and pressure on nature per capita is negative and very poor for developed countries so that the pressure on nature p.c. will decrease by 0.001% with a 10% increase in per capita income. Therefore, a negative relationship between per capita income and per capita environmental pressure is justifiable in developed countries (Boulatoff & Jenkins, 2010). But, this relationship is positive and significant in all developing countries, yet the effect is much stronger in low-income than in high-income countries. These findings are almost consistent with Muradian & Martinez- Alier (2001), Aşıcı (2012), and Ganda (2019b). They concluded that the relationship between growth and damage of nature is not significant in high-income countries and significant and positive in low-income countries. Therefore, it is found that economic growth in developed countries tends to increase the consumption of resources that come from developing countries. On the other hand, according to the EKC analysis, the countries seek to improve their environmental conditions after achieving a desirable level of economic growth and development. This finding is in line with Wang *et al.* (2013), Aşıcı & Acar, (2018), Ulucak & Bilgili, (2018) studies and contradicts Charfeddine & Mrabet, (2017) and Destek & Sinha, (2020) studies. The income coefficient of low-income developing countries is 2.03. Thus, the pressure on nature p.c. will increase by 20.3% with a 10% increase in per capita income. Therefore, the development pattern of developing countries is unsustainable, unlike developed countries.

According to the results, an increase in global trade or trade liberalization raises environmental pressure significantly for all groups of countries except for lower middle-income developing countries. This result has been confirmed in Aşıcı (2012) and Charfeddine (2017) studies and contradicts the finding of Destek & Sinha's (2020) study. The effect of this variable is stronger in low-income countries than in the other groups so that a 10% increase in the trade liberalization is associated with a 14.9% increase in per capita pressure on nature.

Table 10- Fixed Effects IV Coefficients

Variables	Developed	High-income developing	Upper middle-income developing	Lower middle-income developing	Low-income developing
$Log(G)_{-1}$	-0.0001***	1.37***	1.74***	1.83***	2.03***
	(0.00004)	(0.25)	(0.18)	(0.34)	(0.41)
Log(POPDEN)	0.00007	0.71	4.53***	4.45***	3.44*
	(0.00006)	(0.48)	(0.87)	(0.57)	(1.82)
Log(EN)	-1.38***	-2.44***	0.0002	0.22	0.6
	(0.15)	(0.36)	(0.0004)	(0.63)	(0.95)
Log(OPEN)	1.27***	1.28***	0.83***	0.21	1.49***
	(0.30)	(0.21)	(0.14)	(0.16)	(0.53)
(RL)	------	-0.4**	------	-0.77***	-0.88*
		(0.21)		(0.24)	(0.47)
(CO)	0.08***	0.07***	0.017	-0.17***	-----
	(0.02)	(0.02)	(0.01)	(0.05)	
(DEMO)	-----	0.13	0.007	-0.08***	----
		(0.09)	(0.005)	(0.01)	
α	9.49***	5.73**	-6.22***	-13.22***	-15.93***
Wald	217.77***	266667.24***	696925.92***	744496.58***	65217.86***
R^2	0.432	0.563	0.345	0.504	0.481

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels respectively.
Note: The values in parentheses indicate the standard error.
Source: Research findings

The results of the analysis indicate that improving the structure of rules and standards will promote environmental conditions. The coefficient of rules quality variable is negative and significant in different income groups of developing countries. This coefficient is greater in low-income developing countries than the other groups so that 1 unit increase in the rules quality index is associated with a 0.88% reduction in the per capita pressure on nature. The result of this study shows that the effects of trade liberalization and standard quality on environmental pressure are in conflict with one another. This finding is in line with Al-Mulali *et al.* (2015) and Al-Mulali *et al.* (2016) studies and contradicts the findings of Destek & Sinha's (2020) study. Some researchers believe that the effect of rules and standards quality is in conflict with trade liberalization. According to Tisdell (2001) and Esty (2001), the presence of environmental and social limitations leads to institutions like the WTO violating regulations. Similarly, Daly (1993) contends that unrestricted trade fosters competition, which in turn leads to a decline in environmental standards and regulations. However, Steininger (1994) presents findings indicating that free trade in Mexico adversely affects the quality of regulations in border regions.

The relationship between capital openness and environmental pressure is positive and significant in developed and high-income developing countries so that 1 unit increase in the capital openness index is associated with a 0.08% and 0.07% increase in the per capita pressure on the nature of developed and developing with high-income countries, respectively. But, this effect is insignificant or even negative in developing countries with lower incomes. This can be attributed to the fact that capital openness in developed and high-income developing countries lead to the outflow of capital and the reduction of environmental investment (Aşıcı, 2012). This result is different in developing countries with lower incomes.

In democratic societies, it is anticipated that alleviating the strain on the environment will be achieved through increased governmental accountability towards environmental protection. Hence, it is crucial to consider the democracy index. However, the findings in this area do not consistently align. For instance, Knight & Rosa, (2011) demonstrated that democracy does not have a significant impact on life satisfaction (well-being). York *et al.* (2003) and Marquart-Pyatt (2010) indicate that the relationship between democracy and the environmental index is either non-significant or positive. In this study, the influence of the democracy index on environmental pressure remains uncertain. This finding is in line with result of Knight & Rosa, (2011) study. This effect is significant only in lower middle-income developing countries so that 1 unit increase in the democracy index is associated with a 0.08% reduction in per capita pressure on nature in lower middle-income developing countries. In other words, the democracy index improves environmental conditions. This finding contradicts the findings of Roeland & Soysa (2021) study.

Population density has an adverse effect on the environment in developing countries with lower incomes. This finding however, such a relationship was not established in developed or high-income developing countries. A 10% increase in population density increases the pressure on nature through upper middle-income, lower middle-income, and low-income of developing countries by 45.3%, 44.5%, and 34.4%, respectively. This result shows that developing societies rely on natural resources to meet the needs of the population to a greater extent than developed countries. Therefore, developed nations have a more appropriate consumption culture than developing societies.

The coefficient of the school enrollment rate has a significant and negative effect in developed and high-income developing countries. A 10% increase in the school enrollment rate reduces the environmental pressure of developed and high-income developing countries by 13.8% and 24.4%, respectively. However, this variable is not significant in developing countries with lower

incomes. Hence, it can be said that the education quality of developed and high-income developing countries is appropriate in the field of the environment.

Conclusion

The current study utilizes a comprehensive and suitable index, which combines CO_2 damage, mineral depletion, energy depletion, net forest depletion, and classifies countries into different income groups. Panel data is employed to account for the endogeneity of explanatory variables and estimate the actual impact of per capita income and other variables on environmental pressure. Across 213 countries, there is a positive and significant association between economic growth and environmental pressure. This implies that as the global economy expands, the burden on nature increases, necessitating global agreements to address this situation. The findings indicate that in developing countries, there is a positive correlation between income per capita and per capita pressure on nature. However, this effect is more pronounced in low-income countries compared to high-income countries, likely because developed nations have adopted more sustainable alternatives to non-renewable resources while developing countries heavily rely on resource consumption. The study highlights the importance of developing countries shifting towards alternative resources instead of degrading non-renewable natural resources for growth and development. Additionally, it reveals that economic growth contributes to CO2 emissions, mineral and energy depletion, but its impact on net forest depletion is not statistically significant. This suggests that countries worldwide have utilized energy and mineral resources, leading to carbon dioxide pollution during their economic development process. To improve the environment, there is a need to transition towards renewable and clean resources. Furthermore, the study finds that increased global trade intensifies environmental pressure. The quality of institutions, as measured by the enforceability of the rule of law, has a positive effect on the environment. It is recommended that developing countries enhance their legal frameworks, making them more coherent and efficient, while reducing bureaucratic complexity. In developed and high-income developing countries, an increase in school enrollment rates can influence the environment, but this effect is not significant in lower-income groups. This suggests that the educational systems of developing countries have limited emphasis on environmental topics. Consequently, governments should consider reforms to incorporate environmental education into the current system. In conclusion, population control in developing countries is associated with a positive impact on environmental quality.

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Appendix: The list of studied countries by different groups

Developed		High-income developing	
Australia	Latvia	American Samoa	Israel
Austria	Lithuania	Andorra	Korea, Rep.
Belgium	Luxembourg	Antigua and Barbuda	Kuwait
Canada	Malta	Aruba	Liechtenstein
Croatia	Netherlands	Bahamas, The	Macao SAR, China
Cyprus	New Zealand	Bahrain	Monaco
Czech Republic	Norway	Barbados	Nauru
Denmark	Poland	Bermuda	New Caledonia
Estonia	Portugal	British Virgin Islands	Northern Mariana Islands
Finland	Romania	Brunei Darussalam	Oman
France	Slovakia	Cayman Islands	Panama
Germany	Slovenia	Channel Islands	Puerto Rico
Greece	Spain	Chile	Qatar
Hungary	Sweden	Curaçao	San Marino
iceland	Switzerland	Faroe Islands	Saudi Arabia
Ireland	ulgaria	French Polynesia	Seychelles
Italy	United Kingdom	Gibraltar	Singapore
Japan	United States	Greenland	Sint Maarten (Dutch part)
		Guam	Trinidad and Tobago
		Guyana	United Arab Emirates
		Hong Kong SAR, China	Virgin Islands (U.S.)
		Isle of Man	

Continued-

Upper middle-income developing		Lower middle-income developing		Low-income developing
A]lbania	Kazakhstan	Angola	Lesotho	Afghanistan
Argentina	Kosovo	Algeria	Mauritania	Burkina Faso
Armenia	Libya	Bangladesh	Micronesia, Fed. Sts.	Burundi
Azerbaijan	Malaysia	Benin	Mongolia	Central African Republic
Belarus	Maldives	Bhutan	Morocco	Chad
Belize	Marshall Islands	Bolivia	Myanmar	Congo, Dem. Rep
Bosnia and Herzegovina	Mauritius	Cabo Verde	Nepal	Eritrea
Botswana	Mexico	Cambodia	Nicaragua	Ethiopia
Brazil	Moldova	Cameroon	Nigeria	Gambia, The
Bulgaria	Montenegro	Comoros	Pakistan	Guinea-Bissau
China	Namibia	Congo, Rep.	Papua New Guinea	Korea, Dem. People's Rep
Colombia	North Macedonia	Côte d'Ivoire	Philippines	Liberia
Costa Rica	Palau	Djibouti	Samoa	Madagascar
Cuba	Paraguay	Egypt, Arab Rep.	São Tomé and Principe	Malawi
Dominica	Peru	Eswatini	Senegal	Mali
Dominican Republic	Russian Federation	Ghana	Solomon Islands	Mozambique
El Salvador	Serbia	Guinea	Sri Lanka	Niger
Equatorial Guinea	South Africa	Haiti	Tanzania	Rwanda
Ecuador	St. Lucia	Honduras	Tajikistan	Sierra Leone
Fiji	St. Vincent and the Grenadines	Jordan	Timor-Leste	Somalia
Gabon	Suriname	India	Tunisia	South Sudan
Georgia	Thailand	Iran, Islamic Rep	Ukraine	Sudan
Grenada	Tonga	Kenya	Uzbekistan	Syrian Arab Republic
Guatemala	Türkiye	Kiribati	Vanuatu	Togo
Indonesia	Turkmenistan	Kyrgyz Republic	Vietnam	Uganda
Iraq	Tuvalu	Lao PDR	Zambia	Yemen, Rep.
Jamaica	West Bank and Gaza	Lebanon	Zimbabwe	

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بررسی عوامل مؤثر بر عدم سرمایه‌گذاری طبیعی: رویکرد رگرسیون داده‌های پانل

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چکیده

این مطالعه به بررسی همبستگی بین رشد اقتصادی و تأثیر آن بر محیطزیست، به‌ویژه با تمرکز بر مفهوم پایداری محیطی پرداخت. در این راستا، داده‌های پس‌انداز خالص تعدیل‌شده بانک جهانی (ANS) برای سنجش فشار بر محیطزیست، به‌ویژه از طریق اندازه‌گیری عدم سرمایه‌گذاری طبیعی، استفاده شد. این اندازه‌گیری اثرات تجمعی خسارت دی اکسید کربن (CO_2) و همچنین کاهش مواد معدنی، انرژی و منابع جنگلی را در بر می‌گیرد. با توجه به درون‌زایی متغیرهای توضیحی برای برآورد اثر واقعی درآمد سرانه و سایر متغیرها بر میزان فشار بر محیطزیست از داده‌های پانل استفاده شد. در این مطالعه، از روش پانل متغیر ابزاری (IV) با اثرات ثابت و از داده‌های ۲۱۳ کشور در دوره زمانی ۱۹۹۰ تا ۲۰۱۸ بهره گرفته شد. نتایج تحلیل رگرسیون نشان داد که بین درآمد و تأثیر بر محیطزیست در کشورهای در حال توسعه همبستگی مستقیم وجود دارد. با این حال، این رابطه به طور قابل توجهی در کشورهای کم درآمد در مقایسه با کشورهای با درآمد بالا مشهودتر است. علاوه بر این، این مطالعه نشان می‌دهد که گسترش تجارت به افزایش فشار زیست‌محیطی در تمام گروه‌های کشورها مساعدت می‌نماید. افزایش نرخ ثبت نام مدارس می‌تواند بر محیطزیست کشورهای توسعه یافته و در حال توسعه با درآمد بالا تأثیر بگذارد. همچنین اثر متغیر باز بودن سرمایه بر فشار محیطی برای کشورهای توسعه یافته و پردرآمد مثبت برآورد شد. البته این اثر برای کشورهای کم‌درآمد منفی بود. در نهایت، نتایج نشان داد که کشورهای در حال توسعه می‌بایستی ساختار حقوقی خود را بهبود بخشند و همچنین بوروکراسی و پیچیدگی قوانین را کاهش دهند.

واژه‌های کلیدی: رشد اقتصادی، پایداری زیست‌محیطی، کشور در حال توسعه، داده پانل، متغیرهای ابزاری

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Investigating the Appropriate Strategy to Enter the International Market of Organic Agricultural Products

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Abstract

The increasing concern of consumers about the quality and safety of agricultural products all over the world has caused organic products to become one of the most popular options for healthy. The increasing trend and consumption of organic agricultural products has led to the increasing growth of the market of these products in the last two decades. Due to the importance of entering and gaining a share of this growing market, this study investigates the factors affecting the international organic products market entry and determines the appropriate strategy for entering it using structural equation modeling. The data of this study was obtained by collecting 90 questionnaires from producers of organic saffron, pistachio, and raisin products in the year 2021 with available sampling method in Khorasan Razavi province. The obtained results indicate that the variables of risk and motivation to enter the international market directly and the production and marketing ownership indirectly and through influencing the motivation to enter the international market, influence the international market entry strategy. Based on this, the appropriate strategy for entering the international market of organic products, indirect, cooperative and non-attendance strategies such as indirect export, contract production and joint investment was obtained. Therefore, it is suggested that the government should remove or reduce the risks caused by sanctions and obstacles to enter the market for the direct presence of organic product producers in international markets.

Keywords: Entry strategy, Motivation, Organic, Ownership, Risk

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Introduction

In recent years, consumers around the world have become increasingly concerned about the quality and safety of agricultural and food products. Therefore, the need for a healthy diet has been created in them (Hansmann *et al.*, 2020; Wang *et al.*, 2023). Since, no chemical pesticides, chemical fertilizers, sewage, irradiation or any artificial flavors, colors and preservatives have been used in the production and processing of organic products (Akter *et al.*, 2023), these products are one of the most popular options for sustainable consumption among consumers (Rizzo *et al.*, 2020; Iqbal *et al.*, 2021). In such a way that 38% of Chinese consumers (students) are consumers of organic products and drinks and 27% of them are buyers of organic fruits and vegetables (Ali *et al.*, 2021). 55.6% of American consumers buy organic products (Gundala & Singh, 2021) and 66.4% of consumers in western Poland buy organic food (Kułyk & Dubicki, 2019). The increasing tendency and consumption of organic products in different countries has caused the growth of the market of these products. So that, in the last two decades, the global sales of organic food and beverages have increased from around 13 billion euros in 2000 to 125 billion euros in 2021 (Willer *et al.*, 2023). The efforts of different countries to produce organic products and enter the international markets have led to the formation of markets in Asia, Latin America and Africa, and the global share of the United States, the European Union and China in the sale of organic food has decreased (Willer *et al.*, 2021).

Iran has about 7 thousand hectares of organic land and produces crops such as saffron, pistachios and raisins organically (Willer *et al.*, 2023; Iran Organic Association, 2020). Iran also has about 7 thousand hectares of organic land and produces organic products such as saffron, pistachio and raisins and is trying to enter this market. But entering the international markets and choosing the right strategy for its entry is considered a strategic decision for (organic) producers in the countries. Because, the level of commitment to the international market determines the risks they bear and the level of control they have over their production and marketing in the international market. An appropriate entry strategy can increase the performance of the producer, and on the other hand, choosing an inappropriate entry strategy can be very costly and irreparable (Lin & Ho, 2019). Therefore, the strategy of entering the global organic market and the factors affecting it are very important.

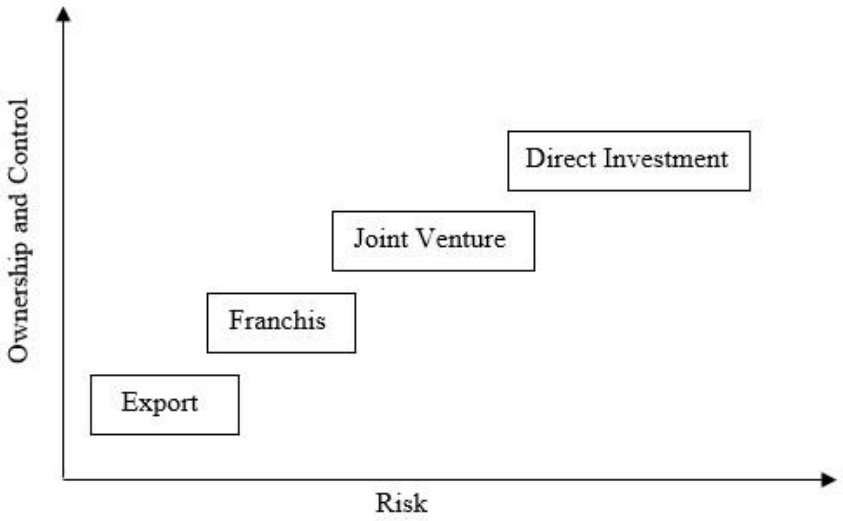

Figure 1- International market entry strategies

In general, strategies for entering the international market include a wide range from export to investment, each of which has its own level of risk, control and ownership over production and marketing operations (Albaum & Duerr, 2008; Lu *et al.*, 2011). In this range, according to Fig. 1, entry strategies through indirect exports are among the least risky with the least control and ownership over production and marketing, and the foreign direct investment strategy is the most risky with the most control over production and marketing operations (Skarmeas *et al.*, 2016; Masum *et al.*, 2020).

Several factors affect the strategy of entering international markets. International studies found factors such as types of risk (Tang & Buckley, 2020), access to resources, innovation, product characteristics, marketing and type of industry, market development, technology development, locational advantage (Nisar *et al.*, 2012), motivation (Zekiri, 2016), demand uncertainty, market size and growth, direct and indirect trade barriers, laws, the regulations of the competitive market (Ravelomanana *et al.*, 2015) and the ownership of production and marketing (Xu *et al.*, 2011) to be effective on the strategy of entering the international market. Iranian studies also include competition, marketing mix, laws and regulations of the country of origin, international experience and government support (Tahernejad *et al.*, 2021), company size, management characteristics, tariff barriers, geographic distance, cultural distance, product type and non-tariff barriers (Pashazadeh & Adel, 2019), export experience, export risks, sanctions, marketing mixes, research and development, variety of export destinations, reliable brand and attractiveness of the place (Mohammadzadeh *et al.*, 2018), core capabilities (Mirahmadi & Hamidizadeh, 2018) and macroeconomic factors, business and market factors, financial and credit factors, technical and specialized factors, and exchange process factors (Nejatianpour & Esmaeili, 2016) have evaluated the strategy of entering the international market as effective.

Each of these studies have addressed some factors affecting the strategy of entering the international market. The sum of these factors can be classified or aggregated in different ways. This study, recognizing the potential for categorizing strategies for entering the international market based on risk and ownership, as well as the significance of evaluating the motivation behind market entry, categorizes these factors into three components: motivation to enter the market, international market risk, and ownership or control over production and marketing. It assesses their impact on entry into the international organic products market and determines the most suitable strategy accordingly. Hollensen (2008) has divided the motives for entering the international market to proactive and reactive motives. Proactive motives are based on producers' internal decisions and their interests and include profit and growth goals, management goals, foreign market opportunities, economies of scale and tax benefits. Meanwhile, the reactive motives reflect the passive behavior of the producer, which comes from the pressure or threats in the domestic or foreign markets, as well as from the pressure in the internal production environment, and includes competitive pressures, small and saturated domestic market, orders foreign is the development of sales of seasonal products and proximity to international customers or psychological distance (Kubickova *et al.*, 2014). Nisar *et al.*, (2012) have found the effects of the motivation of Norwegian companies' managers to be positive and significant and without influence depending on the type of strategy to enter the international market. Zekiri (2016) has evaluated these effects positively in Macedonia. In Iran, considering the smallness of the domestic market of organic products, the existence of orders and foreign market opportunities of the organic products, it seems that the motivation to enter the international market of organic products has a positive effect on the cooperative and indirect strategies of entering the international market.

When risk is studied as a multidimensional

concept, it gives a better understanding of its effect on the company's entry strategy (Ismail, 2017). According to studies, the most important dimensions of risk are: political risk, economic risk, social risk, demand risk and competitive risk (Hauger, 2006; Pehrsson, 2008; Anggara, 2011; Rafat & Farahani, 2019). Studies show that the various risks, in addition to the strategy of entering the international market, have a significant effect on the ownership of production and marketing and the motivation to enter the international market. As risk increases, producers choose indirect entry methods such as indirect export with less ownership and control over production, and their motivation to enter the international market decreases (Tang & Buckley, 2020; Aguzzoli *et al.*, 2021). Ownership or control is the power that the producer exerts on the systems, methods and decisions of the foreign business unit. Based on this, ownership or control over production and marketing operations indicates the power and ability of the producer to carry out production and marketing operations (Brookes & Roper, 2010). Decisions related to full or little control over production and marketing operations are based on factors such as language differences, market attractiveness, industry competition intensity (Golalizadeh *et al.*, 2014). Studies show that the increase in cultural differences makes companies prefer joint investment to full ownership. However, when there is a language difference, the local partner adds to the problems caused by uncertainty and companies prefer to use the methods that bring full control and ownership (López-Duarte & Vidal-Suárez, 2010). Market attractiveness including market size, market growth, market stability, people's income, labor cost, infrastructure, welfare level, lack of entry barriers and the number of competing companies is another factor that affects production ownership (Miecinskienea *et al.*, 2014; Almgren, 2014; Dehghan Shabani, 2017). In addition, the industry competition intensity, which shows the competitive relationship between small, medium and large companies, has an effect on company ownership and entering the market. So that in industries where the competition intensity is less, companies prefer to use the methods that bring full control. At the same time, when the competition intensifies, companies may prefer not to enter fully cooperative strategies. Because participation reduces their decisiveness in quick response to competitors (Tsang, 2005; Koch *et al.*, 2020). Studies have shown that production and marketing ownership has a significant effect on the motivation and entry of producers into the international market. So that private and small producers use cooperative methods more than large producers (Xu *et al.*, 2011; Ahsan *et al.*, 2020).

According to what was mentioned, the following hypotheses can be expressed based on the relationships between the three mentioned factors:

- Hypothesis 1: Production and marketing ownership has a positive and significant effect on the motivation to enter the international market of organic products.
- Hypothesis 2: Risk has a negative and significant effect on production and marketing ownership.
- Hypothesis 3: Risk has a negative and significant effect on the motivation to enter the international organic products market.
- Hypothesis 4: Production and marketing ownership has a positive and significant effect on the strategy of entering the international organic products market.
- Hypothesis 5: Risk has a positive and significant effect on the strategy of entering the international organic products market.
- Hypothesis 6: The motivation to enter the international market has a positive and significant effect on the strategy of entering the international organic products market.

This study has targeted three organic products of saffron, pistachio and raisin in Khorasan Razavi province. These three products are the main organic products of Khorasan Razavi province. According to the statistics and information of the Agricultural Jihad Organization of the province, the cities of Gonabad, Zaveh and Fariman have 450, 235 and 4.5 hectares of organic saffron with an

average yield of 4 kg per hectare, respectively. In 2018, this crop received an organic certificate from Pars Gawah Gostar Company, which is the representative of BCS in Germany, and managed to capture more than 40% of the country's organic saffron cultivation area. Qochan city with 575 hectares of organic grape and yield of 3 tons per hectare in 1997 has more than 40% share of the country's organic grape cultivation area. Fayzabad city in the province with 120 hectares of organic pistachio (20% of the country's organic pistachio cultivation area) and a yield of 500 kg per hectare also has an organic certificate from the German BCS company (Agricultural Jihad Organization of Khorasan Razavi, 2020).

In order to achieve the purpose of the study, structural equation modeling has been used. This study used the formative-reflective measurement model and confirmatory composite analysis. This model is the simultaneous presence of the formative measurement model and the reflective measurement model in the modeling, which distinguishes it from other studies in this field.

Materials and Methods

Measurement model

In this paper, we used Structural Equation Modeling (SEM), which includes two measurement and structural models. The relationships between the latent variables and the observed variables are examined through the measurement model, and the relationships between the latent variables, which enable the testing of statistical hypotheses for the study, are evaluated through the structural model (Byrne, 2010). Based on the causal relationships between observed and latent variables, there are two types of reflective and formative measurement models. So, if the observed variables have a high correlation and the direction of causality is from the latent variables to the observed variables, then the measurement model is reflective (Hair *et al.*, 2013), and if the observed variables are the cause of the latent variables, the measurement model is formative (Petter *et al.*, 2007). To examine the measurement model, it is used confirmatory composite analysis (CCA) method that was suggested by Rigdon (2014), Sarstedt *et al.* (2014) and Henseler *et al.* (2014) in variance-based structural equation modeling. According to this method, the evaluation process of reflective and formative measurement models is shown in Table 1 (Goetz *et al.*, 2013; Howard, 2018).

Table 1- Evaluation Steps of Formative and Reflective Measurement Models Using Confirmatory Composite Analysis (CCA)

Reflective Measurement Model	Formative Measurement Models
1- Estimating of loadings and significance and also, reliability of observed variables	1- Assessing convergent validity – redundancy
2- Assessing reliability of latent variables using Cronbach's α and composite reliability	2- Assessing observed variables multicollinearity using VIF (variance inflation factor)
3- Assessing convergence validity of latent variables using Average Variance Extracted (AVE)	3- Assessing size and significance of observed variables weights
	4- Assessing size & significance of loadings

Source: Hair *et al.*, 2020

After evaluating and confirming the measurement model using the CCA method, the structural model is examined based on evaluation of structural model collinearity, examination of size and significance of path coefficients, and f^2 effect size (in-sample prediction).

These steps are explained as below (Hair *et al.*, 2020):

Evaluation of structural model collinearity

The collinearity of the latent variables is evaluated. Structural models with high collinearity can increase or decrease coefficients and weights or change their signs. For this purpose, the VIF values should be examined. If these values are less than 3, multicollinearity is unlikely to be a problem.

Examination of size and significance of path coefficients

This step includes checking the size and significance of path coefficients. This process enables the researcher to evaluate hypothesized relationships between latent variables. Path coefficients are standardized values that may range from -1 to +1, but rarely approach -1 or +1. The closer the values of the path coefficients are to 0, the weaker they are in predicting the dependent latent variables, and the closer the values are to the absolute value of 1, the stronger they are in predictions.

f^2 effect size

The measure used to predict the structural model is the f2 effect size, which provides an estimate of the predictive ability of each independent latent variable in the model. To calculate this value, every predictive latent variable is systematically removed from the model by SmartPLS software, and a new R2 is calculated without that variable. Then, R2 with the presence of that variable in the model is compared with R2 without that variable, and the difference between these two values determines whether the investigated latent variable is a significant predictor of the dependent latent variable or not (Hair *et al.,* 2017). The effect size, which is called f2, is rated as small, medium and large. Values between 0.02 and 0.15 are small, values between 0.15 and 0.35 are medium, and values 0.35 and above have large effects (Cohen, 1988).

Research conceptual model

The studied variables, i.e. motivation to enter the international market, production and marketing ownership, risk and international market entry strategy are measured through a set of observed variables shown in Fig. 2. Therefore, these four variables are considered as latent variables. Since the observed variables of gain profit, management experience, market opportunity, excess production over demand, close to customers and the existence of foreign orders are the reasons for the variable of motivation to enter the international market. Also, the variables of technical knowledge, marketing skills, competition intensity, market size, market growth, and language difference are the causes of the production and marketing ownership variable, and the variables of sanctions, administrative corruption, differences in economic structure, labor laws, demand, competitors' activities, and variation in prices of competing products are the cause of the risk variable, the measurement model to investigate the relationship between the variables of motivation to enter the international market, production and marketing ownership, risk and the observed variables will be of a formative type according to Fig. 2. But because the latent variable of the international market entry strategy is the cause of the observed variables, its measurement model will be reflective in order to investigate the relationship between the observed and latent variables (Fig. 2).

To gather data for the study, the researcher utilized a questionnaire. The questionnaire comprised questions related to the variables of motivation to enter the international market, ownership of production and marketing, and risk, measured on a five-point Likert scale ranging from "completely disagree" to "completely agree." The validity of the questionnaire was checked and confirmed by experts. The reliability coefficient was obtained by Cronbach's alpha method (0.78), which indicates the validity of the questionnaire.

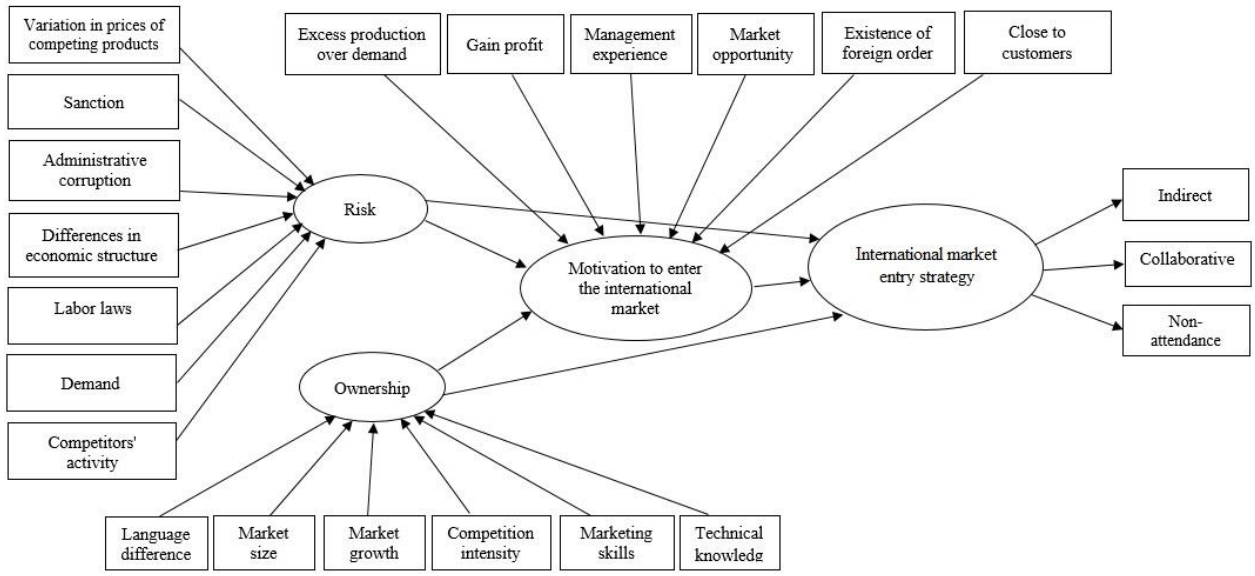

Figure 2- Research conceptual model

Questionnaires were completed in person from organic producers of saffron, pistachio and raisin products in Khorasan Razavi province. According to the information obtained from the Agricultural Jihad Organization of Razavi Khorasan province in 1400, the producers of raisins (grapes), saffron and pistachios in the province are 757, 875 and 8 people, respectively. To determine the sample size in the PLS method, two rules of 10 times the maximum observed variables of the measurement model among the measurement models and the maximum relationships of the structural model in the study were used (Hair *et al.*, 2017). Based on this rule, by multiplying the number 10 by the maximum number of observed variables in the measurement model, which is equal to 7, the number of samples required for the study is 70. However, in order to achieve better results, 90 samples (producers) with a ratio of 41, 41 and 8 people from the producers of raisins (grapes) in Qochan, saffron in Zaveh and pistachios in Fayzabad, respectively were selected through available sampling and were interviewed.

Results and Discussion

Statistical description of the studied sample

The characteristics of organic producers are shown in Table 2. As can be seen, the producers of all three products have received an organic certificate from Pars Gavah Company. Grape producers in Qochan have an average area under cultivation and production per hectare of 0.86 hectares and 2.97 tons. Saffron producers in Zaveh have an average of 0.79 hectares and 4 kg of yield per hectare, and pistachio producers in Fayzabad have a cultivated area of 15 hectares and an amount of 500 kg per hectare.

Table 2- Specifications of sample producers

Number of producers	Product Name	City name	Cultivated area (hectares)	Production amount (tons)	The company providing the organic certificate
41	Soltani grape variety	Quchan	35	102	Pars Gawah Gostar representative of BCS
41	Saffron	Zaveh	41	0.16	Pars Gawah Gostar representative of BCS
8	Pistachio	Fayzabad	120	60	Pars Gawah Gostar representative of BCS

Source: Agricultural Jihad Organization of Khorasan Razavi

Structural equation modeling results

Structural equation modeling has been used to investigate the effect of three variables of motivation to enter the international market, production and marketing ownership, and risk on the international market entry strategy. Based on this, in the first step of modeling, the measurement model that expresses the relationship between the latent and observed variables is evaluated.

Measurement model results

In this study, the measurement model is of the formative-reflective type. So, for the latent variables of motivation to enter the international market, production and marketing ownership, and risk, the measurement model is of a formative type, and for the latent variable of international market entry strategy, the measurement model is of a reflective type. The evaluation results of these two models are shown in Table 3. In the formative measurement model, in the first step, the convergent validity or redundancy analysis, which indicates the degree of correlation of each latent variable with the observed variables reflecting the same latent variable, is checked. The results of this step are shown in the last column of Table 3 and it shows that these coefficients are greater than 0.7 and significant. Therefore, the model has good convergent validity. In the second step, the collinearity of the observed variables was evaluated through the VIF index, and its results in the fifth column of the table indicate that the values of the VIF index for all the observed variables are less than 3. Therefore, there is no problem of multicollinearity in model.

In the third step, the relative contribution of each formative observed variables in the formation of the latent variable is checked. The results in the third column of Table 3 indicate that among the observed formative variables that form the latent variable of motivation to enter the international market, gain profit, management experience and the existence of foreign order, have the largest contribution in the formation of the motivation of organic product producers to enter international markets, respectively. As for the latent variable of risk, the variables of sanctions, administrative corruption and differences in economic structure have the largest contribution in the formation of this variable, respectively. Regarding the variable of production and marketing ownership, technical knowledge, market size and marketing skill have the largest share in the formation of this variable, respectively.

In the fourth step, the absolute contribution (outer loading) of the observed variables in the formation of latent variables is evaluated. Its results in column 4 of Table 3 show that among the observed variables, the latent variable of motivation to enter the international market, gain profit, management experience and excess production over demand have the highest share, respectively. Regarding the latent variable of risk, sanctions, differences in economic structure, and administrative corruption have the largest contribution in the formation of this variable, respectively. Regarding the variable of production and marketing ownership, marketing skill, market size and competition intensity have the largest contribution in the formation of this variable, respectively.

In the reflective measurement model, the outer loadings and validation of the observed variables are checked in the first step. The results of this model in the third column of the second part in Table 3 indicate that the observed variables reflect their latent variables well. In other words, the observed variables have the necessary accuracy to measure the latent variables of the study. In the second step, validation of latent variables is evaluated using Cronbach's alpha coefficient and composite reliability coefficient. In columns 4 and 5 of Table 3, the results of this validation show that the value of both coefficients is greater than 0.7, therefore, the measurement model under investigation and the latent variable of international market entry strategy have adequate validity.

Table 3- Evaluation results of the formative-reflective measurement model

Latent variables	Observed variables	Outer weight of observed variables	Outer loading	Collinearity (VIF)	Convergent Validity (Redundancy Analysis)
Motivation to enter the international market	gain profit	0.491***	0.798***	2.087	0.71***
	Management experience	0.469***	0.716***	1.558	
	market opportunity	0.241***	0.562***	1.191	
	Excess production over demand	0.249***	0.687***	1.450	
	Close to customers	0.115	0.565***	1.713	
	Existence of foreign order	0.346***	0.661***	1.278	
Risk	Sanction	0.511***	0.813***	1.502	0.75***
	Administrative corruption	0.446***	0.430***	1.114	
	Differences in economic structure	0. 327***	0.633***	1.703	
	Labor laws	0.211*	0.322***	1.195	
	Demand	0.110	0.424***	1.685	
	Competitors' activity	0.215*	0.347***	1.543	
	Variation in prices of competing products	0.20**	0.344***	1.372	
Production and marketing ownership	Technical knowledge	0.387***	0.631***	1.247	0.73***
	Marketing skills	0.339***	0.699***	1.279	
	Competition intensity	0.223**	0.645***	1.541	
	Market size	0.367***	0.683***	1.361	
	Market growth	0.310**	0.625***	1.441	
	Language difference	0.098	0.298***	1.089	
		Outer loading	Cronbach's α	Composite reliability	Average Variance Extracted (AVE)
International market entry strategy	- Indirect	0.817***	0.71	0.71	0.55
	- Collaborative	0.787***			
	- Non-attendance	0.784***			

Source: Research findings (***, **, * statistically significant at the 1, 5, 10 percent level, respectively)

In the third step, the convergence validity of latent variables is evaluated using average variance extracted (AVE), the results of which are presented in the last column of Table 3. Based on this, considering that this index is greater than 0.5, it can be said that there is a high correlation between the latent variable and the observed variables.

Structural model results

The second step of structural modeling is assessing the structural model. In other words, after confirming the measurement model using the CCA method, the structural model is examined based on the following steps:

In the first step, the collinearity of the latent variables of the structural model is evaluated. For this purpose, VIF values were used, the

results of which are shown in Table 4. As can be seen, these values are less than 3 and there is no multicollinearity problem in the structural model.In the second step, in order to evaluate the hypothetical relationships between the latent variables, the size and significance of the path coefficients are checked. Based on the results of these values in Table 4, the variable production and marketing ownership is a good (positive) and significant predictor of the motivation to enter the international market. This means that the ability to own production and marketing increases the motivation of producers to enter the international market.

Based on the results of Table 4, the latent risk variable is a strong (negative) and significant predictor of production and marketing ownership and the motivation to enter the international market. It means that different risks reduce the willingness of producers to own the production and marketing of their products, as well as their motivation to enter the market. In addition, the risk variable is a good (positive) and significant predictor of the international market entry strategy. In such a way that the existence of different risks increases entering the market through cooperative and indirect methods. The variable of motivation to enter the international market is another variable that is a strong (positive) and significant predictor of entering the international market strategy. In other words, producers are motivated to use cooperative and indirect strategies to enter the international market of organic products. Therefore, from 6 hypotheses considered in the study, 5 hypotheses are confirmed.

Table 4- Structural model result

Hypothesis	Path	Path coefficient	P-value	Inner VIF	Effect size f^2
1	Production and marketing ownership Motivation to enter the ⟶ international market	0.59	0.00	1.22	0.78
2	Risk⟶ Production and marketing ownership	-0.43	0.00	1.00	0.22
3	Risk ⟶Motivation to enter the international market	-0.33	0.00	1.22	0.24
4	Production and marketing ownership⟶International market entry strategy	0.20	0.09	2.18	0.15
5	Risk ⟶ International market entry strategy	0.53	0.00	1.52	0.71
6	Motivation to enter the international market ⟶ International market entry strategy	0.29	0.00	2.72	0.21

Source: Research findings

In the third step, the predictive ability of the structural model is examined. For this purpose, the f2 effect size index, which is an estimate of the model's prediction ability or the size of the effect of one latent variable on another latent variable, has been used. The values of this index are reported in Table 4. Since values between 0.15 and 0.35 and values of 0.35 and above show moderate and high predictive power or effect size, respectively (Cohen, 1988), it can be said that predictive power and effect Two models 1 and 5 are high and the rest are average. In other words, the effect of production and marketing ownership on the motivation to enter the international market, as well as the effect of risk on international market entry strategy is high and the rest is medium.

Conclusions and Suggestions

Increasing concern of consumers about the quality and safety of agricultural and food products around the world has caused them to

tend to organic products and food as an alternative to conventional agricultural products and foods. The increase in trend and consumption of organic products has caused the growth of the market of these products, so that the global sales of organic food and beverages have grown about 9 times in the last two decades. Therefore, different countries are trying to enter this market and gain a share of it. Iran also produces major export products such as saffron, pistachios and raisins organically, and it is necessary to adopt a suitable strategy to enter the international market of organic products. Due to the importance of this issue, this study has investigated the influencing factors on the strategy of entering saffron, pistachio and raisin products into the international market of organic products and determining appropriate strategies. For this purpose, the factors affecting the strategy of entering the international organic market were analyzed and investigated in a new category under the three factors of motivation to enter the market, international market risk, and production and marketing ownership or control. The data of the study was collected through available sampling method and interviews with about 90 producers of these products in Khorasan Razavi province.

In order to achieve the aim of this study, structural equation modeling was used. In this study, unlike most studies in the field of structural equation modeling, a formative-reflective measurement model was employed in the initial stage of modeling. In other words, to explore the relationship between observed variables and latent variables, both reflective and formative measurement models were utilized. This approach was adopted because some latent variables are the cause of the observed variables, while others are the result. In other words, the latent variable of the International market entry strategy is the cause of the observed variables, including the indirect, collaborative and non-attendance strategy, and it is the opposite for the latent variables of risk, production and marketing ownership, and the motivation to enter the international market. It means that the observed variables include sanctions, administrative corruption, differences in economic structure, labor laws, demand, competitors' activities, and variation in prices of competing products are the cause of the risk variable. The variables of technical knowledge, marketing skills, competition intensity, market size, market growth, and language difference are the cause of the variable production and marketing ownership, and the variables of gain profit, management experience, market opportunity, excess production over demand, close to customers and the existence of foreign orders are the cause for the variable motivation to enter the international market. Therefore, due to the presence of two types of measurement models in the study, the analysis of the results was slightly different from the studies based on a reflective measurement model.

The results of the formative measurement model showed that the model has good convergent validity based on redundancy analysis. The collinearity evaluation of the observed variables through the VIF index indicates that there is no multicollinearity problem in the formative measurement model. The relative contribution of each of the formative observed variables in the formation of the latent variables indicates that among the formative observed variables that form the latent variables, gain profit, sanctions and technical knowledge have the largest share in the formation of the motivation to enter the international market, risk and production and marketing ownership, respectively. In evaluating the absolute share of the observed variables in the formation of latent variables, gain profit, sanctions and marketing skills have the largest share in the formation of the latent variables of motivation to enter the international market, risk and production and marketing ownership, respectively. In essence, the primary factor shaping the motivation to enter the international market of organic products is the profit gained by producers. The predominant factor influencing risk is the sanctions imposed on the country, while the principal factor shaping production and marketing ownership is technical knowledge

relative to marketing skills in absolute terms. The results of the reflective measurement model indicate that based on outer loadings, the observed variables, including indirect, collaborative and non-attendance strategies, well reflect the latent variable of the international market entry strategies and they have the accuracy required for measuring the latent variable of the international market entry strategy. Validation of the latent variable using Cronbach's alpha coefficient and composite reliability coefficient also confirms the appropriate validity of the measurement model under investigation and the latent variable of the international market entry strategy. In addition, the convergence validity of the latent variables using the average variance extracted (AVE) showed that there is a high correlation between the latent variable of the international market entry strategies and the observed variables.

The results of the second step of structural modeling, which is the examination of the structural model using the CCA method, show that there is no internal collinearity problem of the latent variables of the structural model. The evaluation of hypothetical relationships between latent variables, size and significance of path coefficients also showed that 5 of the hypotheses of the study are confirmed. So that the variable of production and marketing ownership has the biggest effect on the motivation of producers to enter the international market. In fact, the ability to own the production and marketing of agricultural products increases the power of producers and increases their motivation to enter the international markets of these products. This result is in line with the findings of Ahsan *et al.* (2020)'s study (Ahsan *et al.*, 2020). Based on this, it is suggested that institutions such as the Ministry of Jihad Agriculture hold training programs to increase the ability of producers in the field of organic product production and marketing. In addition, risk reduces production and marketing ownership and the motivation to enter the international market. It means that different risks reduce the ability of producers to own the production and marketing of their products and the motivation to enter the market. In other words, despite the various risks in international markets, producers have problems in having full ownership of their production and marketing operations, and with a sense of risk, their motivation to enter the international market decreases. The findings of Tang & Buckley, (2020) also confirm this influence. On the other hand, the positive effect of risk on the international market entry strategy indicates that the presence of various risks increases the strategy of entering the market through cooperative and indirect methods, and in other words, direct entry strategies. This finding is in line with the findings of Aguzzoli *et al.* (2021). Therefore, for the direct presence of organic producers in international markets, the government should try to eliminate or reduce some risk factors such as sanctions.

Finally, the positive effect of the variable of motivation to enter the international market on the strategy of entering the international market of organic products shows that the tendency of producers is to use cooperative and indirect strategies to enter this market. The results of Zekiri's study Zekiri (2016) and Nisar *et al.* (2012) also confirm this finding. Based on the results, the hypothesis of the effect of production and marketing ownership variable on the strategy of entering the international market was rejected. Although this means that the production and marketing ownership does not have a significant effect on the strategy of entering the international market, but this variable indirectly has a positive effect on the international market entry strategies through a strong effect on the motivation to enter the international market and indirectly increases the international market entry strategy through cooperative and indirect methods.

From all the hypotheses of the study, it can be concluded that due to the positive and significant direct effect of risk and the motivation to enter the international market on the international market entry strategy, as well as the positive and significant indirect effect of production and marketing ownership on the international organic products market entry strategy, the best strategy to enter the

international market of organic products is indirect, cooperative and non-attendance strategies such as indirect export, contract production and joint investment.

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بررسی راهبرد مناسب ورود به بازار بین‌المللی محصولات کشاورزی ارگانیک

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چکیده

افزایش نگرانی مصرف‌کنندگان از کیفیت و ایمنی محصولات کشاورزی در سراسر جهان سبب شده است تا محصولات ارگانیک به یکی از محبوب‌ترین گزینه‌های مصرف سالم و پایدار تبدیل شوند. گرایش و مصرف روزافزون محصولات کشاورزی ارگانیک، رشد فزاینده بازار این محصولات را در دو دهه اخیر به همراه داشته است. به دلیل اهمیت ورود و کسب سهمی از این بازار رو به رشد، این مطالعه به بررسی عوامل مؤثر بر راهبرد ورود به بازار بین‌المللی محصولات ارگانیک و تعیین راهبرد مناسب برای ورود به آن با استفاده مدل‌سازی معادلات ساختاری می‌پردازد. داده‌های این مطالعه با جمع‌آوری ۹۰ پرسشنامه از تولیدکنندگان محصولات زعفران، پسته و کشمش ارگانیک در سال ۱۴۰۰ با روش نمونه‌گیری در دسترس در استان خراسان رضوی به‌دست آمده است. نتایج به‌دست آمده حاکی از آن است که متغیرهای ریسک و انگیزه ورود به بازار بین‌المللی به طور مستقیم و متغیر مالکیت بر تولید و بازاریابی به‌طور غیرمستقیم و از طریق اثرگذاری بر انگیزه ورود به بازار بین‌المللی، بر راهبرد ورود به بازار بین‌المللی اثر مثبت و معنادار دارند. ضمن این‌که ریسک اثر کاهنده و معنادار بر انگیزه ورود به بازار بین‌المللی محصولات ارگانیک دارد. بر این اساس، راهبرد مناسب برای ورود به بازار بین‌المللی محصولات ارگانیک، راهبردهای غیرمستقیم، مشارکتی و غیرحضوری مانند صادرات غیرمستقیم، تولید قراردادی و سرمایه‌گذاری مشترک به‌دست آمد. از این‌رو، پیشنهاد می‌شود دولت برای حضور مستقیم تولیدکنندگان محصولات ارگانیک در بازارهای بین‌المللی، ریسک‌های ناشی از تحریم و موانع انگیزه‌ای برای ورود به بازار را رفع نموده یا کاهش دهد.

واژه‌های کلیدی: انگیزه، ریسک، مالکیت بر تولید و بازاریابی، محصولات ارگانیک، ورود به بازار

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The Potential Effects of Developing Different Marketing Channels on Waste Reduction in the Leafy Vegetable Supply Chain in Kermanshah Province

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Abstract

Every year, approximately one-third of the total food produced for human consumption is lost or wasted due to various reasons. This level of wastage has substantial adverse impacts on the environment, economy, and society. Numerous studies have proposed various policies to address the issue of food waste, such as incorporating technology into existing supply chains. However, concerns about their effectiveness and unintended consequences have led researchers to emphasize market-based approaches for waste reduction. The present study was carried out to estimate waste and investigate the potential for developing different marketing channels as market-based approaches to reduce waste in the leafy vegetable supply chain in Kermanshah province. To achieve this purpose, a system dynamics modelling of the waste system in the leafy vegetable supply chain was developed by using the literature review and interviews with experts and stakeholders. The tool for collecting research data was a questionnaire. The statistical population of this study is two groups including 22 experts and 728 actors in the leafy vegetable supply chain. Based on the findings, around 31,000 tonnes (39%) of leafy vegetables are wasted annually across the supply chain. The research scenarios indicate that the establishment of processing industries will effectively decrease the overall waste of leafy vegetables from around 31,000 tons to approximately 20,000 tons annually. Therefore, government initiatives and policies in the field of leafy vegetable exchange in the study area must focus on supporting businesses associated with leafy vegetable processing industries and establishing infrastructure prerequisites for these industries.

Keywords: Food chain, Food waste, Leafy vegetables, Marketing channels, System dynamics modeling

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Introduction

A considerable quantity of fresh agricultural products, specifically fruits and vegetables, is annually lost or wasted across different operational channels and levels of the supply chain (Anand & Barua, 2022). This wastage has major economic, environmental, and societal consequences resulting from the inefficient utilization of resources, e.g. land, water, energy, and labor (Ganesh *et al.*, 2022; Parsafar *et al.*, 2023). For instance, the inefficient utilization and wastage of agricultural products at the farm level result in increased expenses and decreased revenue for farmers (Lipinski *et al.*, 2013). Similarly, at the household level, the disposal of food leads to higher expenditures for consumers per unit of food purchased (Latka *et al.*, 2022). Moreover, food waste is one of the most important contributors to greenhouse gas emissions (Amicarelli *et al.*, 2021). Despite ongoing endeavors to accurately measure and implement efficient strategies to mitigate food waste, a comprehensive assessment of the current literature in this area reveals persistent gaps and limitations. The lack of comprehensive global data on food waste, along with restricted geographical coverage, poses challenges in establishing a baseline for tracking progress towards the Sustainable Development Goals. Therefore, there is a pressing requirement for additional studies into the magnitude of food waste and the implementation of effective mitigation strategies, particularly in developing countries.

In Iran, a substantial portion of agricultural products goes to waste each year for various reasons across the supply chain (Nakouzi, 2017). According to the Food and Agriculture Organization of the United Nations (FAO), approximately 35 million tons of agricultural products are discarded annually in Iran, accounting for 2.7% of global food waste (FinancialTribune, 2017). Vegetables are identified as a significant contributor to food waste in Iran, alongside bread, fruit, and rice (FinancialTribune, 2017). Among these vegetables, leafy vegetables have been found to have particularly high waste rates (Moradi *et al.*, 2023). The primary obstacle in the supply chains of these products is ensuring their freshness from the time they are harvested until they reach the end customer (Kumar & Agrawal, 2023; Mohan *et al.*, 2023). The supply chain can be defined as a complex network of activities, individuals, organizations, information, and resources that work together to ensure the efficient delivery of goods from the initial production stages to the end customer (Van der Vorst *et al.*, 2007). As a result, any challenges or inefficiencies within the supply chain cause a substantial portion of these products to be withdrawn from the consumption chain (Parsafar *et al.*, 2023). Studies indicate that in Kermanshah province, a considerable amount of leafy vegetable production is wasted each year across the supply chain (Moradi *et al.*, 2023). This wastage can be attributed to various factors such as the perishable nature of these products, production challenges, inadequate marketing infrastructure, and improper consumer food consumption management (Abadi *et al.*, 2021; Moradi *et al.*, 2023). In recent years, extensive literature has focused on various strategies to address food waste in the supply chain. These strategies include the implementation of technical solutions at different stages of the supply chain (Gardas *et al.*, 2017; Kör *et al.*, 2022; Magalhães *et al.*, 2022). However, concerns about the effectiveness and potential unintended consequences of these approaches have prompted researchers to highlight the importance of market-based approaches to tackle food waste (Adebola, 2020; Aramyan *et al.*, 2016). The marketing channels that are used have a considerable impact on the waste generated within the agricultural product supply chain. Hence, recognizing the potential of these channels as a form of market-based approach can be effective in guiding the decisions of policymakers and relevant planners to implement appropriate policies and measures to reduce waste. Given the significance of the topic, this study employed system dynamics modelling to quantify waste

and assess the potential of different marketing channels in minimizing waste within the leafy vegetable supply chain in Kermanshah province. System dynamics is a powerful methodology for accurately representing real-world events, which enables the evaluation of different policies on the overall performance of the system over time (Forrester, 1992). The utilization of system dynamics modelling by assessing the interdependencies among various variables within the leafy vegetable waste system provides a comprehensive overview of the efficacy of the suggested waste reduction initiatives. This study seeks to answer questions on what is the exact structure and process of the leafy vegetable supply chain in Kermanshah province, how much waste is annually generated within the leafy vegetable supply chain in Kermanshah province, what will be the projected trend of waste in the leafy vegetable supply chain in the upcoming years, and what impact will the development of different marketing channels have on the overall waste amount in the leafy vegetable supply chain?

Materials and Methods

The geographical area under investigation is Kermanshah province in the west of Iran (Fig. 1). This study specifically concentrated on leafy vegetables within the category of fruits and vegetables. Leafy vegetables hold significant dietary value for Iranians as staple food items, commonly consumed in cooked dishes and desserts. Leafy vegetables encompass various green edible plants, including celery, spinach, leek, watercress, mint, parsley, coriander, etc. In this research, the inclusion of lettuce and cabbage was omitted due to the distinct marketing and sales characteristics of these products compared to other leafy vegetables, as well as the difficulty in monitoring their waste. This study does not differentiate between the terms "food waste" and "food loss" and examines waste within the leafy vegetable supply chain from farm to table. Consequently, the term "leafy vegetable waste" is used broadly in this study to encompass those portions of the products intended for human consumption but are discarded from the supply chain for various reasons (FAO, 2014; Parfitt *et al*., 2010).

Sampling method

The statistical population consisted of two categories. The first category comprised national and regional subject matter experts, such as university faculty members, researchers from the Horticulture Research Center, and agricultural experts and managers in Kermanshah province. Additionally, a group of individuals with relevant executive experience were included. This group played a role in ensuring the quality of the questionnaire, identifying the structure and process of the leafy vegetable supply chain, and validating the model and its results. The total number of studied samples in this section was 22 participants who were selected purposefully. The second category focused on stakeholders involved in various sectors of the supply chain, such as farmers, wholesalers and retailers, processing units, and final consumers in Kermanshah province. The data collected from this group was utilized to simulate the research model. In the farmers and households sections, samples were selected in a stratified sampling with proportional assignment, following Cochran's formula to determine the sample size. For the other groups, a full count was conducted. A total of 728 samples were chosen and analyzed, consisting of 172 farmers, 83 wholesalers and retailers, 16 processing units, 384 households, and 73 food services. Furthermore, population data and future trends were calculated based on United Nations (UN) forecasts for Iran's population in the upcoming years (UN, 2018).

Analytical process and method

Identifying research variables and the structure of their interactions

Initially, studying the literature and the opinions of experts and actors using the focus group discussion technique, the structure, and procedure of the leafy vegetable supply chain were compiled.

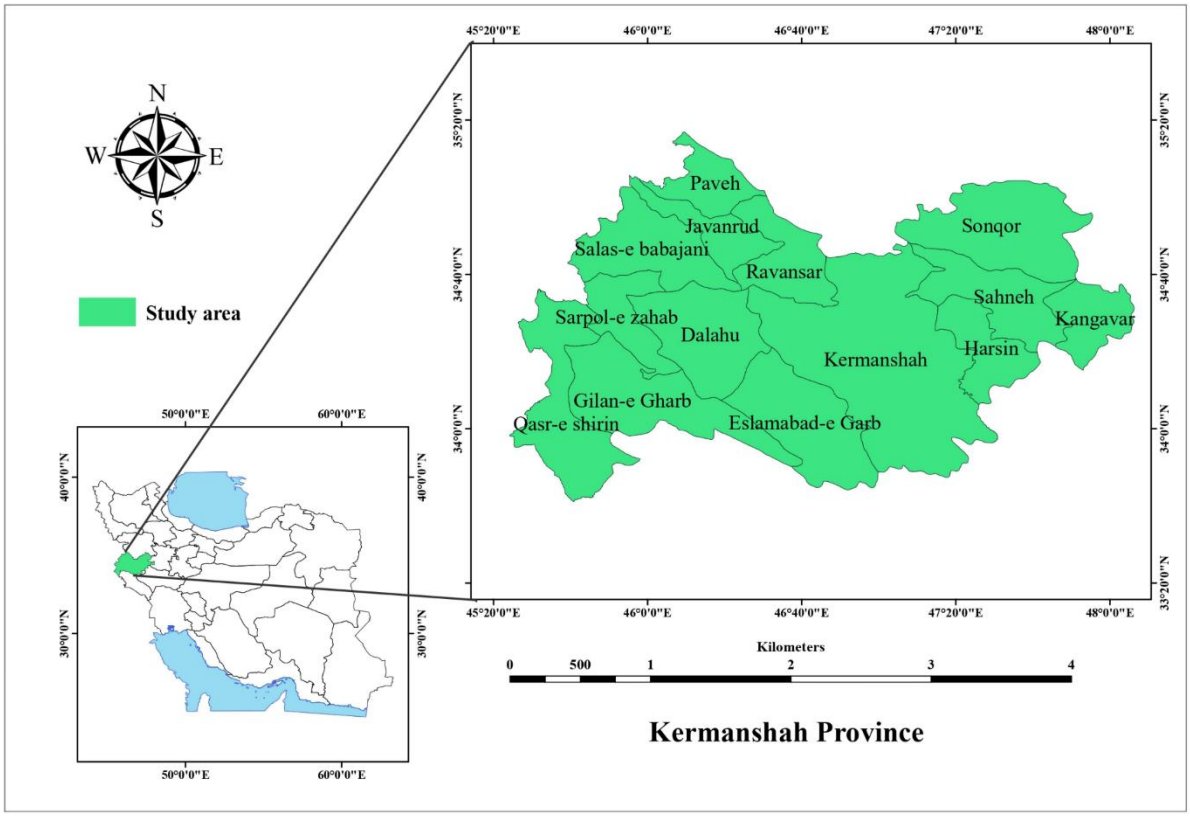

Figure 1– A map of the study area

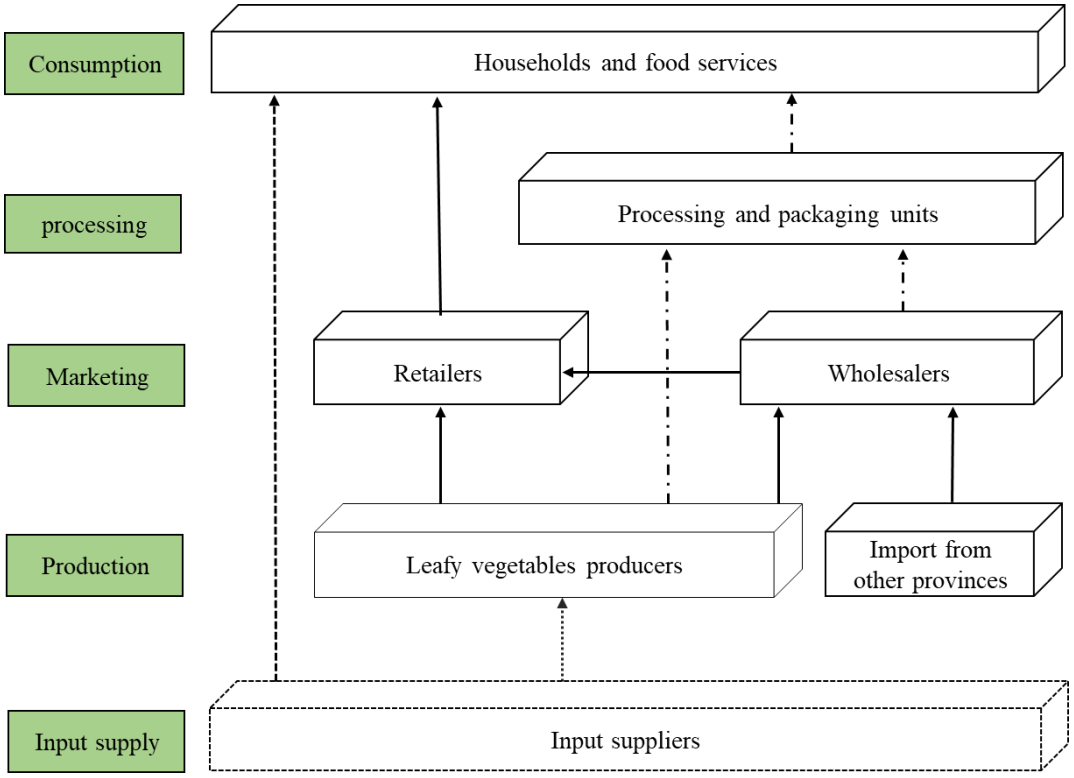

Figure 2- Leafy vegetable supply chain in Kermanshah province

Leafy vegetable supply chain

In the case of Kermanshah province, the leafy vegetable supply chain can be categorized into five main groups: suppliers, producers (farmers), marketing and distribution (retailers and wholesalers), processing industries, and consumers (food services and households) (Fig. 2).

Marketing channels

Marketing channels refer to the methods through which farmers supply their products to consumers. In Kermanshah province, leafy vegetable farmers utilize a variety of marketing strategies to successfully reach their target customers. One common method is direct marketing, wherein farmers sell their produce directly to customers through stalls and stores located within the fields or along roadsides. The second approach involves the traditional system of distributing agricultural products to consumers. In this marketing strategy, fresh leafy vegetables are provided to consumers through various markets, including wholesale and retail stores. The third approach entails processing and preparing leafy vegetables in specialized facilities and subsequently distributing them to customers. In this marketing strategy, a portion of the leafy vegetables is transformed into frozen products, while the rest is packaged and delivered fresh to consumers. It is important to note that during the winter season when severe weather conditions restrict local production, a portion of the leafy vegetables required in the study area are supplied from other provinces and subsequently distributed in the market (Fig. 3).

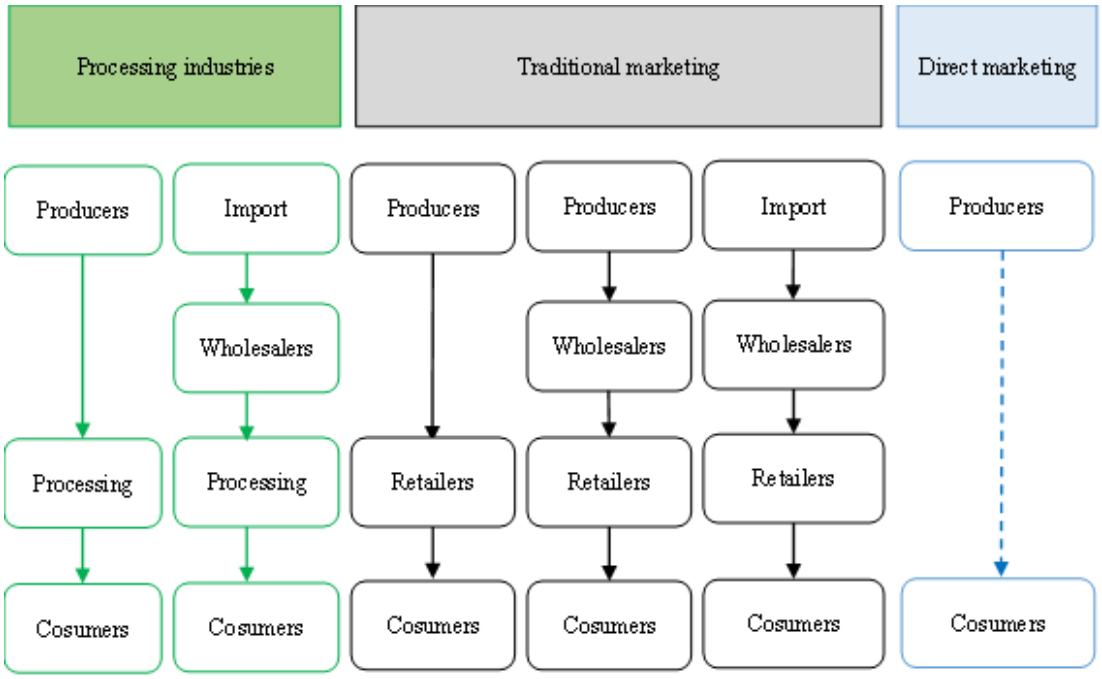

Figure 3- Leafy vegetable marketing channels in Kermanshah province

System dynamics modeling of waste within the leafy vegetable supply chain

After identifying the research variables and their relationship structure, the waste system within the leafy vegetable supply chain was modelled using the system dynamics modelling. To develop the waste system in the leafy vegetable supply chain in Kermanshah province, the following steps were followed:

Problem Statement

The first stage in system dynamics

modelling involves defining the structure and extent of the research problem (Sterman, 2000). In socioeconomic research, the boundaries of a system are defined by two key factors: 1) the research purpose, and 2) the importance and effect of various factors on the elements within the boundaries of the system.

Designing a conceptual model

After formulating the research problem and defining the boundaries of the system, the next step is to create a conceptual model. Fig. 4 provides a structured overview of the variables and their key component interactions for testing the research hypotheses.

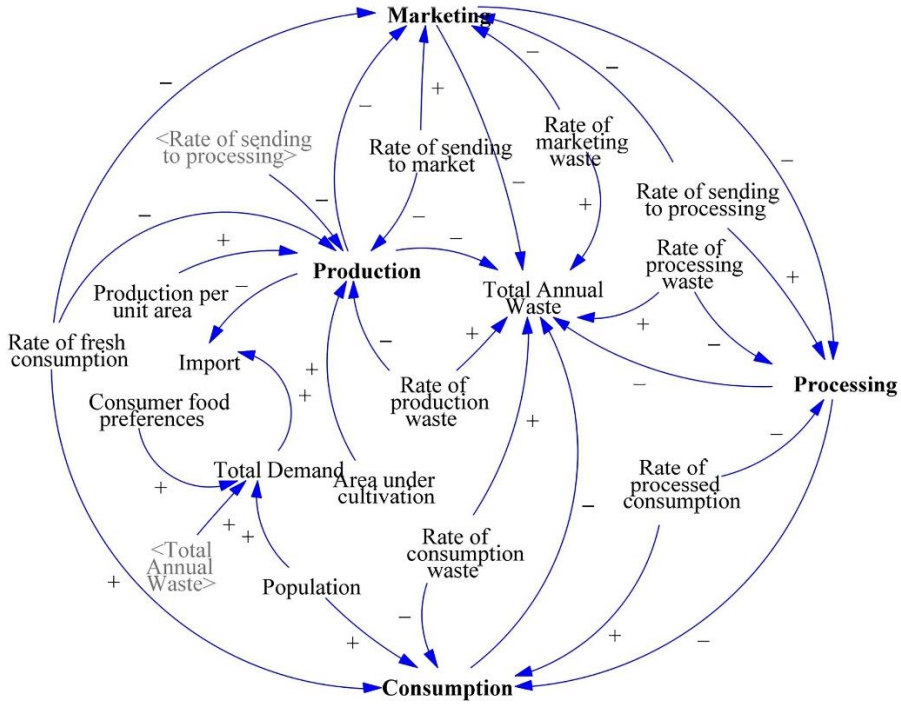

Figure 4- Causal loops diagram of a waste system within the leafy vegetable supply chain

Formulation of the simulation model

To simulate the results of the model, the causal loop diagram is required to be converted into a stock and flow diagram. This part encompasses specifications of the system structure, parameter estimations, model interactions, and initial values (Fig. 5 and Table 1).

The ultimate model created comprises multiple sub-models, which are detailed as follows:

1) Estimating the total demand for leafy vegetables

The total demand for leafy vegetables in this study was estimated by considering the population of the province, the per capita consumption of leafy vegetables, and the total annual waste across the supply chain. This model acknowledges that a portion of the demand for leafy vegetables in Kermanshah province is met through local production, while during the colder seasons of the year, another portion is sourced through imports from other provinces (Equation 1).

$$Total\ demand = (Po \times PLVC) + TAW \quad (1)$$

Where; Po is the population of the province, PLVC is the per capita consumption of leafy vegetables, and TAW is the amount of total annual waste.

2) Production subsystem modelling

Cumulative production indicates the overall volume of leafy vegetables during the production stage over a year (Equation 2).

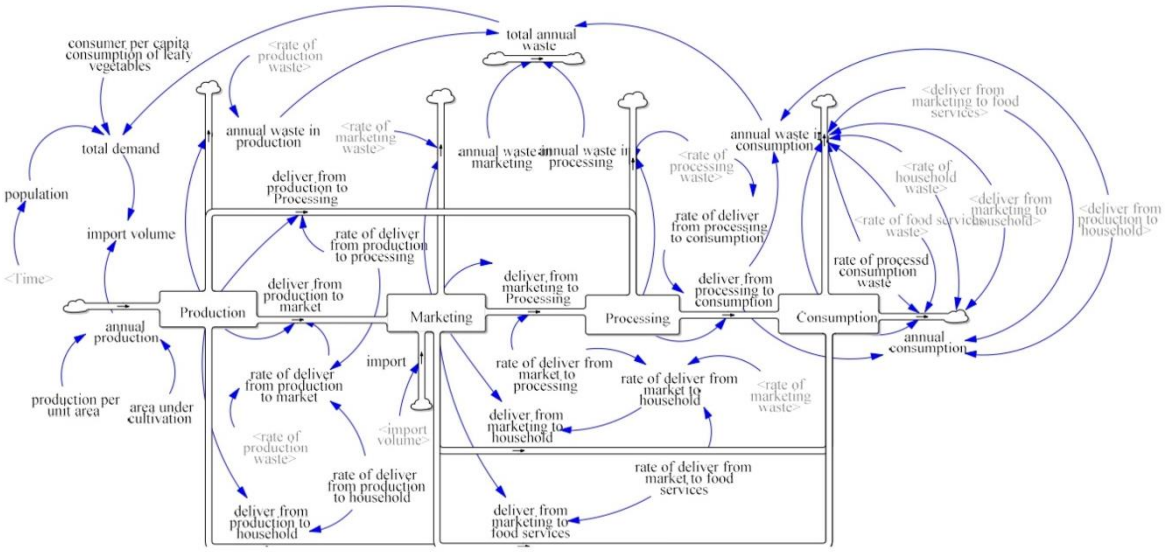

Figure 5– Stock and flow diagram of waste system in Leafy vegetable supply chain

Table 1- Initial values of research variables

Subsystems	Flows	Variables		Symbol	Value	Units
Demand subsystem	-	Population		Po	2.070	Person
	-	Per capita leafy vegetable consumption		PLVC	24	kg
Production subsystem	Input flows	Annual production of leafy vegetables		AP	52000000	kg/year
	Output flows	Deliver from production to household		DPH	25	%
		Deliver from production to processing		DPPro	4	%
		Deliver from production to market		DPM	47	%
		Annual waste in production		AWP	24	%
Marketing subsystem	Input flows	Import		I	28492000	kg/year
		Deliver from production to market		DPM	47	%
	Output flows	Deliver from market to household		DMH	84.5	%
		Deliver from market to processing		DMPro	1.5	%
		Deliver from market to food services		DMFS	3	%
		Annual waste in marketing		AWM	11	%
Processing subsystem	Input flows	Deliver from production to processing		DPPro	4	%
		Deliver from market to processing		DMPro	1.5	%
	Output flows	Deliver from processing to consumption		DProC	93.5	%
		Annual waste in processing		AWPro	6.5	%
Consumption subsystem	Input flows	Deliver from production to consumption		DPC	25	%
		Deliver from market to consumption		DMC	84.5	%
		Deliver from market to food services		DMFS	3	%
		Deliver from processing to consumption		DProC	93.5	%
	Output flows	Annual consumption		AC	48740000	kg/year
		Annual waste in consumption (AWC)	Annual waste in household	AHW	21	%
			Annual waste in food services	AWFS	18	%
			Annual waste of processed leafy vegetable	AWPC	5	%

Source: Research findings

$$Cumulative\ production = \int_{t_0}^{t} AP - (AWP + DPH + DPPro + DPM) \quad (2)$$

Where; AP is the annual production of leafy vegetables, AWP is the annual waste in production, DPH is delivered from production to household, DPPro is delivered from production to processing, and DPM is delivered from production to market.

3) Marketing subsystem modelling

Cumulative marketing quantifies the overall amount of leafy vegetables in the marketing stage over a year.

$$Cumulative\ marketing = \int_{t_0}^{t} (I + DPM) - (DMH + DMPro + AWM) \quad (3)$$

Where; I is the import, DPM is delivered from production to market, DMH is delivered from market to household, DMPro is delivered from market to processing, and AWM is the annual waste in marketing.

4) Processing subsystem modelling

Cumulative processing integrates the input and output flow of leafy vegetables in the processing stage over one year (Equation 4).

$$Cumulative\ processing = \int_{t_0}^{t} (DPPro + DMPro) - (DProC + AWPro) \quad (4)$$

Where; DPPro is delivered from production to processing, DMPro is delivered from market to processing, DProC is delivered from processing to consumption, and AWPro is the annual waste in processing.

5) Consumption subsystem modelling

Cumulative consumption indicates the total amount of leafy vegetable consumption over one year, including household and food services (Equation 5).

$$Cumulative\ consumption = \int_{t_0}^{t} (DPC + DMC + DMFS + DProC) - (AC + AWC) \quad (5)$$

Where; DPC is delivered from production to consumption, DMC is delivered from market to consumption, DMFS is delivered from market to food services, DProC is delivered from processing to consumption, AC is the annual consumption, and AWC is the annual waste in consumption.

6) Waste estimation modelling in the supply chain

The total waste of leafy vegetables was estimated by considering the cumulative waste generated at various stages of the supply chain, including production, market, processing, and consumption (Equation 6).

$$TAW = AWP + AWM + AWPro + AWC \quad (6)$$

Where; TAW is the amount of total annual waste, AWP is the annual waste in production, AWM is the annual waste in marketing, AWPro is the annual waste in processing, and AWC is the annual waste in consumption.

After developing and formulating the model simulation, the parameters were estimated using Vensim (Version 9.0) software.

Scenario Development

We defined four scenarios to address which marketing channel development can play a more impactful role in minimizing waste within the leafy vegetable supply chain. These scenarios are maintaining the current condition, development of processing industries, development of direct marketing, and development of traditional marketing. At this stage, by directing the flow of distribution of leafy vegetables in each of the marketing channels, their potential to reduce the amount of waste in the supply chain of leafy vegetables was documented. Policy scenarios were

simulated based on the conditions in Table 2.

Table 2– Model variable values in four different scenarios

Variables	Baseline	Development of direct marketing	Development of traditional marketing	Development of processing industries
Deliver from production to household	25	76	0	0
Deliver from production to processing	4	0	0	76
Deliver from production to market	47	0	76	0
Deliver from market to household	84.5	84.5	86	0
Deliver from market to processing	1.5	1.5	0	89
Deliver from market to food services	3	3	3	0

Source: Research findings

Assessment of model validity

The validation of a system dynamics model is a crucial step in ensuring its accuracy and reliability. Thus, initially, the results of evaluating the validity and accuracy of the model are presented. Fig. 6 presents the results of sensitivity analysis for the four main variables of the study based on four different ranges of changes (50%, 75%, 95%, and 100%). Based on these findings, it can be concluded that the outputs of the model are sensitive to the changes in its inputs, which indicates the reliability of the model.

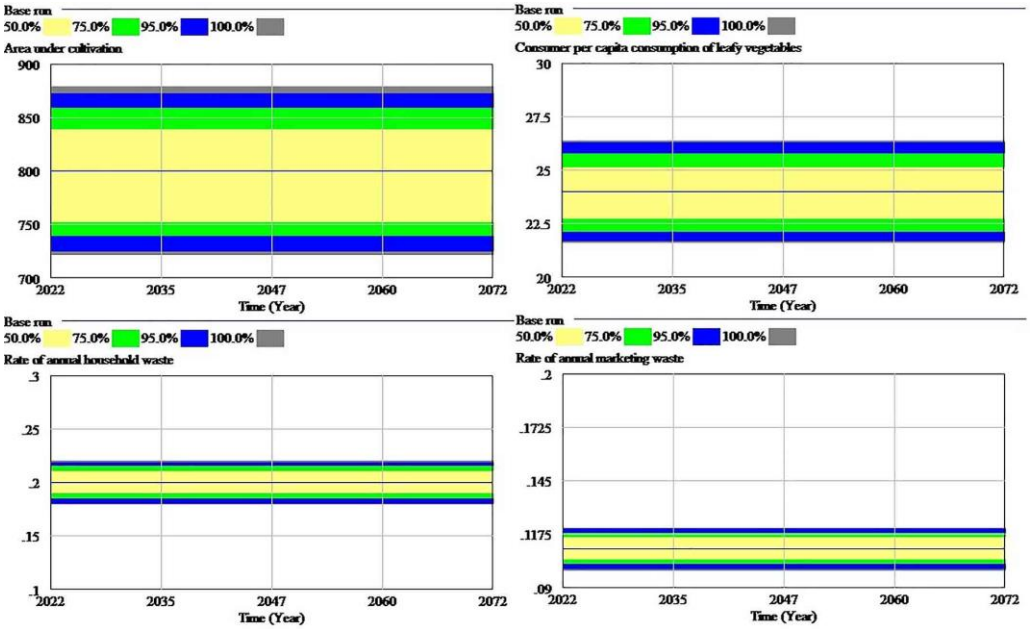

Figure 6– Confidence limits for four of the most important model variables

Results and Discussion

Scenario 1) Continuation of the current condition

Model estimates show that of the total annual demand of 80,000 tons for leafy vegetables, approximately 31,000 tons (around 39%) are wasted across the supply chain. The highest amount of waste occurs during

production, accounting for 12,500 tons (40.6%), followed by consumption with 12,300 tons (40.1%), and the market with 5,700 tons (18.7%) (Fig. 7 and Fig. 8). This finding is consistent with global trends and highlights the significant levels of waste during both the production and consumption stages in developing nations (UNEP, 2021).

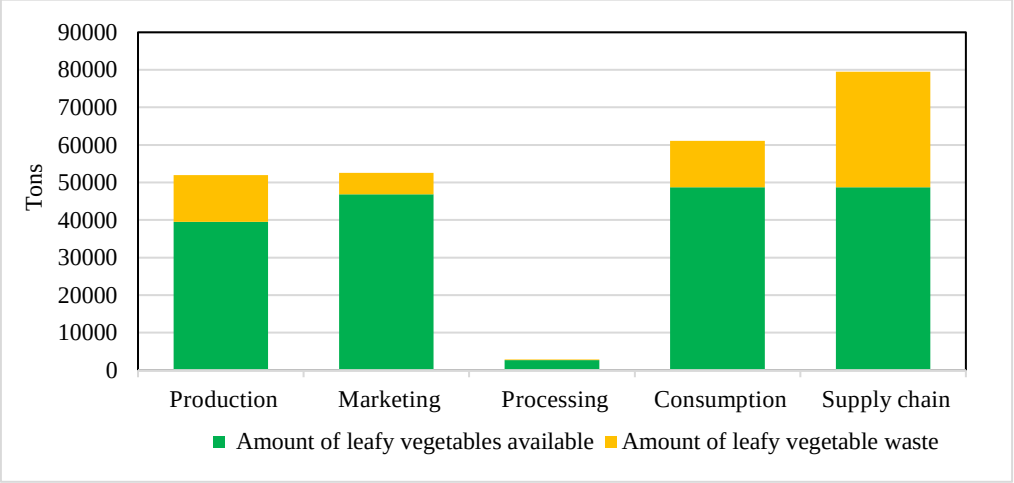

Figure 7- Amount of leafy vegetables available and waste in the leafy vegetable supply chain

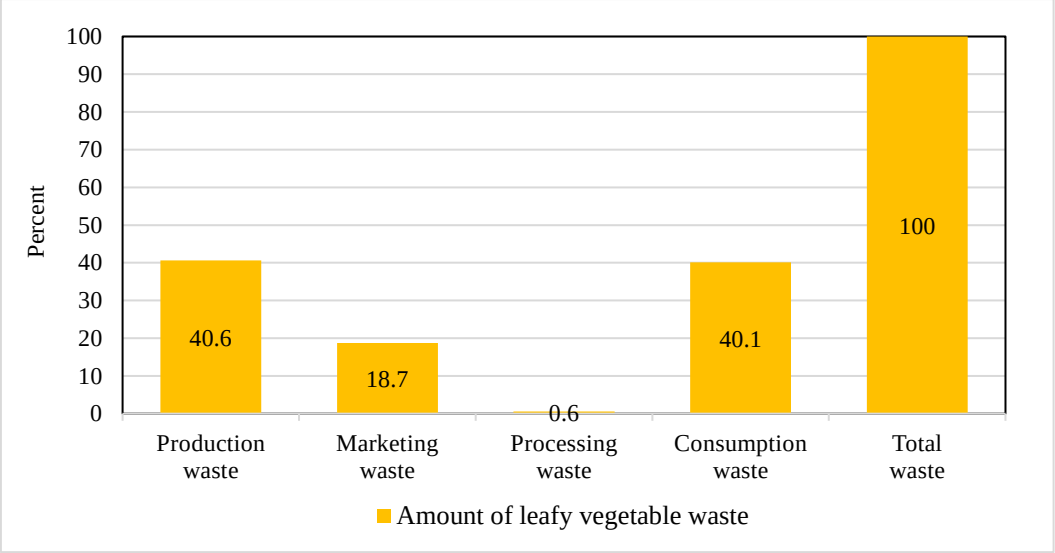

Figure 8- The proportion of waste generated in each stage of the leafy vegetable supply chain from the total waste

The leafy vegetable consumption sector encompasses fresh vegetables consumed by households, fresh vegetables consumed by food services, and processed vegetables consumed by both households and food services (Table 1 and Fig. 5). At the household level, approximately 57,000 tons of leafy vegetables are consumed, with 11,900 tons (21 percent) being wasted. In the food service sector, approximately 1,600 tons of fresh leafy vegetables are consumed each year, with 270 tons (18%) being wasted. Furthermore, approximately 2,700 tons of processed leafy vegetables are eaten in the consumer sector, with 130 tons (5%) ending up as waste (Fig. 9). Although the findings of this study align with the United Nations Environment Office report, which highlights a significant amount of food waste during the consumption stage in developing countries, a closer examination of

the data reveals a distinction between the quantity of leafy vegetable waste supplied to consumers in fresh form and that provided to households in processed form. Upon analyzing the causes of this difference, Moradi *et al.* (2023) have concluded that the primary reason for the disparity in leafy vegetable waste at the household level and food services in the studied area is the deterioration of fresh product quality across the supply chain. The high waste of fresh leafy vegetables at the household and food service level is primarily attributable to the poor quality of the product, rather than the behavioural patterns of consumers. This issue stems from unfavourable actions and decisions made by other actors in the supply chain (Moradi *et al.*, 2023; Siddiqui, 2018).

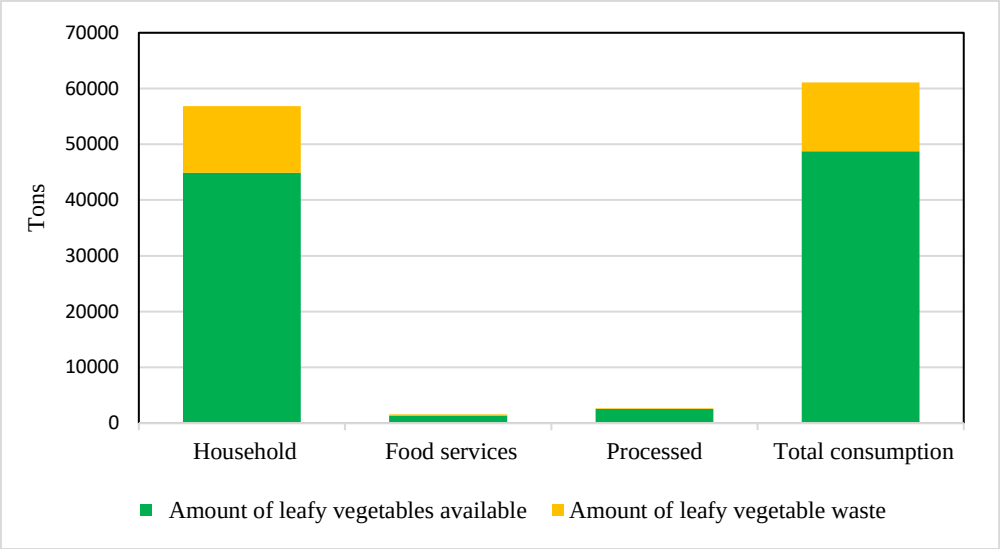

Figure 9- The amount of leafy vegetable waste in the consumption stage

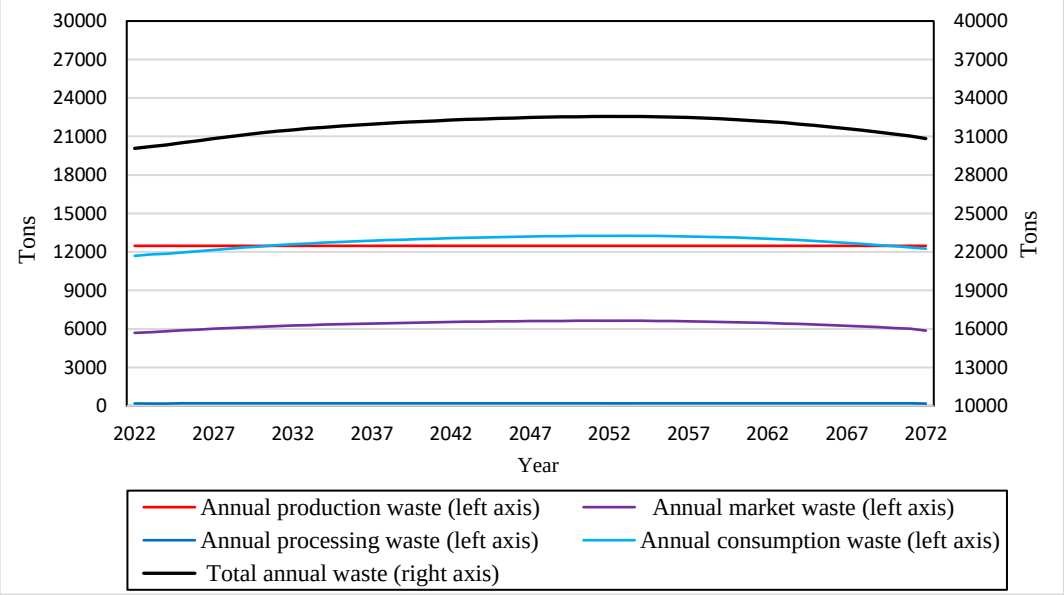

Figure 10- Waste estimation assuming the current trend continues

The simulation of the amounts of waste at different stages of the supply chain of leafy vegetables during the simulation period showed that the total annual waste of leafy vegetables is projected to increase initially and then decrease with the population growth trend (Fig. 10). This

trend indicates that the continuation of the current trend and lack of intervention to reduce the waste of leafy vegetables will have detrimental economic, social, and environmental consequences for supply chain actors and communities.

Scenario 2) Development of processing industries

Investigating the effects of the development of leafy vegetable processing industries on waste across the supply chain showed that implementing this scenario leads to an increase in waste during the processing stage while reducing marketing waste (Fig. 11 and Fig. 12). These changes occur as a result of an increased volume of leafy vegetables being processed and the elimination of marketing activities for fresh leafy vegetables in wholesale and retail stores. In addition, the effect of this scenario on waste during the consumption stage was significantly greater compared to the base scenario. According to this scenario, the amount of waste generated in the consumption stage will decrease from 12,300 tons to 3,200 tons (Fig. 13). This reduction can be attributed to several factors. Firstly, the waste generated from processed leafy vegetables is significantly lower compared to that from fresh vegetables. Secondly, the development of processed products leads to a decrease in the consumption of fresh leafy vegetables at the household level. As a result, the amount of low-quality leafy vegetables and discarded parts, such as stems, decreases (Moradi *et al.*, 2023). Thirdly, processing units are generally less affected by the poor quality of purchased leafy vegetables compared to households. Consequently, a significant portion of leafy vegetables that were previously discarded at the household level now remains in the consumption chain. Although this study does endorse the strategy of fostering processing industries to minimize leafy vegetable waste, the limited quantity of processed leafy vegetables in the studied region implies that there are obstacles to establishing a successful leafy vegetable processing sector. These challenges can be analyzed from various perspectives. Firstly, extensive research has indicated that the majority of regions in Iran lack adequate infrastructure for the development of agricultural product processing industries (Khodayi Steyar *et al.*, 2018; Varmazyari *et al.*, 2016). The presence of an institutional gap and the absence of a clear strategy for the advancement of these industries are among the primary factors contributing to this problem (Varmazyari *et al.*, 2016). Secondly, the implementation of this approach necessitates substantial behavioural modifications from households and other stakeholders within the leafy vegetable supply chain. For instance, from the demand perspective, the establishment of leafy vegetable processing industries calls for a shift in consumer preferences toward purchasing processed and packaged products. In recent years, there has been growing concerns have been raised regarding the use of unconventional water in the cultivation of leafy vegetables and the lack of consumer confidence in compliance with health regulations in processing units. These challenges have significantly impacted the motivation of households to purchase processed leafy vegetables. Therefore, many individuals choose to directly purchase the leafy vegetables they require from local farmers. In addition, the implementation of this strategy necessitates substantial investment in cold chain infrastructure and facilities to support the distribution and marketing of processed products by market actors.

Scenario 3) Development of direct marketing

In scenario 3, it is assumed that all leafy vegetables produced in the studied area will be supplied directly to consumers through stalls and stores located within the fields and alongside the roads. It is important to note that in this scenario, leafy vegetables imported from other regions are still distributed through traditional marketing methods within the supply chain. The simulation results indicate that implementing this marketing approach in the studied area would result in a significant reduction of 3,000 tons of wasted leafy vegetables at the market stage, compared to the baseline scenario (Fig. 11). In line with the

results of this study, Kirci *et al.* (2022), concluded that direct marketing is effective in minimizing product spoilage by eliminating unnecessary intermediaries in the supply chain, especially for perishable products such as leafy vegetables. This approach also minimizes losses incurred from rejected products that fail to meet the standards set by wholesale and retail centers (Johnson *et al.*, 2019). Despite the benefits offered by the direct marketing approach in reducing waste, it is important to acknowledge that it cannot fully replace existing marketing systems due to seasonal limitations and limited access to all consumers (Priefer *et al.*, 2016). Furthermore, in this particular scenario, the decrease in processed vegetable consumption and the rise in fresh vegetable consumption may lead to a slight increase in waste at the consumer stage. Nevertheless, implementing the direct marketing approach could still lead to a significant reduction of approximately 2,500 tons of waste per year compared to the baseline scenario (Fig. 13).

Scenario 4) Development of traditional marketing

In scenario 3 direct marketing and processing industries will cease. Instead, the entire demand for leafy vegetables in the studied area will be met by providing fresh produce to consumers through intermediaries like wholesalers and retailers. The results indicate that implementing this scenario will lead to an increase in the total waste volume of leafy vegetables in the studied area by 2,000 tons per year (Fig. 14). The high volume of food loss and waste in traditional marketing channels is one of the challenges of the agricultural product supply chain in numerous countries, which has been extensively addressed in numerous studies (Anand & Barua, 2022; Kör *et al.*, 2022).

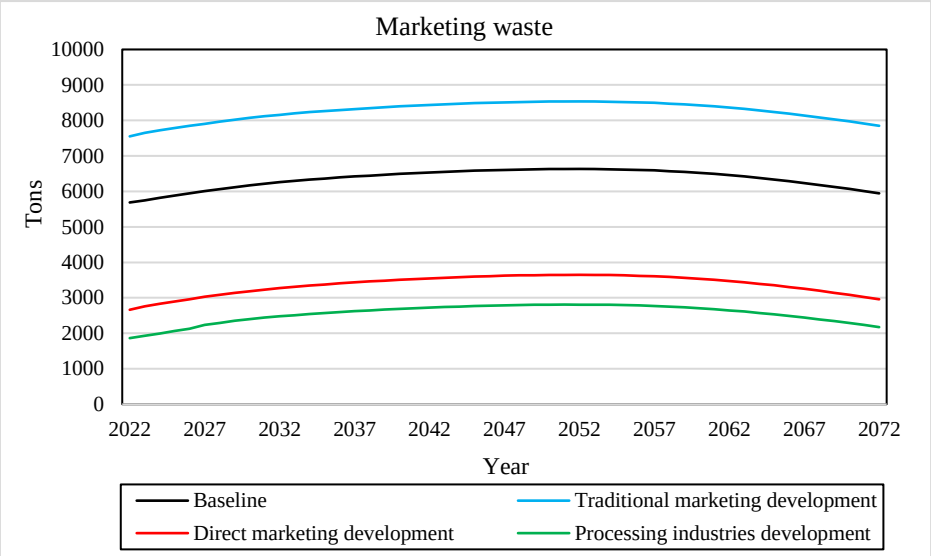

Figure 11- The effects of different scenarios on waste reduction in the market stage

Conclusion

The present study developed a system dynamics model for the waste system across the leafy vegetable supply chain in Kermanshah province to investigate the potential of different marketing channels in minimizing waste. The findings of estimating waste at various stages of the supply chain revealed that approximately 39% of the total volume of leafy vegetables, equivalent to 31,000 tons, in Kermanshah province, ends up as waste. These findings highlight the entry points where intervention and waste reduction strategies can be implemented effectively. This study examined the potential impact of three marketing channels (traditional marketing, direct marketing, and processing industries) on waste

reduction in the study area. The findings indicate that among these approaches, the development of processing industries shows the highest potential for reducing waste in leafy vegetables. By adopting this approach, it is possible to decrease total waste by a significant amount, approximately one-third or 10,000 tons per year. However, it's important to note that a single marketing channel alone may not be sufficient to meet the diverse demands of consumers due to varying interests. Nevertheless, given the effectiveness of processing industries in waste reduction, it is recommended that policy actions and measures in the studied area prioritize the development of leafy vegetable processing industries.

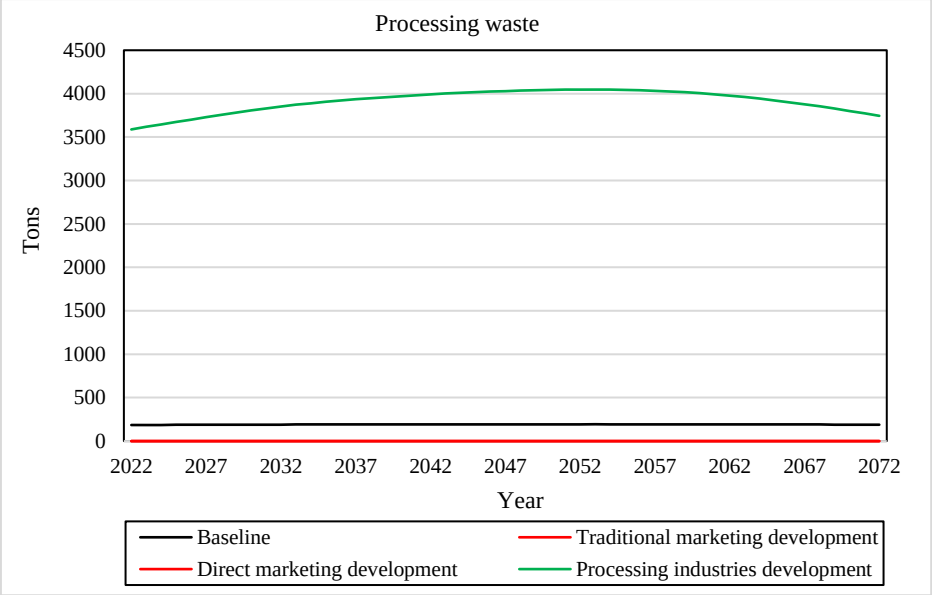

Figure 12- The effects of different scenarios on waste reduction in the processing stage

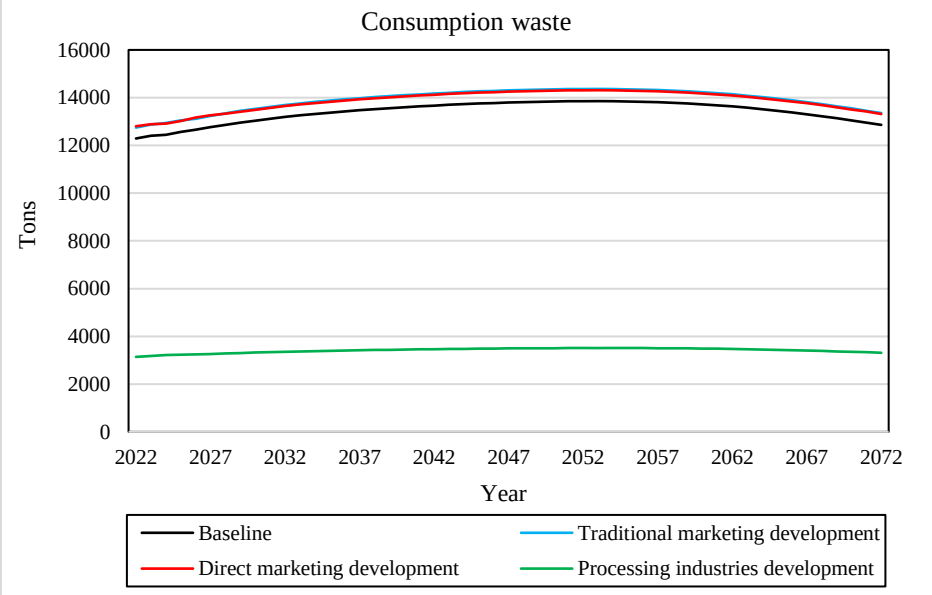

Figure 13- The effects of different scenarios on waste reduction in the Consumption stage

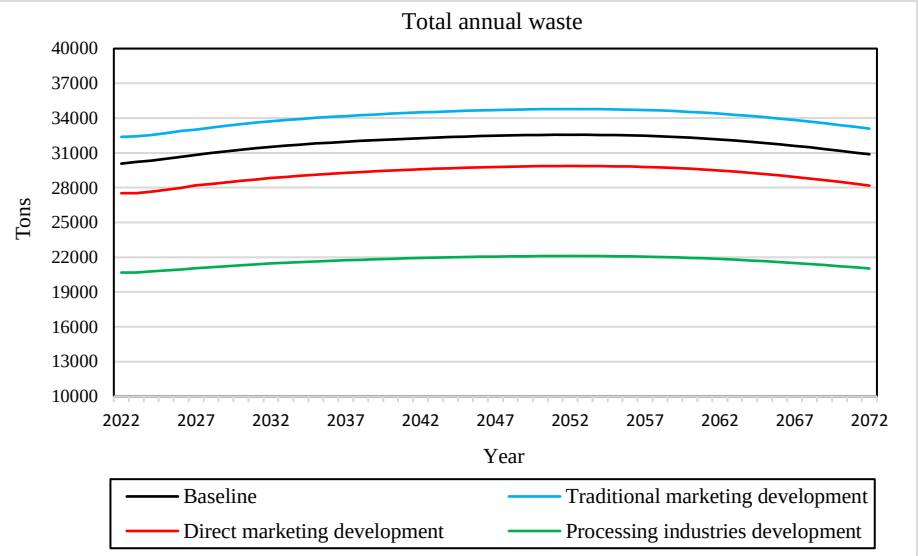

Figure 14- The effects of different scenarios on total waste

The following suggestions are proposed to develop leafy vegetable processing industries in the studied area:

- It is recommended that the governance structure, with the help of effective policy mechanisms and tools, establishes the framework for collaborative investments between private entities and the government to develop essential infrastructure for leafy vegetable processing industries. This infrastructure may include processing facilities, cold storage units, and specialized transportation networks. In addition, offering affordable facilities, subsidies, tax incentives, and facilitating the licensing process are key measures that can encourage entrepreneurs to invest in leafy vegetable processing facilities and infrastructure.
- One commonly used approach for the development of processing industries is contract farming. To successfully implement this production approach, it is recommended that the governance structure through the development of appropriate laws and regulations to manage relations between farmers and processing units provides the basis for farmers' participation in these projects. It is important to note that the establishment of processing units in rural areas and the ownership of farmers on these units while creating a connection between farmers and processing units, can maximize the benefits of the local community from the added value of leafy vegetable cultivation in the study area.
- To implement this approach, it is necessary to invest in and provide market actors with cold chain infrastructure and facilities. One possible strategy is to utilize the existing capacity of supermarkets or equip the existing retail sector with storage facilities specifically tailored for processed and frozen leafy vegetables.
- To facilitate the development of leafy vegetable processing industries, it is essential to implement market development strategies that encourage consumer consumption of processed products. Given that 70% of leafy vegetables are consumed in cooked form, there is a significant opportunity to promote the use of processed vegetables. Educating consumers about the advantages and value of processed products through consumer awareness campaigns, media outlets, and social networks can effectively stimulate their interest in purchasing such products.
- Given the increasing concerns among

consumers regarding health issues associated with processed products, it is imperative to establish robust regulatory frameworks that guarantee the quality and safety of these products across the supply chain. This entails implementing mechanisms to closely monitor the usage of water and other resources during the production process. Additionally, conducting routine health inspections in processing units is vital for upholding the safety standards of processed products.

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مقاله پژوهشی

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اثرات بالقوه توسعه کانال‌های مختلف بازاریابی بر کاهش ضایعات در زنجیره تأمین سبزیجات برگی در استان کرمانشاه

مصطفی مرادی [۱]- حسین شعبانعلی فمی [۲*]- علی‌اکبر براتی [۳]- رضا صالحی محمدی [٤]

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چکیده

سالانه تقریباً یک‌سوم کل مواد غذایی تولید شده برای مصرف انسان به دلایل مختلف به ضایعات تبدیل می‌شود. این میزان اتلاف پیامدهای منفی قابل‌توجهی بر محیط‌زیست، اقتصاد و جامعه دارد. مطالعات متعددی سیاست‌های مختلفی از جمله استفاده از راهکارهای فنی برای کاهش ضایعات مواد غذایی پیشنهاد کرده‌اند. با این حال، تردید در اثربخشی و پیامدهای ناخواسته اجرای این راهکارها موجب تأکید محققان بر رویکردها و مداخلات مبتنی بر بازار برای کاهش ضایعات شده است. بر این اساس، مطالعه حاضر با هدف برآورد ضایعات و بررسی پتانسیل‌های بالقوه توسعه کانال‌های مختلف بازاریابی به‌عنوان اشکالی از رویکردهای مبتنی بر بازار بر کاهش ضایعات در سراسر زنجیره تأمین سبزیجات برگی در استان کرمانشاه انجام شد. بدین منظور با استفاده از مرور ادبیات و مصاحبه با متخصصان و کنشگران کلیدی زنجیره تأمین یک مدل پویایی سیستم ضایعات در زنجیره تأمین سبزیجات برگی در استان کرمانشاه توسعه داده شد. ابزار جمع‌آوری داده‌های تحقیق پرسشنامه بود. جامعه آماری این مطالعه شامل دو گروه از متخصصان موضوعی و کنشگران زنجیره تأمین زنجیره تأمین سبزیجات برگی بود. در مجموع، ۲۲ متخصص و ۷۲۸ کنشگر از مراحل مختلف زنجیره تأمین مورد مطالعه قرار گرفتند. بر اساس نتایج، سالانه تقریباً ۳۱.۰۰۰ تن (۳۹ درصد) از تولیدات سبزیجات برگی در سراسر زنجیره تأمین به ضایعات تبدیل می‌شود. پیش‌بینی روند آینده ضایعات نیز نشان می‌دهد که در صورت تداوم وضعیت فعلی، میزان ضایعات در دهه‌های آینده همچنان افزایش خواهد یافت. نتایج شبیه‌سازی سناریوهای تحقیق نشان داد که توسعه صنایع فرآوری، ضایعات کل در زنجیره تأمین سبزیجات برگی را از تقریباً ۳۱.۰۰۰ تن به حدود ۲۰.۰۰۰ تن در سال کاهش می‌دهد. بنابراین، لازم است که سیاست‌ها و برنامه‌های دولت در زمینه مبادله سبزیجات برگی در منطقه مورد مطالعه بر حمایت از کسب‌وکارهای مرتبط با صنایع فرآوری سبزیجات برگی و ایجاد زیرساخت‌های اولیه مورد نیاز این صنایع متمرکز شود.

واژه‌های کلیدی: زنجیره غذا، سبزیجات برگی، ضایعات غذا، کانال‌های بازاریابی، مدلسازی پویایی سیستم

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Investigation of Developing Smart Agriculture in Greenhouses of Tehran Province

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Abstract

Food production in controlled cultivation areas plays a crucial role in increasing productivity and offsetting supply shortages. Product yields, water consumption, and energy use are the main parameters determining the performance of food production in a greenhouse. Smart technology is an effective solution to improve these parameters. This study aimed to identify the components, challenges, and requirements for the development of smart agriculture in greenhouses. Our case study focused on Tehran province, which encompasses a significant portion of the total greenhouses in Iran. The statistical population consisted of 20 subject-matter experts with research or executive experience in greenhouse automation, selected purposefully. Questionnaires and semi-structured interviews were used in this study to collect data. First, we identified the variables affecting the development of smart agriculture in greenhouses by using a literature review and semi-structured interviews with experts, Then, the experts were asked to evaluate the cross-influence of the identified variables through pairwise comparison. Finally, data analysis was done using MICMAC software. The findings indicate that the identified requirements and challenges have had a significant influence on the lack of smart agriculture in greenhouses. Through network analysis of influence and dependence relationships, it was found that economic requirements and challenges, technical and infrastructural requirements and challenges, legal and regulatory requirements, and institutional requirements were the most influential variables in the development of smart agriculture in Tehran province.

Keywords: Smart agriculture development, Smart greenhouse, Smartening challenges, Smartening requirements

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Introduction

One of the biggest issues facing nations is guaranteeing food security (World Health Organization (WHO), 2022). One potential solution that has caught the interest of agricultural experts to boost the productivity of production resources is production in greenhouse conditions as a means of addressing the aforementioned issues (Watson *et al*., 2018). Currently, the environmental parameters are controlled manually in most of Iran's greenhouses (Hatefi, 2021). Because greenhouses must have a consistent climate, manually adjusting environmental factors leads to temperature fluctuations in greenhouses, which has an impact on greenhouse performance (Morrow, 2020; Newcombe, 2019). Understanding the elements of smartening and integrating technologies into production processes is one of the stressed ways to overcome challenges and maximize the utilization of production resources. Smart technologies include a range of innovative technologies, such as smart irrigation systems, greenhouse climate control sensors, and software, etc., that integrate advanced and smart control systems into greenhouse operations (Edwin *et al.*, 2019). The implementation of smart technologies in greenhouses offers significant benefits. It increases crop performance by creating an optimal environment for plant growth, resulting in healthier and higher-quality productions (Jamal *et al.*, 2021). In addition, it improves resource efficiency by optimizing water and energy consumption, reducing waste and costs (Tao *et al.*, 2021). Smart greenhouses also reduce labor costs by automating certain tasks that were previously done manually (Fountas *et al.*, 2020). The ability to monitor and control remotely is an additional benefit. Greenhouse operators can remotely monitor and change greenhouse conditions by using real-time data supplied over the Internet of Things (Said Mohamed *et al.*, 2021; Terence & Purushothaman, 2020).

Iran's Ministry of Agriculture intends to renovate and build 50,000 greenhouses by 2025 in order to take advantage of the potential benefits of greenhouse crops (Sharghi *et al.*, 2020). Despite the efforts made in this area, data on the cultivated area of greenhouses indicates that, by the end of 2022, only 9856 hectares of greenhouses were constructed in Iran (Statistical Center of Iran, 2023), and there are also issues with the structure and management of greenhouses (Rezaei *et al.*, 2023; Zarei, 2017). According to surveys, the majority of greenhouses currently operate using outdated production methods, leading to reduced productivity and inefficient consumption of various resources such as water and energy. A comparison of Iran's greenhouse performance metrics with those of top-producing nations, including agricultural output, water usage, and energy consumption, reveals a significant performance gap (Abbasi, 2015; Moghaddasi & Anoushe Pour, 2016; Naseri, 2019; Zarei & Momeni, 2017). For example, the performance of cucumber production in the Netherlands' greenhouses is 800 tons per hectare (CBS, 2017) while, in Iran, it is up to 300 tons per hectare (Banaeian, 2020). Despite the advances in technology and the emergence of modern methods of irrigation (Abbasi *et al.*, 2017), greenhouses still have low efficiency in water consumption in terms of water management. The water efficiency in the production of tomatoes in Iran's greenhouses is 31.4 kg/m^3, while the average water efficiency in the world's greenhouses for tomato cultivation is 43 kg/m^3, and in leading countries such as the Netherlands, it is 92 kg/m^3. This difference is also true for cucumber and pepper (Zarei & Momeni, 2017). The analysis of energy consumption statistics also shows that energy usage is considerably higher than the average value in other countries, for instance, Turkiye (Abbasi *et al.*, 2020). In addition, Tehran province has 2574 greenhouse units and 4123 hectares, or 28 percent, of the total cultivated area of greenhouses in Iran (Agricultural Jihad Organization of Tehran province, 2021). Despite the emphasis on the

quantitative and qualitative development of greenhouses in the Iranian National Acts, the greenhouses located in Tehran province are faced with the inefficient use of production resources and the weakness of using new technologies (Hatefi, 2021). Researches reveal that developing countries frequently struggle with inadequate infrastructure to make use of these technologies, including restricted Internet and electricity access, a lack of funds to invest in infrastructure development, and a shortage of professionals to offer services (Maraveas & Bartzanas, 2021). Furthermore, utilizing these technologies presents a technical lack to integrate and connect technologies, the incompatibility of current Internet of Things networks with other protocols, the inability to handle signal interference, the incompatibility with powerful devices, and the absence of support infrastructure because of their recentness (Elijah *et al.*, 2018; Maraveas & Bartzanas, 2021). Consequently, technological adoption will encounter difficulties with things like network security and the precision of agricultural data (Jamil *et al.*, 2022; O'Shaughnessy *et al.*, 2021). Another challenge of using smart technologies in developing countries is related to the problems of the economy of scale. The small scale of greenhouses, the lack of financial ability of farmers, their weak knowledge and skills, and their unwillingness to use technologies are the important issues in this field (de Bourgogne, 2021; O'Shaughnessy *et al.*, 2021). Due to the challenges mentioned in the development of smart agriculture (DSA), some studies have expressed that smartness requires the creation of the necessary technical and infrastructure platforms for the implementation of these technologies. The most crucial technological and infrastructure requirements for implementing smart technologies are developing smart technologies inside the country, preventing the import of inefficient smart systems (Abbasi *et al.*, 2020), developing agricultural automation and mechanization (Ghara Biglo & Zand, 2015), developing information and communication technology infrastructures (Lakhwani *et al.*, 2019; Saiz-Rubio & Rovira-Más, 2020; Shekhar *et al.*, 2017), increasing the security of databases, and using protection improvement methods (Elijah *et al.*, 2018; Narwane *et al.*, 2022; Quy *et al.*, 2022; Sontowski *et al.*, 2020). The development of smart agriculture also requires efficient regulations to support and promote investment.

Therefore, based on the literature review, it can be concluded that, firstly, measuring the level of smart agriculture necessitates the development of a composite index that encompasses various dimensions of smartening. Secondly, the smartening of agriculture encounters challenges and requirements that directly and indirectly impact the different dimensions of the smart agriculture index. Consequently, enhancing this index entails addressing the challenges while also fulfilling the requirements. This concept can be illustrated through a conceptual model, as depicted in Fig. 1.

According to Fig. 1, considering smart agriculture in greenhouses requires interconnected components and challenges. The present study was conducted with the general aim of analyzing the development of smart agriculture in greenhouses in Tehran province. To achieve this goal, the current study seeks to identify the most important variables in developing smart agriculture in greenhouses in Tehran province the network of relationships between these variables and their priority, the most important solutions for developing smart agriculture in the greenhouses of Tehran province.

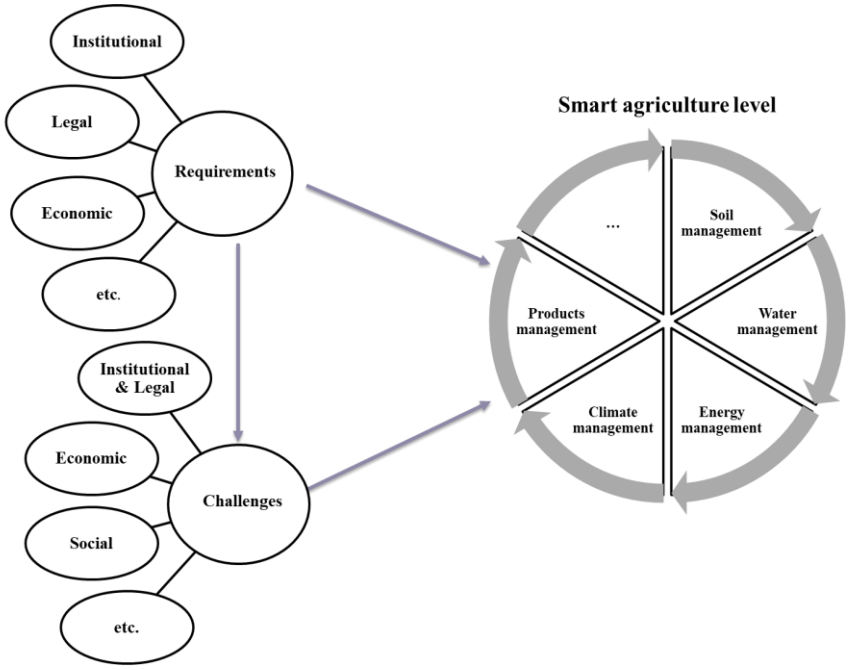

Figure 1- The conceptual model of the study

Materials and Methods

20 subject-matter experts were included in the study's statistical population. These experts included faculty members from educational and research institutions, specialists from the Ministry of Agriculture, experts from knowledge-based businesses, manufacturers of smart greenhouse equipment, and some knowledgeable greenhouse owners. Experts were selected purposefully. The data collection methods employed in this study comprised semi-structured interviews and questionnaires. Initially, through a combination of literature review and semi-structured interviews with experts, the variables influencing the development of smart agriculture, including smart components and the requirements and challenges specific to smart agriculture in greenhouses, were identified. The sample size was determined based on theoretical saturation, with each participant typically undergoing approximately 45 minutes of semi-structured interviews. Following each interview, the information gathered from participants was analyzed using the content analysis method, and the main factors were categorized according to the research's theoretical framework. To ensure the reliability of the research, a triangulation method was employed, utilizing a data pluralism strategy. This involved gathering feedback from participants, conducting self-reviews by the researcher, and meticulously documenting the interview process. Moreover, methods such as feedback from participants, self-review by the researcher, and accurate documentation of the interview process were utilized to enhance the validity of the research.In the second step, we developed a paired comparison questionnaire after identifying the key variables of the research to complete the cross-impact matrix. We asked the participants to indicate the degree of influence of each variable (x_i) on the other variable (x_j) using discrete values 1, 2, 3 and 4 which represent the no influence, weak influence, moderate influence, strong influence, , and potential influence, respectively. Finally, the information was analyzed with the MICMAC software. This software presents the distribution of factors based on their influence, dependence, and the role that they play in the system in the form of a diagram similar to Fig. 2 (Godet *et al.*, 2008). This diagram consists of five areas (Barati *et al.*, 2019):

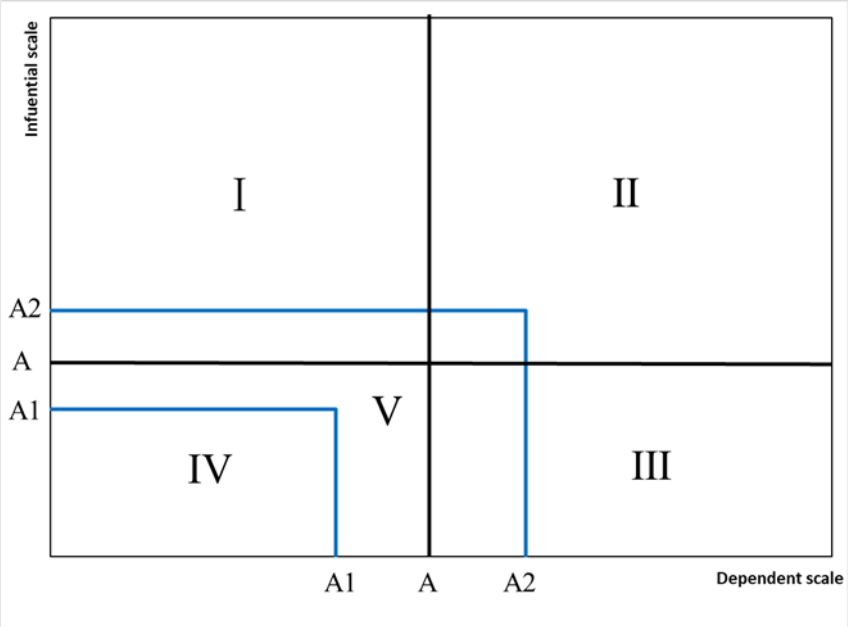

Figure 2- The influence-dependence chart area of variables
Notes: a. A refers to the average influence score (in Y axis) or dependence score (in X axis), A1= A-(0.25A), A2 = A+(0.25A)

Results and Discussion

Personal and professional characteristics of respondents

60% of the respondents had a doctorate, 30% had a master's degree, and 10% had a bachelor's degree. In terms of organizational position, 8 participants were experts in greenhouse production, 6 participants were faculty members of universities and research centers, 4 participants were greenhouse owners, and 2 participants were CEOs of knowledge-based companies. Also, 80 percent of respondents were male with an average age of 44 years, and

Identifying the effective variables for the DSA

After coding and conceptual refinement of the data obtained from semi-structured interviews, the requirements (Table 1), challenges (Table 2), and components (Table 3) of the DSA in the greenhouses of Tehran province were identified and categorized in the form of three main categories and 16 subcategories.

Out of a total of 256 evaluated relationships, the existence of 114 relationships was confirmed, and weak relationships (60 cases) and moderate relationships (35 cases) were the most frequent, respectively. The degree of matrix filling was 44.5%, and the number of iterations of the matrix to achieve optimality was 6 iterations.

Identifying the network of relationships between the variables of the DSA in greenhouses

Table 4 shows the amount and degree of direct and indirect influence of research variables on each other. Based on the results, among the requirements for the DSA in greenhouses, the economic requirements variable was ranked first with 31 scores in the direct influence, which indicates the significant importance of economic requirements in the development of smart greenhouses in Tehran province. After that, technical and infrastructural requirements, legal and regulatory requirements, institutional requirements, and learning and psychological requirements were placed in the next ranks of

direct influence on the DSA. In the challenges of developing smart agriculture, economic challenges are the priority, followed by infrastructural and technical, social, and legal regulatory challenges in the next ranks of direct influence. The components of greenhouse smartening (including water management, energy, climate, products, and soil) have been the most dependent variables. The lowest level of direct influence also belonged to the variables of legal and regulatory requirements and institutional and legal challenges, respectively. In the indirect influence classification, the institutional and economic requirements and then the economic challenges are the most influential variables, and the most dependent variables are the same as in the direct influence section, respectively, the variables of the components of products management, energy, and soil.

The results of the matrix of direct and indirect influences (Fig. 3 and 4) confirm the accuracy of the research conceptual model (Fig. 1).

Table 1- Prerequisites for the development of smart agriculture in greenhouses

Subcategories	Indicators
Institutional Requirements	Development of the institution in charge of national policy and planning
	Development of companies providing technical-engineering services and...
	Improving the role of the Ministry of Agriculture-Jihad
	Attracting the participation of the private sector
	Using the capacity of greenhouse cooperatives
	Improving the role of universities
	Development of innovation centers, growth centers, and science and technology parks
	Creating an assembly of smart small-scale greenhouses
	Encouraging networking among active greenhouse producers
Legal and Regulatory Requirements	Compilation of codified policies for smart greenhouses in the country
	Compilation of legal incentives in the field of greenhouse smartening
	Compilation of rules and instructions about the Internet of Things
	Compilation of rules and instructions regarding obtaining a license
	Compilation of programs for the development of smart greenhouses
	Compilation of rules related to the insurance of smartening equipment
Economic Requirements	Reducing the interest rate of banking facilities related to smartening
	Encouraging and supporting investment in the development of IT infrastructure
	Financial support for start-ups and new knowledge-based companies
	Supporting venture capital for smartening
	Providing appropriate financial incentives (tariffs and taxes).
	Providing product and equipment insurance services in smart greenhouses
learning and Psychological Requirements	Improving producers' trust in active organizations
	Improving the risk tolerance of producers in adopting technologies
	Increasing familiarity, interest, and knowledge of producers with the process of greenhouse smartening
	Training of the research team and skilled human resources for service provision
	Content production and publication of specialized scientific publications
	Facilitating communication with experts and technical advisors in the smart greenhouse
Technical and Infrastructure Requirements	Facilitating access to the physical infrastructure of IT technologies
	Facilitating access to monitoring devices
	Facilitating access to smart ventilation, smart lighting, cooling, and heating equipment
	Facilitating access to smart irrigation and fertilizing equipment
	Facilitating access to data security, safety, and protection equipment
	Development of local, cheap, and suitable smart technologies
	Facilitating the import of suitable technologies according to the rate of return on capital
	Optimizing and facilitating the process of using data
	Using International experiences in smart greenhouse management
	Development of data storage systems

Source: Research findings

Table 2- Challenges to the development of smart agriculture in greenhouse farming

Subcategories	Indicators
Infrastructural and Technical Challenges	Poor IT infrastructure and a lack of reliable access to high-speed internet The small scale of most greenhouses Non-local and expensive greenhouse technologies lack of integrity and incompatibility of technologies Limited capacity of existing technologies in data storage Installation, maintenance, and support problems of greenhouse technologies due to technical complexity The lack of knowledge of the senior managers of the agricultural sector about smartening Importing inefficient and low-quality smart systems
Institutional and Legal Challenges	Lack of suitable institutions to provide smartening services The existence of many bureaucracies for active agricultural start-ups Violation of intellectual property of agricultural startups Violation of industrial property rights of smart technologies The uncertainty of data privacy and security in this field Lack of transparency in the duties and missions of various government and private institutions Lack of consideration of research units for the smartening of greenhouses
Economic Challenges	High cost of smart equipment and technologies Lack of appropriate and sufficient investment in the necessary infrastructure Lack of financial support and sufficient bank facilities
Social Challenges	Insufficient training in the field of smart greenhouses Lack of young manpower and the old age of producers Lack of technicians and skilled labor to provide smart technology services Lack of consideration of mass media, publications, and websites

Source: Research findings

Table 3- Components of the development of smart agriculture in greenhouse farming

Subcategories	Indicators
Water Management	Water temperature, EC and PH sensors, rainwater storage, disinfection, water recycling devices, etc.
Soil Management	Temperature, humidity, PH, and soil salinity sensor, soil disinfectant, etc.
Energy Management	Inside and outside light sensors, heating, shade, energy saving, etc.
Climate Management	Environment temperature and humidity sensors, carbon dioxide and carbon monoxide gas sensors, outside sensors, ceiling vents, exhaust fans, fans and pads, cooling systems, etc.
Products and Pest Management	Leaf temperature sensor, pest management method, LEDs, etc.
Harvesting and Packing Management	Harvesting technologies and equipment, etc.
Marketing Management	Information storage and analysis software, information and communication technologies, greenhouse marketing management software, etc.

Source: Research findings

According to them, out of the three categories of studied variables (components, requirements, and challenges of smartening in greenhouses), the requirements and challenges are the most influential, and the components of smartening are the most dependent variables, respectively (Fig. 3 and 4).

Also, according to Fig. 3 and 5, among the requirements, economic and technical infrastructure requirements are the most influential. Economic requirements directly influence different components of smartening, including water, soil, climate, and energy management. They also directly influence various challenges, including economic and technical infrastructure challenges. According to Fig. 5, the institutional requirements, both directly through the economic requirements and indirectly (Fig. 6) through influencing the components of energy management, products, soil, and climate, influence the smartening of agriculture.

Table 4- Ranking and amount of direct and indirect influence of variables

Variables	Direct influence				Indirect influence			
	Influence		dependence		Influence		dependence	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Institutional requirements	18	5	6	11	5445649	1	166333	14
Legal and regulatory requirements	19	3	3	16	3191183	4	75161	16
Economic requirements	31	1	7	10	5059947	2	306319	10
Learning and psychological requirements	10	7	8	9	921869	9	367847	9
Technical and infrastructure requirements	22	2	6	12	1411364	8	284723	12
Infrastructure and technical challenges	15	6	5	14	1714100	6	260064	13
Institutional and legal challenges	7	10	5	15	2776753	5	97679	15
Economic challenges	19	4	6	13	3464505	3	306030	11
Social challenges	10	7	9	8	1630771	7	403356	8
Water management	10	9	19	5	222996	10	3227594	5
Soil management	2	15	21	3	62960	14	4003224	3
Climate management	7	11	20	4	196818	11	3697995	4
Energy Management	6	12	22	2	180446	12	4437860	2
Products management	6	13	23	1	117765	13	4568002	1
Harvesting and packing management	2	16	16	6	45234	16	2479680	6
Marketing Management	3	14	11	7	51436	15	1811929	7

Source: Research findings

Among the challenges, economic challenges are the most effective, both directly and indirectly. After those, there are technical and infrastructural challenges that directly affect other variables (Fig. 3). Of course, institutional and legal challenges should not be ignored because they also indirectly (Fig. 4) influence the whole system. Solving and managing challenges will directly create the background for the provision of institutional requirements (Fig. 5) and indirectly (Fig. 6) lead to the improvement of various components of smartening. Among the components of smart agriculture, the components of products, energy, and soil management are the most dependent, either directly or indirectly.

In general and based on the location of variables, economic, technical and infrastructural, institutional, and finally legal and regulatory requirements, as well as the economic and technical infrastructural challenges due to being located in the Ⅰ area (Fig. 3) are considered key factors in developing strategic plans for developing smart agriculture in greenhouses. Furthermore, the placement of water, soil, energy, climate, and harvesting and packaging management in the Ⅲ area (resultant area) means that they depend on input and intermediate variables (requirements and challenges), which is a confirmation of the conceptual model presented in Fig. 1. The performance of these variables, which are known as the components of smartening in greenhouses, mainly depends on the variables located in Ⅰ and Ⅱ areas. The variables of institutional and legal challenges are also in the Ⅳ area, which can be ignored due to the small relationship with other variables. The Ⅴ section contained the variables of social challenges, learning and psychological requirements, and marketing management. Although this group of variables is not considered crucial due to their low influence and dependence, they should be investigated in future studies.

Fig. 5 shows the intensity, direction of influence, and dependence of key variables in the development of smart greenhouses. Considering the network of direct relationships between variables, economic, technical, and infrastructure requirements have a central and sensitive role and deserve attention. Moreover, economic, technical infrastructural, and legal-regulatory requirements are the sources of the most severe influences on other system variables, which indicates their importance in developing smart agriculture in greenhouses.

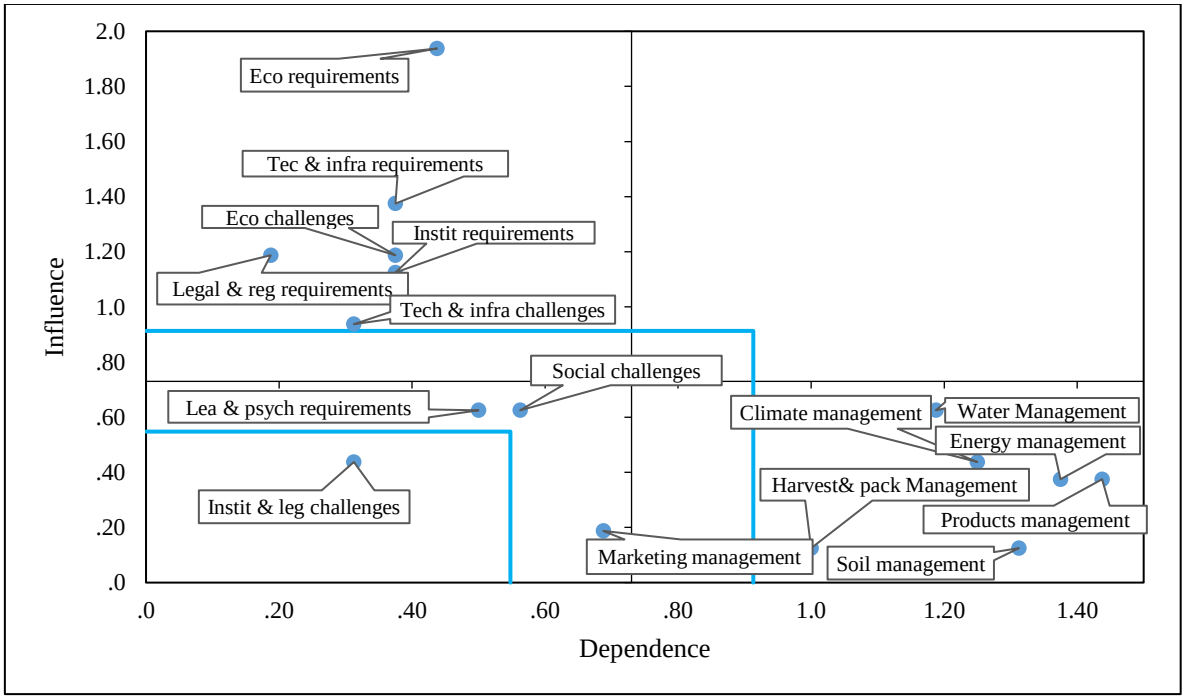

Figure 3- The position of study variables on the influence-dependence chart in the direct influence matrix

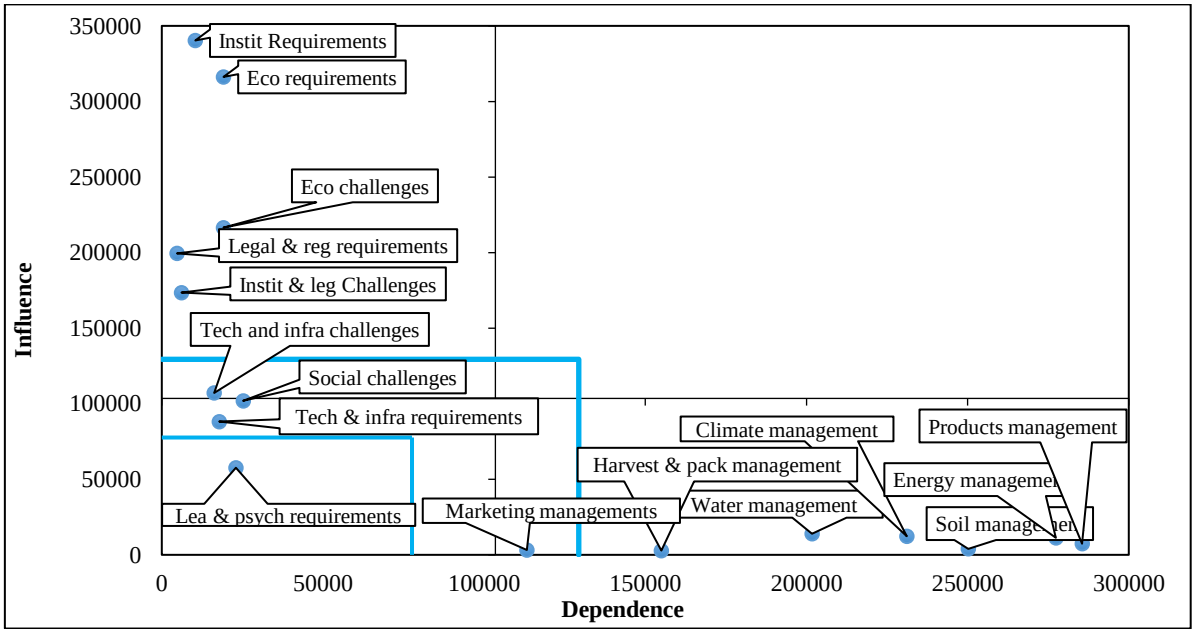

Figure 4- The position of study variables on the influence-dependence chart in the indirect influence matrix

In other ways, the components of smartening in greenhouses are strongly dependent on other system variables. In other words, improving each of the smartening components in greenhouses requires meeting the requirements and solving the challenges found in the current study. The indirect relationships graph (Fig. 6) indicates that the biggest indirect influence on other variables is derived from institutional and economic requirements.

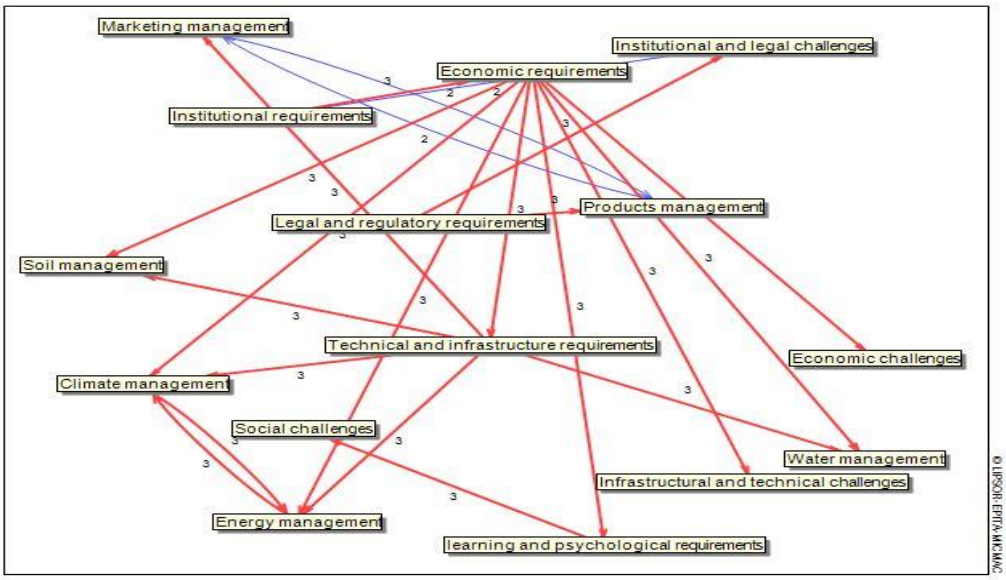

Figure 5- The graph of direct relationships between the study variables at the 25% level

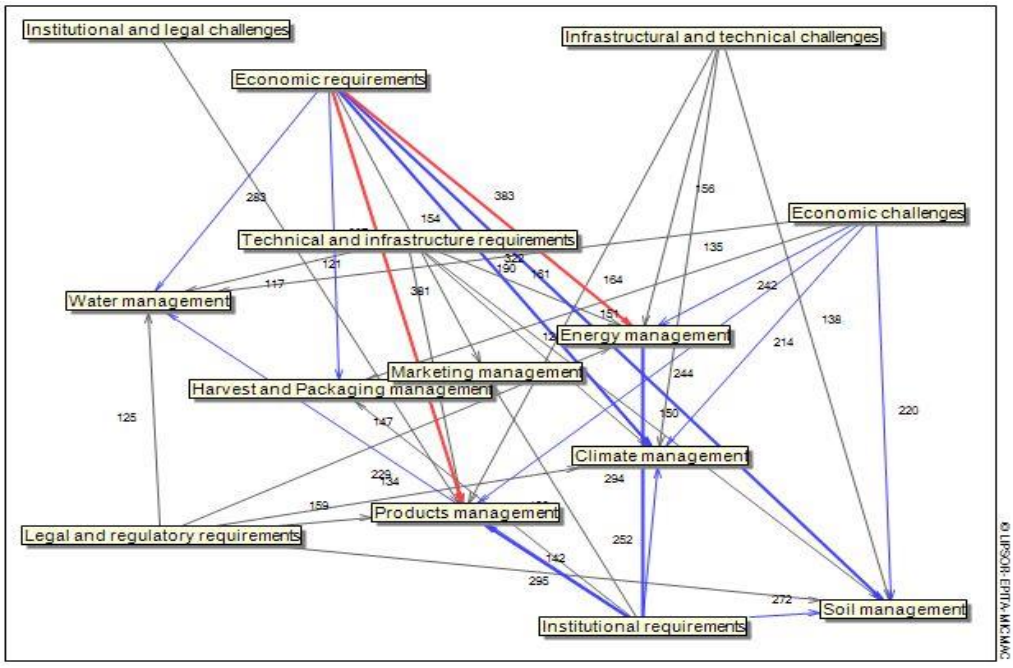

Figure 6- The graph of indirect relationships between the study variables at the 25% level

Finally, as shown in Fig. 3 to 6, the smartening components depend on the challenges and requirements identified in the development of smart greenhouses. The achievement of the goals of smart greenhouses requires intervention to overcome challenges and meet the requirements identified in this study, according to Fig. 7. In this figure, the numbers on the arrows show the general relationships of the variables based on the sum of the calculated levels.

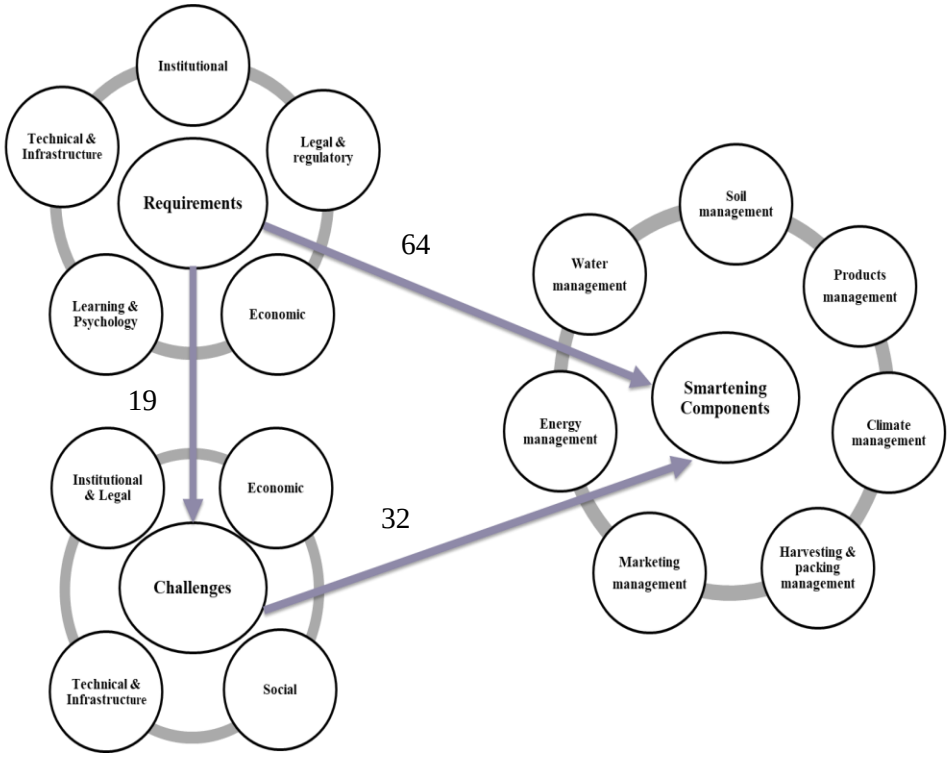

Figure 7- Final model of the study

Discussion

Developing smart agriculture in greenhouses requires addressing three categories of key factors, including requirements, challenges, and components. Predominantly, the results of this study showed that developing smart greenhouses primarily requires the provision of the requirements. Providing requirements is the direct basis for the development of smart greenhouses and helps to improve the level of smartness of greenhouses by overcoming the challenges of developing smart agriculture.

Understanding technologies and their application domains is the initial phase in their development. This study identified seven components to represent the smart technologies employed in greenhouses: water, soil, climate, energy, products, harvesting and packaging, and marketing management. Among these components, three were identified as particularly critical for greenhouse smartening: water, climate, and energy management. Investing in technologies associated with water, climate, and energy management in greenhouses not only enhances the smartness level but also establishes a foundational platform for the implementation of other smart components in greenhouses.

Therefore, the main efforts and planning for developing smart technologies in greenhouses should primarily focus on the establishment of technologies related to the three key components of water, climate, and energy management. Challenges in the field of developing smart technologies in greenhouses have influenced the success rate of using technologies in greenhouses. The network of relationships between challenges and components of smart greenhouses showed that economic, infrastructural, and technical challenges are the most important challenges influencing the development of smart greenhouses. One of the important economic challenges faced by the target community is the insufficient investment needed to develop the necessary infrastructure to make use of technologies. Studies have pointed out the shortcomings of infrastructure investment (Maraveas & Bartzanas, 2021). Given that most rural areas lack the energy, information, and communication technology infrastructures needed for smart technologies, promoting and supporting investment in developing these

infrastructures can help establish the platforms needed for the expansion of smart agriculture in greenhouses. Furthermore, there is another economic challenge to the implementation of smart technologies in greenhouses: the high cost of investment, which only justifies the application of these technologies to large-scale production. Many farmers are unable to invest in technologies because of their limited financial resources and the low scale of the majority of greenhouses in the research area. Also, the lack of credit facilities to fully cover the costs of using technologies and the challenges associated with obtaining facilities are major barriers for investors and farmers looking to integrate smart technologies into their greenhouses.

Another challenge was the infrastructural and technical factors. The technical and infrastructural challenges of developing smart greenhouses can be divided into two categories: barriers related to the infrastructure as well as limitations related to farmers' access to the technologies and equipment. Many farmers will not be able to adopt greenhouse technologies even if they would like to because of barriers like weak infrastructure for information and communication technology, the small size of most greenhouses, and issues with installation, upkeep, and support. Prior research has also highlighted inadequate access to infrastructure as a barrier to the advancement of smart agriculture (de Bourgogne, 2021; Dhanaraju *et al.*, 2022). The technical shortcomings of current technologies and their incompatibility with existing agricultural operations are other limitations that have influenced developing technologies. A major part of these challenges can be attributed to the weakness of related research and the import of low-quality smart systems to the country (Abbasi *et al.*, 2020).

Considering the challenges mentioned, part of the efforts of policymakers and planners must be focused on improving the access of farmers to the basic infrastructure and the technical standards of these technologies. Based on the network of relationships between the variables of developing smart greenhouses, addressing the economic, technical, and infrastructural requirements by influencing the economic, infrastructural, and technical challenges of the development of smart greenhouses plays a central role in improving the smartness of greenhouses in Tehran province.

The results of this study are consistent with previous research (Caffaro & Cavallo, 2020; Mukhopadhyay & Suryadevara, 2014; Rayhana *et al.*, 2020), which emphasizes the importance of addressing economic issues in the process of developing smart technologies in the agricultural sector. As mentioned earlier, developing smart greenhouses in Tehran province faces important economic and technical challenges, including poor access to smart technologies and infrastructure, high investment costs, and limited access to capital. One of the strategies to overcome these challenges is to provide economic requirements through policies such as encouraging and supporting investment in information and communication technology infrastructures, investing and supporting innovations, and providing appropriate credit and insurance facilities. Therefore, farmers' incentives to invest in smart technologies can be strengthened by providing economic requirements along with a supportive economic environment.

Legal and regulatory requirements were another factor influencing the DSA in greenhouses. From the expert's point of view, legal and regulatory requirements include various aspects such as user privacy, laws related to the payment of incentives, the development of programs aimed at promoting and facilitating the adoption of these technologies, licensing procedures, and insurance laws for smart facilities and equipment. The above finding shows that developing smart technologies in greenhouses requires the development of codified rules and policies to facilitate the business environment and manage the interactions of farmers, producers, and other stakeholders involved in the smart agriculture industry. The necessity of developing appropriate laws and regulations to arrange the interactions of activists has also

been considered in other studies (Atri, 2018; Narwane *et al.*, 2022; Ojha *et al.*, 2021). For instance, protecting farmers' information security is one of the top concerns for users of smart technology, as highlighted by numerous studies.(Elijah *et al.*, 2018; Quy *et al.*, 2022; Sontowski *et al.*, 2020). Therefore, it is necessary to pass detailed laws and regulations that can protect the privacy of users. This issue should be prioritized in the plans of relevant politicians. Laws and regulations can facilitate the development and adoption of smart technologies by creating a favorable business environment. For example, investment in infrastructure, comprehensive development of insurance for smart facilities and equipment, allocation of financial resources to research, and payment of incentives and credit facilities to farmers for technology adoption require the passing of laws and regulations to support these policies. This means that the success of other support efforts and programs for the DSA in greenhouses, including providing economic, technical, and infrastructure requirements, requires the passing of appropriate laws and policies to support these programs.

Another important requirement influencing the development of smart greenhouses was institutional. Institutions create a supportive environment for the implementation of smart agriculture projects by formulating appropriate policies, regulations, and guidelines. This confirms the importance of institutions in fulfilling other requirements of smart agriculture development and overcoming the challenges facing this sector. The DSA primarily requires appropriate laws and policies, such as investment in infrastructure, allocation of incentives and credit facilities, research budgets, ensuring privacy and data security, etc., to coordinate efforts and implement relevant programs. The relevant institutions are in charge of making these policies. Additionally, the development of smart technologies in greenhouses requires institutions such as universities, research centers, and innovation centers. They play a fundamental role in conducting research related to smart greenhouses and help to continuously improve the development of technology in this sector. Considering the importance of technical and infrastructural requirements and challenges, technology development by these institutions provides the basis for the realization of technical and infrastructural requirements and overcoming the related challenges in the study area. For example, the Ministry of Agriculture, as a provider of information and training needed by farmers, facilitates the decision-making process regarding the adoption of smart technologies offered to farmers by providing educational-extensional programs and other interventions. In fact, by formulating laws and regulations, conducting research and development of technology, and building capacity among farmers, institutions can help create a suitable environment for the deployment of smart technologies in greenhouses.

Conclusion

In recent years, using the capabilities of smart technologies in greenhouses has attracted the attention of policymakers and agricultural planners. To effectively prioritize efforts and allocate resources for the development of smart technologies in greenhouses, understanding the factors influencing greenhouse smartness is paramount. The current study aimed to investigate the Development of smart agriculture (DSA) in greenhouses within Tehran Province. Three categories of key variables were identified and analyzed: components, challenges, and requirements. The components of smartening were classified into seven groups. Water management, climate management, and energy management components were identified as the most important components of smart greenhouses. Considering the importance of the mentioned components in the efficiency of production operations, addressing the challenges and requirements influencing these components has a vital role in the successful deployment of smart technologies in greenhouses. The analysis of the relationships between research variables showed that the implementation of smart technologies in the greenhouses of

Tehran province primarily requires the creation of a favorable economic environment by providing economic requirements, including the payment of financial incentives, credit facilities, and investment in the foundation infrastructure. Another effective factor in the development of smart greenhouses is addressing technical and infrastructural requirements and challenges. Due to the weakness of the infrastructure for the implementation of smart technologies in the country, as well as the lack of access to suitable equipment and technologies, it is necessary to take the necessary actions to overcome the mentioned challenges. Legal and institutional requirements were identified as other important factors influencing the DSA in greenhouses. As discussed, any action for overcoming the economic challenges and infrastructural and technical problems to achieve smart greenhouses requires the creation of institutions and strong legal and regulatory frameworks to coordinate efforts and support policies for the DSA in greenhouses. Therefore, to realize smart greenhouses while passing appropriate supporting laws and regulations to regulate the relations of actors, it is necessary to determine the duties of the responsible institutions in the priority of the programs of the Ministry of Agriculture and other related institutions.

Finally, according to the mentioned results, the following suggestions are presented to promote the DSA in greenhouses:

Considering economic challenges, the payment of financial incentives and special credit facilities with appropriate interest rates can increase the motivation of farmers to adopt these technologies. Moreover, regarding the importance of innovations, startups, and new knowledge-based companies in the field of smart agriculture, supporting research activities and allocating financial resources to invest in innovative ideas related to smart agriculture can create a favorable environment for the growth of related businesses.

Considering the pivotal role of information and communication technology (ICT) infrastructures in enhancing the intelligence of greenhouses, it is recommended that responsible institutions extensively provide the necessary platforms for implementing smart systems in greenhouses by investing in ICT infrastructures. The development of reliable and cost-effective internet connections in rural areas to facilitate data exchange and communication is one of the most important actions to be taken in this field.

Due to the importance of access to infrastructure and technical equipment, it is necessary to invest and make necessary arrangements for the development of supporting infrastructure and technologies required for smart greenhouses, such as smart equipment, advanced sensors, automation systems, etc. Investing in research and development to produce new technologies suited to the needs of the country's greenhouses is one of the solutions that can improve farmers' access to the necessary and cost-effective equipment and technologies in smart greenhouses.

Owing to the significant importance of institutional requirements, it is suggested that the national program for smart greenhouses in the country be formulated as soon as possible and the detailed duties of the institutions responsible for the DSA in this field be determined.

Paying attention to the role of laws and regulations in providing a suitable environment for the activities of stakeholders, it is necessary to create codified policies that outline clear guidelines and standards for farmers, producers, and other stakeholders involved in smart agriculture. These policies should cover various aspects, including implementation guidelines, incentives, user privacy, licensing procedures, and smart equipment insurance rules.

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تحلیل توسعه کشاورزی هوشمند در گلخانه‌های استان تهران

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چکیده

در دهه‌های اخیر کشت در محیط‌های گلخانه‌ای به‌عنوان یکی از راه‌حل‌های بالقوه جهت افزایش بهره‌وری منابع تولید و پاسخگویی به تقاضای غذایی فزاینده ناشی از رشد جمعیت مورد توجه کشورها قرار گرفته است. بااین‌حال، شکاف عملکردی قابل‌توجهی از نظر شاخص‌های عملکردی گلخانه‌ها نظیر عملکرد محصول، مصرف آب، انرژی و غیره در کشور ایران با کشورهای پیشرو در صنعت تولیدات گلخانه‌ای وجود دارد. یکی از راهکارهای مورد تأکید برای غلبه بر این چالش‌ها و بهینه‌سازی استفاده از منابع تولید، پیاده‌سازی فناوری‌های هوشمند در گلخانه‌ها است. با توجه به عدم توسعه فراگیر فناوری‌های هوشمند در گلخانه‌های استان تهران و اهمیت این استان در تولید محصولات گلخانه‌ای در کشور، مطالعه حاضر با هدف تحلیل توسعه کشاورزی هوشمند در گلخانه‌های استان تهران انجام گرفت. جامعه آماری پژوهش شامل ۲۰ نفر از خبرگان موضوعی دارای سابقه تحقیقاتی یا اجرایی در زمینه هوشمندسازی گلخانه‌ها بودند. انتخاب این افراد نیز به روش هدفمند انجام شد. ابزار جمع‌آوری داده‌ها در این پژوهش مصاحبه نیمه ساختاریافته و پرسشنامه بود. در ابتدا با استفاده از مرور ادبیات موضوع و مصاحبه‌های نیمه ساختارمند با خبرگان موضوعی، متغیرهای عوامل مؤثر بر توسعه کشاورزی هوشمند در گلخانه‌ها (شامل مؤلفه‌ها، الزامات و چالش‌های توسعه کشاورزی هوشمند) شناسایی شدند. سپس، از خبرگان خواسته شد تا اثرات متقاطع، متغیرهای شناسایی شده را از طریق مقایسه زوجی ارزیابی کنند. درنهایت، تجزیه و تحلیل داده‌ها به روش تحلیل اثرات متقابل با استفاده از نرم‌افزار MICMAC انجام شد. بر مبنای تحلیل شبکه روابط اثرگذاری و اثرپذیری به‌ترتیب الزامات و چالش‌های اقتصادی، الزامات و چالش‌های فنی و زیرساختی، الزامات قانونی و مقرراتی و الزامات نهادی به‌عنوان تأثیرگذارترین متغیرهای مؤثر بر توسعه کشاورزی هوشمند در استان تهران شناسایی شدند.

واژه‌های کلیدی: الزامات هوشمندسازی، توسعه کشاورزی هوشمند، چالش‌های هوشمندسازی، گلخانه هوشمند

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Climate Change and Agricultural Trade in Iran: A Dynamic Input-Output Analysis

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Abstract

In recent decades, the significance of the issue of climate change has escalated due to its intensified impacts, potentially diminishing or halting economic growth, particularly in developing countries and vulnerable sectors such as agriculture. Climate change may be considered the most important and complex human challenge. Among the economic effects, trade variables have been examined inadequately. Accordingly, the focus of this study is to investigate the impact of climate change on the export and import of agricultural products in Iran over a forty-year horizon, which was carried out using a dynamic input-output model. This study uses scenarios of temperature anomaly to examine the impact of climate change on different sectors of Iran's economy. The findings indicate that climate change has a significant impact on the growth of both exports and imports of agricultural products. Under normal conditions without climate change, the average annual growth rate of agricultural product imports is 2.7 percent. However, this rate decreases to 1-1.8 percent when different climate change scenarios are taken into account. Regarding the exports, the corresponding value is 2.75 percent, expected to be reduced to 0.55-1.8 percent. In addition, it was found that agricultural trade will be dominated by cereals import. Also, the total trade of the Iranian economy will change in favor of non-agricultural commodities.

Keywords: Agricultural trade, Climate change, Input-output

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Introduction

Climate change is the most important and complex human challenge (Hoegh-Guldberg, & Bruno, 2010) because it not only has extensive climatic effects, but it will also have significant economic effects (Dell *et al.*, 2014; Burke *et al.*, 2015). The impact of climate change is multidimensional and not limited to specific regions. However, the main consequence is natural and economic damage (Liu *et al.*, 2020), which is directly reflected in economic variables (Farajzadeh *et al.*, 2022).

While scientists focused on the reasons and ecological consequences of climate change, economists' concerns centered on the relationship between economics and climate change. Several studies on the role of climate change on the economy began in the 1990s (Tol, 2009). Over the recent decades, with the intensification of the effects of climate change, the importance of this issue has increased because it may decrease or halt economic growth, especially, in developing countries (Piontek *et al.*, 2019). A wide range of studies emphasize that a three-degree increase in temperature in different regions may reduce GDP by 5-35 percent, and the highest damages are related to developing countries located in ecologically sensitive areas (Fankhauser & Tol, 2005; Piontek *et al.*, 2019; Swiss Re Institute, 2021). Other economic variables such as welfare level, consumption, and price level are also affected by climate change (Farajzadeh *et al.*, 2022). The effects of climate change on economic sectors are also different. The agricultural sector holds significant importance due to its heavy reliance on climatic factors. Despite the neglect of climate change effects on the trade of agricultural products, numerous studies have examined the impact of climate change on agricultural output.

One of the main variables studied in this context is the total production of the economy, which has been examined at the sectoral (Vatankhah *et al.*, 2020; Manuel *et al.*, 2021) and economy-wide levels (Piontek *et al.*, 2019; Dalagnol *et al.*, 2022). These studies predict a decrease in total production (output) by up to 40 percent. However, other variables are also expected to be affected by climate change accordingly including trade. Most studies related to trade and climate change have focused on the role of free trade in mitigating the effects of climate change (Balogh & Attila Jámbor, 2020). Among the sectors of the economy, the agricultural sector, due to its high importance in food security and its greater vulnerability to climate change, is the focus of empirical works (Pakmehr *et al.*, 2020). Accordingly, a significant body of literature related to trade has focused on the effects of trade liberalization of agricultural products on the damages caused by climate change and environmental performance. Some of these studies confirm the reduction of climate change damages caused by liberalization (Weinzettel & Wood, 2018; Walters *et al.*, 2017), and others have seen liberalization ineffective or even destructive (Bourgeon and Ollivier 2012; Dang & Konar, 2018; Antonelli *et al.*, 2017; Balogh & Attila Jámbor, 2020; Alavi & Mohammadi, 2023). However, to the best of our knowledge, none of the studies in this field have paid attention to the effects of climate change on the export and import of agricultural products.

Iran, as a developing country in an ecologically sensitive area, has always been the focus of climate change and economics researchers. Iran is classified as a dry, and semi-arid region with average rainfall of 250 mm that is less than a third of the global average (Malakootikhah & Farajzadeh, 2020). Also, studies on temperature and precipitation indicate a decrease of 2.1 mm of precipitation and an increase of 0.02 degrees Celsius in recent years (Abbasi *et al.*, 2019). The results of the studies conducted in Iran show that the added value of the agriculture sector, productivity, and the production will decrease significantly due to the destructive effects of climate change. Mosavi *et al.* (2020) predicted a 19-26 percent decrease in the added value of the agriculture sector by 2090. Also, Ghaffari Esmaeili *et al.* (2019) confirmed the reduction of agricultural economic variables, including production, consumption, investment, and

export, by around 4.5, 5, 4.5, and 14.8 percent, respectively, by 2030.

The above discussion shows that the effects of climate change on the agriculture sector in Iran are significant. Given Iran's sensitive climate conditions, the trade of agricultural products has become increasingly crucial for the country. A substantial portion of agricultural product consumption in Iran relies on imports. For instance, approximately 40 percent of sugar and barley consumption is sourced through imports. Iran's dependence on more basic products such as corn and oilseeds may amount to approximately 80 percent (FAO, 2023). On the other hand, Iran is known as a significant exporter of some products, such as saffron and pistachios. The exports of Iran's agricultural products in 2021 was around USD 2.47 billion, and its share is approximately 3 percent of Iran's total export. The imports of raw agricultural products in 2021 was over USD 13.9 billion, which amounts to 18 percent of the total imports (FAO, 2023; World Bank, 2022).

Most climate change's studies examining the agricultural activities are experimental based studies at regional level, and interactions between activities are not considered. Therefore, it is necessary to use models that consider inter-sectoral and comprehensive interactions, such as Computable General Equilibrium (CGE) and Input-Output (IO). In addition to the CGE model that has been widely used in this field, a more detailed look at the economics of climate change can be made possible with IO models. To the best of our knowledge, empirical works using IO models have a consistent framework and provide a high resolution of economic sectors and structural economic composition (Donati *et al.*, 2020) but are not a well-established approach to the dynamic nature of climate change. Therefore, one of the goals of the present study is to develop a dynamic IO model to investigate the effects of climate change.

The focus of this study is to investigate the effects of climate change on the amount of export and import of agricultural products of Iran in a forty-year horizon, which was carried out using a dynamic IO model. The main concern of the current research is to examine the amount of damage caused by climate change on the trade of Iran's agriculture sector. In this study, the effects of climate change in the form of several temperature change shocks are investigated. The IO model offers the advantage of enabling a comprehensive examination of various sectors within the economy, including agricultural activities. The remainder of this paper unfolds as follows :The second section reviews relevant literature and illustrates the contribution of the present study to the existing body of knowledge. Section three elaborates on the quantitative simulation tools developed. Subsequently, the simulation results are deliberated upon. Lastly, in section five, the conclusion and policy implications are delineated.

Method and data

The analytical tool to examine the effects of climate change on the import and export of agricultural activities is an IO model which will be described in the following section. In the modeling framework, climate change effects are related to I-O via damage function.

Input-Output model

The input-output model is based on the interrelationships between production and consumption and imported products in activities or production sectors. In the IO framework, the total demand for output consists of intermediate and final demand, which, in terms of value, is equal to the payments made to the output producers. The primary step in building an IO model is to divide the economic activities into production sectors and measure the flow between sectors in monetary values. Given that the economy consists of N sectors, the total output of production sector i, X_i is divided into final demand, F_i, and intermediate demand, Z_{ij}, which is the demand of sector j from industry i; thus, the corresponding equation is written as follows (Miller & Blair, 2009; Liu *et al.*, 2020):

$$X_i = \sum_{j=1}^{N} Z_{ij} + F_i \quad (1)$$

where X_i is the total product, Z_{ij} is intermediate or interindustry demand, and F_i is the final demand. Final demand includes private and public sector consumption, export and import amount, and other items of final demand. Eq. 1 indicates that the total output or the total supply of sector i is equal to total demand for the sector products, including its own demand. The matrix arrangement of the Eq. 1 is presented as follows. Also, Z_{ij} is related to total output using equation (2):

$$Z_{ij} = a_{ij}X_j \quad (2)$$

which, a_{ij} is known as technical coefficients (Miller & Blair, 2009; Liu *et al.*, 2020).

$$\begin{bmatrix} X_1 \\ \vdots \\ X_N \end{bmatrix} = \begin{bmatrix} Z_{11} & \cdots & Z_{1N} \\ \vdots & \ddots & \vdots \\ Z_{N1} & \cdots & Z_{NN} \end{bmatrix} + \begin{bmatrix} F_1 \\ \vdots \\ F_N \end{bmatrix} \quad (3)$$

The F matrix, which represents the final demand, includes consumer purchases (C), purchases for investment (I), government purchases (G), and net exports (E) (Miller & Blair, 2009).

There are different modeling approaches in IO-based models. The current study applies the supply-side IO model for two reasons. First, climate changes affect the output through three channels, including value-added inputs, as illustrated in the literature (Tsigaris & Wood, 2019; Tol, 2009). Second, as a novel empirical examination, it develops a dynamic modeling approach in which the growth in productivity and endowment of labor and capital accumulation are the primary features (Aroche Reyes & Marquez Mendoza, 2021; Jabilles & et al., 2019).

Analogue to Eq. (2), the payments segment (value-added) (V) has also been added. Payments segment in supply-side representation is divided into, labor payments (L), capital payments (K), and depreciation (D) as follows:

$$\begin{bmatrix} X_1 \\ \vdots \\ X_N \end{bmatrix} = \begin{bmatrix} Z_{11} & \cdots & Z_{N1} \\ \vdots & \ddots & \vdots \\ Z_{1N} & \cdots & Z_{NN} \end{bmatrix} + \begin{bmatrix} V_1 \\ \vdots \\ V_N \end{bmatrix} \quad (4)$$

The matrix arrangement in Eq. (4) can be presented as follows:

$$X = B'X + V \quad (5)$$

where the value of Z_{ij} and X_i is specified in Eq. (3). Matrix B is the allocation coefficient, which is defined as the ratio of the demand of sector j from sector i (Z_{ij}) to the total production of section i (X_i). Matrix B is defined as follows (Miller & Blair, 2009; Galbusera & Giannopoulos, 2018):

$$b_{ij} = {Z_{ij}}/{X_i} \quad (6)$$

In relation (5), V is the matrix of the payment segments. Therefore, the total demand (X) is equal to:

$$X = (I - B')^{-1}V \quad (7)$$

Equation (7) shows that any change in the payment to value-added factors will affect the X matrix and then the Z matrix. Regarding Eq. 1, the final demand block, including the net export, may be as follows:

$$F_i = X_i - \sum_{j=1}^{N} Z_{ij} \quad (8)$$

Also, similar to Eq. 2, the matrix form is Eq. 9:

$$\begin{bmatrix} F_1 \\ \vdots \\ F_N \end{bmatrix} = \begin{bmatrix} X_1 \\ \vdots \\ X_N \end{bmatrix} - \begin{bmatrix} Z_{11} & \cdots & Z_{1N} \\ \vdots & \ddots & \vdots \\ Z_{N1} & \cdots & Z_{NN} \end{bmatrix} \quad (9)$$

where, the final demand includes N components, including net export.

In the dynamic model, the yearly evolution of fixed capital influences the total output by affecting the income derived from capital returns. Consequently, the equation governing the movement of fixed capital should be calculated using Equation 10. This equation presents the fixed capital of the following period, which is the sum of the current period investment and fixed capital discounted for depreciation. The related equations are Eqs. 10-12 (Miller & Blair, 2009):

$$K_{t+1} = (1 - \delta_t)K_t + I_t^n \quad (10)$$

$$I_t^n = S_t \quad (11)$$

$$S_t = Q_t - C_t \quad (12)$$

where I_t^n, S_t , and K_t represent investment, total savings, and total physical capital in the period (t). Q stands for total income and C

indicates consumption. δ[1] is depreciation measured as a fixed percentage of the total physical capital. For year $t+1$, the income obtained from capital stock is calculated based on a fixed amount of income for each unit of capital. Similarly, the time path motion of labor productivity (A) is presented by Eq. (13), in which the rate of annual labor productivity growth (g_A) is considered exogenous and fixed (following Eq. 13).

$$A_{t+1} = (1 + g_A)A_t \quad (13)$$

where, labor productivity is grown yearly at a fixed rate of 1 percent, as applied by the related literature for the Iranian economy (AlShehabi, 2013; Gharibnavaz & Waschik, 2015; Farajzadeh, 2018).

Climate change effects

Climate effects block is related to the I-O via damage function. This includes three channels of interrelationship. Climate change may damage output directly, known as the output level effect. Other channels are capital stock depreciation, and loss in productivity growth (Tsigaris & Wood, 2019) which affect output indirectly. Damage function (D) is defined as a convex function related to the temperature anomaly (T_t) relative to the pre-industrial level (Weitzman, 2012; Dietz & Stern, 2015):

$$D_t = 1 - \frac{1}{(1+\pi_1 T_t + \pi_2 T_t^2 + \pi_3 T_t^{6.754})} \quad (14)$$

In the standard damage function from the DICE model[2], for the temperature anomaly of 2-3 ºC (N-damages), π_3=0. As presented by Eq. 15, the damage function is incorporated into the production function (Weitzman, 2012; Dietz & Stern, 2015, Farajzadeh *et al.*, 2022):

$$X_t^N = (1 - D_t^x) f_{(Z_{1N}. \ldots . Z_{NN}.F_N)} \quad (15)$$

where D_t^x is the damage factor for the output level component in time t defined by Eq. 16 (Dietz & Stern, 2015):

$$D_t^x = 1 - \frac{(1-D_t)}{(1- D_t^K - D_t^A)} \quad (16)$$

D_t^K and D_t^A are other components of the damages related to capital stock and labor productivity, respectively, which are quantified as follows (Dietz & Stern, 2015):

$$D_t^K = f^K D_t \quad (17)$$

$$D_t^A = f^A D_t \quad (18)$$

f^K and f^A are allocated values of 0.3 and 0.05, respectively (Dietz & Stern, 2015). Accordingly, the corresponding motion equations of the value-added factors adjusted for climatic effects are presented in Eq. 19 and 20 (Farajzadeh *et al.*, 2022):

$$A_{t+1} = (1 - D_t^A)(1 + g_A)A_t \quad (19)$$

$$K_{t+1} = (1 - D_t^K)(1 - \delta_k)K_t + I_t^n \quad (20)$$

The effects of climate change (D_t^A *and* D_t^K) are not expected to be the same for different sectors. It is worth noting that there is a widely held view that climate change is expected to affect the agricultural sector more significantly than the telecommunications sector, that are less dependent on climatic variables.

Now, we may rewrite the above-mentioned equations incorporating the climate effects. Thus, the corresponding to Eq. (7) will be presented as Eq. (21):

$$X_{t+1} = (1 - D_t^x)\,(I - B_t')^{-1} V_t \quad (21)$$

Eq. (21) indicates that under the climate change effect, part of the total output will be lost in the next period due to the damage caused by climate change as D_t^x is allocated a value between zero and one.

Scenario setting

The BAU (Business as Usual) condition ignores the effects of climate change. This study uses scenarios of temperature anomaly (temperature increase shock) to examine the impact of climate change on different sectors of Iran's economy. The first scenario is the warming tendency under the Representative Concentration Pathway (RCP) model, i.e., RCP 2.6 (1.5–2 degrees Celsius Global Mean Temperature Increase). Other scenarios are

1 - The effective rate of depreciation applied in the modeling is 3.95 percent every year (Farajzadeh *et al.*, 2022)

2 - Dynamic Integrated model of Climate and the Economy (the DICE model) attempts to use the tools of modern economics to determine an efficient strategy for coping with the threat of global warming (Nordhaus, 1992).

RCP4.5 (2.5 – 3 degrees Celsius Global Mean Temperature Increase), RCP6 (3 – 3.5 degrees Celsius Global Mean Temperature Increase), and RCP8.5 (5 degrees Celsius Global Mean Temperature Increase). The scenarios for the damage function used in the present study are W-damage and DS-damage. After analyzing climate change in the form of scenarios, the results of each scenario on Iran's economy are studied in the form of the IO model. SSP1-1.9 W is considered to have the least damage, and the most damage is related to the SSP5-DS scenario.

Data

The primary data applied for this study includes Iran's IO table published by the Central Bank of Iran (2016). Another primary data is the damage caused by climate change, which for non-agricultural activities, was mainly obtained from Farajzadeh *et al.* (2022). For agricultural activities, the Iranian Environmental Organization (2021) provides the data for the current production damages. Also, the damages to agricultural natural resources were calculated based on data presented by the UNFCCC report (2017). The data issued in the Iranian literature (Dalir *et al.*, 2021; Malakootikhah & Farajzadeh, 2020) was used to calculate the damages to the forestry sector. Other variables including labor productivity growth and physical capital depreciation, were extracted from Farajzadeh *et al.* (2022). Temperature anomaly and projection average temperature based on CMIP6 by 2060 were obtained from the World Bank Climate Change Knowledge Portal (CCKP, 2022).

Results

In this study, the results of changes in the volume of imports and exports due to climate change with other conditions being constant, are given under different scenarios. Fig. 1 shows the temperature time path under different scenarios. The highest temperature increase in the early years is associated with the SSP1-1.9 scenario, but the SSP5-8.5 scenario predicts the most severe temperature increase. The annual average temperature of Iran until 2060 is predicted to be higher than 21°C, which is 2.5°C higher than the current average. The lowest temperature anomaly is more than 0.5°C, which is expected to happen under SSP1-1.9.

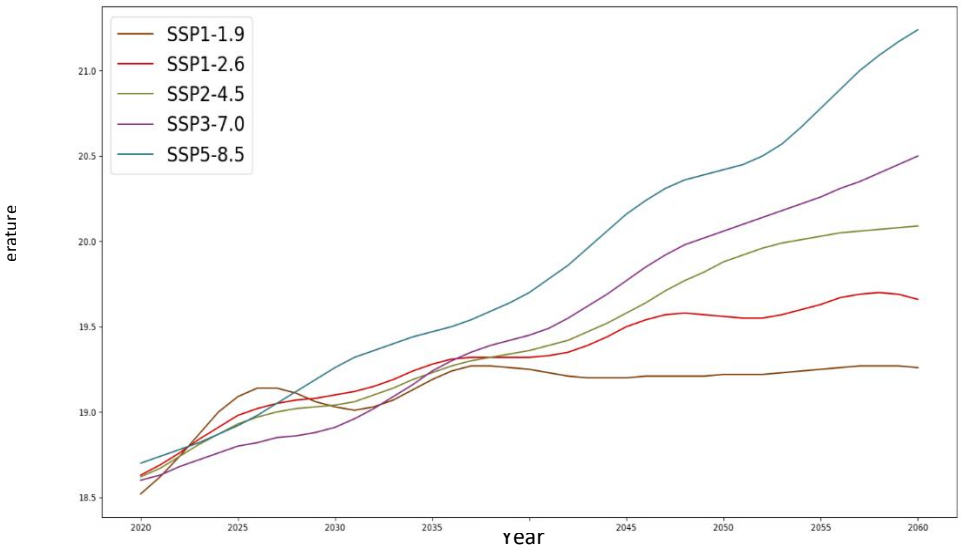

Figure 1- Temperature time path under different scenarios

The alterations in exports and imports resulting from the impacts of climate change stem from three key factors: labor productivity, capital, and final output. Figs. 2 and 3 show the combination of damage from these channels. Fig. 2 shows the decomposition of damages on the import of total agricultural products. In all scenarios, output damage has the most significant contribution, and the lowest contribution is related to labor productivity damage. Output channel accounts for around 39 percent of output damage under SSP1-2.6 and it increases to more than 41 percent under SSP 3 and SSP5. The corresponding values for productivity damage range 26-28.5 percent, while the capital damage channel will be allocated 32-34 percent. In terms of damage share, the W-scenarios contribute slightly more to output damage compared to the DS scenarios, although the difference is minimal. Conversely, higher temperature anomaly scenarios are associated with greater shares of output damage and reduced contributions from productivity sources. These results suggest that in scenarios with more stringent temperature increase levels, the most immediate impact of damage (output damage) plays a more significant role.

Figure 2- Contribution of damaging channels to import

Fig. 3 shows the decomposition of damage sources for the export of agricultural products. Here, as in import, a larger share belongs to output damage, while compared to import, output damage is more significant. In other words, the level or direct effects will be more determinant in the export of agricultural commodities. In the SSP1-2.6 DS-scenario, the labor productivity damage share is 22 percent, and the output damage share is 49 percent, and

under the SSP5 DS-scenario, the corresponding values are 21 percent and 48 percent, respectively, which shows a slight change in share values. Contrary to import results, for export, the W and DS scenarios results illustrate more differences. For instance, regarding the W-scenarios, the share of output damage ranges from 40 percent to 49 percent and the corresponding range for labor productivity damage is from 28 percent to 22 percent. In addition, it is worth noting that, to a great extent, in terms of damage share, there is a trade-off between productivity and direct effect of damage (output damage) while the damage share of capital remains with slight variations. This may arise from the fact that under marginal conditions of production, the role of rival inputs is more than productivity growth.

Figure 3- Contribution of damaging channels to export

Fig. 4 and Table 1 show changes in the volume of imports of agricultural products. BAU shows that the annual growth of total agricultural imports is 2.73 percent per year on average. Among the agricultural sectors, livestock has the highest import growth, with an annual growth of 2.8 percent, and forestry has the lowest growth, around 2.65 percent. In other words, under the current situation, there is an insignificant difference among the agricultural sectors, and the time path shows an increasing trend for all sectors.

As shown in the first column (Table 1), around 31 percent of imports are allocated to livestock, followed by cereals with a contribution of more than 25 percent. In other words, the livestock industry and the cereals that contribute to providing protein food item are responsible for more than 56 percent. Rice and oilseeds account for 19.5 and 14 percent, respectively.

Contrary to the ever-increasing trend under BAU, with the application of climate change scenarios, a significant divergence is observed.

Cereals, rice, fishery, and aquaculture exhibit lower susceptibility to climate change across all climatic scenarios, with their overall trend closely aligning with the business as usual (BAU) scenario. In contrast, other sectors experience substantial impacts from climate change, with import trends significantly declining compared to BAU. Particularly notable is the decreasing trend observed in sectors such as oilseeds and sugar beet. The average growth of imports of the total agricultural sector, compared to the BAU, decreases for all scenarios. This reduction is 0.95 percent for the optimistic scenario and 1.7 percent for the pessimistic scenario per year (Table 1 and Fig. 4). The total output at the economy-wide level and the decrease in disposable income are responsible for these changes.

Among the agricultural sub-sectors, the decline in oilseed imports is more pronounced compared to other products. In the SSP5-DS scenario, the average change in the import of this product is -2.49 percent. Conversely, the reduction in cereal imports is comparatively less significant. Additionally, it's noteworthy that the amount of cereal imports decreases with the mitigation of damage across different scenarios. The cereals import trend, even under the most restricting scenario, remains above 2 percent, ranging from 2.05 to 2.30 percent. Regarding the current population increase of 1.24 percent (Statistical Center of Iran, 2022), this figure shows an increase in per capita consumption, which is in accordance with expectations since the current consumption of Iranian households is not high enough. Regarding import growth, cereals are followed by fishing and aquaculture products. The above range for these sectors is 1.7-2.05 and 1.5-1.9 percent, respectively. These ranges are higher than those of aggregate agriculture.

The import fluctuations for other agriculture and livestock, which constitute a substantial portion of agricultural output, exceed 1 percent in all scenarios except for SSP5. Regarding production interrelationships, there is a close association between livestock and cereals. Higher import growth of creels, which is accompanied by lower import growth of livestock output, may indicate that the domestic output of livestock produced by imported cereals provides higher output, requiring lower levels of import of livestock products. In all scenarios, cereals import grows over 2 percent, while the corresponding value for livestock is mostly less than 1.5 percentOverall, the changes in agricultural imports tend to favor cereals and aquaculture products, while other crops, particularly those utilized as intermediate inputs in food processing activities, are projected to experience declines in imports. In order to provide a comparison, in the last row of Table 1, the import value and the changes in non-agricultural import are also presented. Under all climatic scenarios, the import growth of non-agricultural commodities is higher than that of agricultural ones. The import growth of agricultural commodities is almost less than 1.5 percent while for non-agricultural one is around 1.9-2 percent. It is also worth noting that the value of the current imports of agriculture is less than 7 percent of total imports, and under climatic scenarios, this value will be dampened.

As is shown in Table 1, climatic scenarios are examined under two options of the damage function, i.e., W-damage and DS damage. It seems that the effect of damage option is more significant under higher temperature anomalies compared to the lower ones. For example, under SSP1-1.9, the import growth of agriculture in W and DS options are 1.61 and 1.60, and the corresponding values for scenario SSP5 are 1.12 and 1.03. The same implication is observed for non-agriculture as well. In terms of the extent of the effects, there are substantial differences between sectors.

Table 1- Import growth under different scenarios

	Base Year (10^ 6 Billion Rls.)	BAU	SSP5-DS	SSP5-W	SSP3-7.0 D	SSP2-4.5 D	SSP1-2.6 D	SSP3-7.0 W	SSP2-4.5 W	SSP 1-2.6 W	SSP 1-1.9 W
Agriculture	185.2	2.73	1.03	1.12	1.33	1.45	1.60	1.36	1.46	1.61	1.78
Wheat	2.4	2.72	0.13	0.19	0.81	1.08	1.40	0.83	1.09	1.41	1.69
Rice	36.1	2.71	1.48	1.56	1.70	1.76	1.81	1.72	1.77	1.81	1.86
Cereal	47.8	2.73	2.18	2.29	2.17	2.14	2.09	2.20	2.15	2.09	2.05
Oilseeds	26.0	2.73	-2.49	-2.44	-1.29	-0.72	0.07	-1.27	-0.71	0.07	0.95
Sugar beet	0.2	2.72	-1.51	-1.45	-0.45	-0.43	0.66	-0.42	-0.42	0.66	1.30
Livestock	57.3	2.80	0.62	0.71	1.17	1.36	1.59	1.19	1.37	1.60	1.81
Forestry	9.5	2.65	-0.29	-0.28	0.15	0.35	0.65	0.16	0.35	0.65	0.98
Fishing and aquaculture	0.2	2.73	1.72	1.84	1.91	1.96	2.00	1.94	1.97	2.00	2.04
Other Agriculture	5.6	2.74	0.34	0.41	0.99	1.24	1.53	1.02	1.25	1.53	1.79
Non-Agriculture	2589.8	2.73	1.67	1.85	1.91	1.96	2.00	1.95	1.97	2.00	2.04

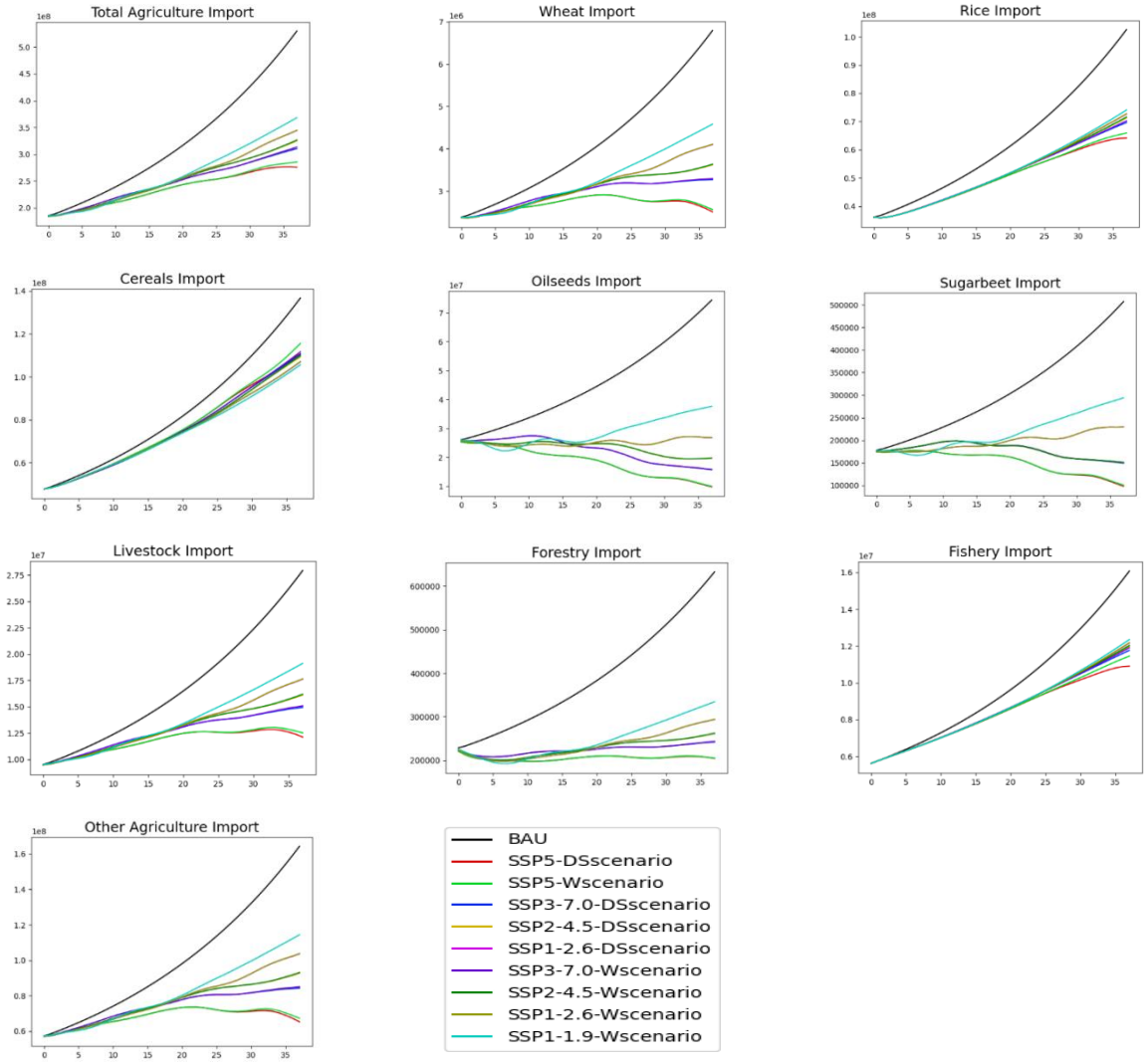

Figure 4- Time path of imports under different scenarios

X-axis indicates time horizon and Y-axis shows corresponding values in Rials multiplied by exponents

In terms of exports, agricultural activities account for only around 3 percent. It is worth noting that energy-related commodities account for most of Iranian exports. Livestock products account for more than two-thirds of agricultural exports, followed by forestry, contributing to 22 percent of agricultural exports. Around 9 percent of agricultural export is also allocated to other agricultural products that are mainly horticultural products.

Table 2 and Fig. 5 show the status of agricultural export growth. In the base year, the total export volume of agricultural products is less than half of the import, but the annual growth rate of exports in BAU conditions is estimated to be 2.75 percent on average. Among the subsections, livestock has the highest export growth, with an annual growth of 2.8 percent. On the other hand, the export of wheat, rice, oilseeds, and sugar beets is zero. In general, the export trend of the agricultural sector is increasing under different scenarios; however, it is less substantial compared to the increasing import trend, and only under the SSP1- 1.9 W scenario, the annual growth trend of exports exceeds imports.

Partially, the growth trend of cereals, and fishery and aquaculture exports show the lowest damage, so the growth trend of cereals exports will not be less than 2 percent per year under any of the scenarios. However, it should be noted that the amount of grain exports in the base year is slight. Regarding aquaculture, the amount of export is three times the amount of import in the base year, and the annual growth rate of its export is between 1.7 and 2.04 under different scenarios.

Since Iran does not export wheat, rice, oilseeds, and sugar beet, the export change for these products is zero. When considering the export of other goods, forestry exhibits the lowest rate of export growth at 2.65 percent per year. Intriguingly, this sector also experiences the highest damage from climate change. Under the most restricting scenario, the annual growth rate of forestry exports is -0.29 percent, and under the most optimistic scenario it is 0.98 percent, which is significantly lower than other sectors.

Climate change will reduce non-agricultural exports growth since its current annual growth of 2.7 percent is lower than those under climatic scenarios. However, the corresponding value for agricultural export is lower. Under the BAU, the export growth is around 2.7 percent for both agricultural and non-agricultural commodities; however, climate change cut the growth by half for most scenarios. This indicates that under climate change, export composition is expected to be more inclined toward non-agricultural commodities.

Table 2- Export growth under different scenarios

Sections Scenarios	Base Year (10^ 6 Billion Rls.)	BAU	SSP5-DS	SSP5-W	SSP 3-7.0 D	SSP 2-4.5 D	SSP1-2.6 D	SSP3-7.0 W	SSP2-4.5 W	SSP1-2.6 W	SSP1-1.9 W
Agriculture	90.7	2.75	0.56	0.64	1.12	1.34	1.59	1.15	1.35	1.59	1.81
Wheat	0.0	0	0	0	0	0	0	0	0	0	0
Rice	0.0	0	0	0	0	0	0	0	0	0	0
Cereals	0.3	2.73	2.18	2.29	2.17	2.14	2.09	2.20	2.15	2.09	2.05
Oilseeds	0.0	0	0	0	0	0	0	0	0	0	0
Sugar beet	0.0	0	0	0	0	0	0	0	0	0	0
Livestock	61.7	2.80	0.62	0.71	1.17	1.36	1.59	1.19	1.37	1.60	1.81
Forestry	20.1	2.65	-0.29	-0.28	0.15	0.35	0.65	0.16	0.35	0.65	0.98
Fishing and aquaculture	0.6	2.73	1.72	1.84	1.91	1.96	2.00	1.94	1.97	2.00	2.04
Other Agriculture	7.9	2.74	0.34	0.41	0.99	1.24	1.53	1.02	1.25	1.53	1.79
Non-Agriculture	3250.6	2.73	1.67	1.85	1.91	1.96	2.00	1.95	1.97	2.00	2.04

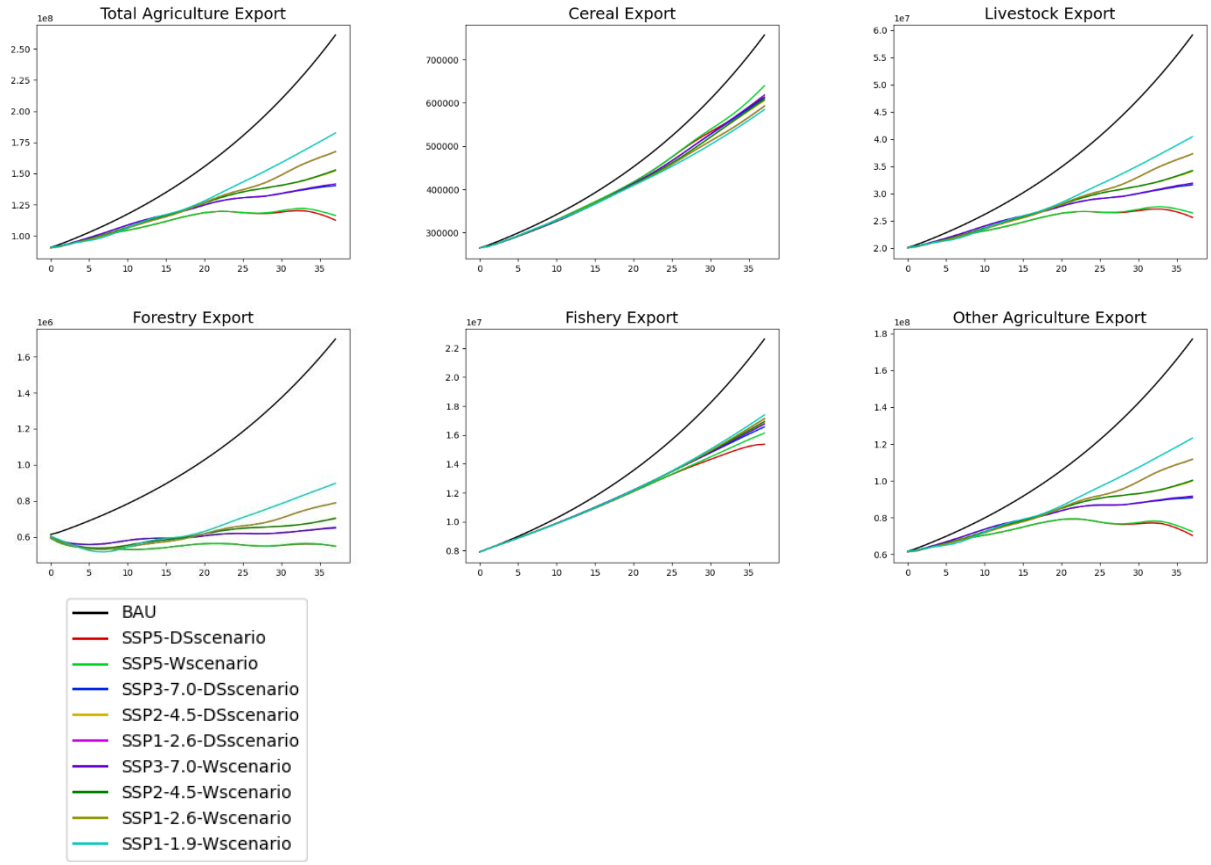

Figure 5- Time path of exports

X-axis indicates time horizon and Y-axis shows corresponding values in Rials multiplied by exponents

To analyze the import and export of agricultural commodities collectively, the trade balance is evaluated. Regarding net exports, agricultural commodities can be divided into two groups. As depicted in Fig. 6, the import of wheat, rice, grains, oilseeds, and sugar beet products notably exceeds their exports, leading to a negative trade balance for these items. Consequently, the overall export of the agricultural sector is lower than its import. The interesting point is that climate change leads to a higher trade balance in this category since it induces a more significant reduction in their import compared to their export. Especially in the last decade of the simulation horizon, improvement in trade balance tends to increase significantly. Among the sectors, oilseeds and sugar beet, for some scenarios, approaches to positive net export values. Export of livestock, forestry, aquaculture, and other products in the base year is more than their import, and the trade balance is positive. For this group, also, climate change dampens the net export potential. Especially for forestry, climate change wears out the potential. This is due to significant damage to natural resources in this sector.

Conclusion

Agricultural trade in Iran is remarkably subjected to trade barriers like tariffs or non-price barriers such as quotas. In addition, the prohibitive sanctions have also restricted trade, including agricultural trade. There is evidence supporting the positive effect of economy-wide trade liberalization (Farajzadeh *et al.*, 2017) and agricultural free trade (Farajzadeh *et al.*, 2012; Zolanvari Shirazy & Farajzadeh, 2023). This implicitly may indicate that there is potential in the Iranian economy, including agriculture, to benefit from free trade. However, climate change, especially at the higher temperature anomalies, harms the possibility of enjoying the advantages.

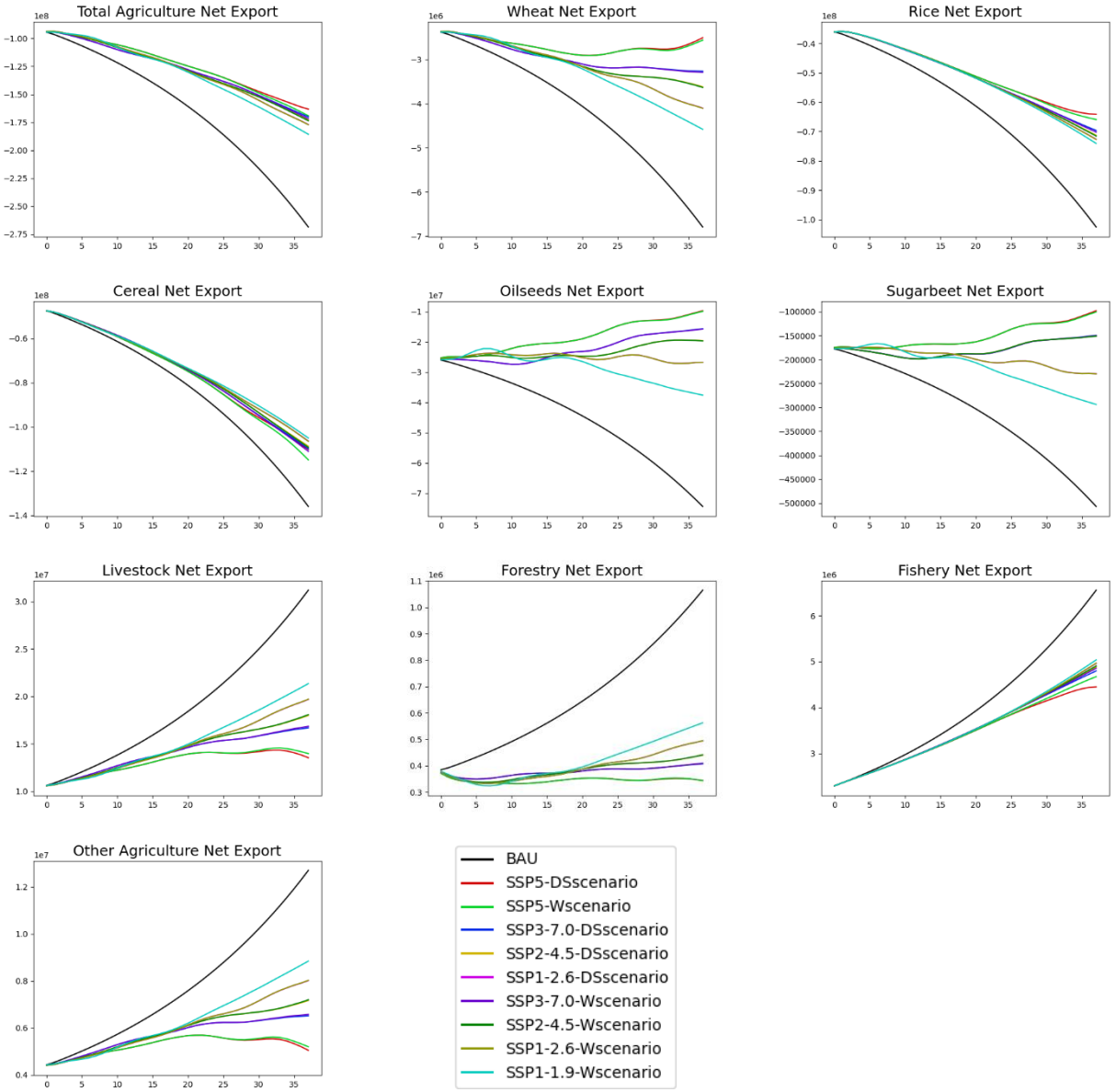

Figure 6- Time path of trade balance (net export)
X-axis indicates time horizon and Y-axis shows corresponding values in Rials multiplied by exponents

Based on this, active participation in trade, especially in the less climate vulnerable sectors, partially offsets the negative impact of climate change on production, capital and labor productivity, and further improves the economy's capacity for more trade in climate vulnerable sectors. However, there is a difference between the channels of damage and different measures to dampen the adverse effects. Damage to output level may be more complicated, while two other channels, i.e., productivity and capital damage, sound more straightforward. Developing measures to increase the capital resistance against depreciation and technologies enhancing labor's ability to perform under severe conditions should be considered. However, especially for export, around half of the damages are carried out through output level damage indicating significant damage to output.

Climate change is anticipated to alter the

trade composition both at the economy-wide level and within agricultural sectors at the national level. Non-agricultural trade is projected to expand relatively, while at the sectoral level, cereals, livestock, and forestry are expected to play a more prominent role in trade compared to other activities. Total net export of agriculture is expected to be improved via, to a great extent, a reduction in import; however, this should be addressed more deeply since output expansion of water-intensive products such as cereals will be difficult. During the years 1988 to 2017, Iran's average rainfall decreased by 2.1 mm, and on the other hand, the average temperature increased by 0.025 degrees Celsius (Abbasi *et al.*, 2019). Since Iran is located in an arid and semi-arid region, this decreases in rainfall and increase in temperature, which will continue in the coming years, will have wide-ranging effects on the production of water-intensive products. Therefore, the cultivation of less water-intensive crops can highlight the importance of the role of Iran's agricultural sector in trade.

The current situation of the Iranian economy, including agricultural, is characterized by government dominance in policy adoption, leading to limited advantages from a market-based economy. Thus, significant reform will be expected in the agricultural sector. Climate change will put pressure on agricultural trade; however, there is a wide held view that agriculture may benefit from these reforms (Zolanvari Shirazy & Farajzadeh, 2023). Therefore, it is recommended to proceed with the reforms along with the climate change occurrence.

Although agricultural trade and especially its export may be dampened based on the current situation of the Iranian economy as depicted by the IO table of 2016, there is some evidence that may provide more chances for agricultural export expansion. For example, adopting environmental restrictions may grant agricultural exports because of its less energy and emission intensity especially if it is accompanied by higher efficiency in natural resources use (Jebli & Youssef, 2017; Baker *et al.*, 2018; Dang & Konar, 2018).

Overall, as outlined in the literature, there exists substantial potential for agricultural trade, particularly agricultural exports. However, climate change poses a threat to this potential, necessitating the implementation of policies and actions to mitigate the damages caused by climate change. Trade liberalization and the reduction of export barriers can serve as crucial measures in alleviating the effects of climate change on agricultural trade. A possible extension for the current study that other empirical studies may investigate is the climate change effect under trade liberalization. Iranian agricultural trade will be significantly important in both exports and imports. As far as export is concerned, the necessity of expanding non-oil export revenues assigns a high priority to agricultural export.

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مقاله پژوهشی

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تغییر اقلیم و تجارت کشاورزی در ایران: تحلیل داده-ستانده پویا

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چکیده

در دهه‌های اخیر با تشدید پیامدهای تغییر اقلیم، اهمیت این موضوع فزونی یافته است. زیرا ممکن است این پدیده در کشورهای درحال توسعه و به‌ویژه در مورد فعالیت‌های کشاورزی، موجب کاهش رشد اقتصادی یا توقف آن شود. می‌توان تغییر اقلیم را مهم‌ترین و پیچیده‌ترین چالش فعلی جامعه بشری تلقی نمود. در همین راستا مطالعه حاضر کوشیده است پیامدهای تغییر اقلیم را در حوزه صادرات و واردات محصولات کشاورزی در طی یک افق ۴۰ ساله و با استفاده از مدل داده-ستانده پویا ارزیابی کند. تغییر اقلیم به‌صورت سطوح مختلفی از ناهنجاری دما منظور و پیامدهای آن در بخش‌های مختلف اقتصاد ارزیابی شد. یافته‌ها نشان داد تغییر اقلیم رشد صادرات و واردات بخش کشاورزی را بشدت تحت تأثیر قرار می‌دهد. متوسط رشد سالانه واردات کالاهای کشاورزی در شرایط بدون تغییر اقلیم ۲/۷ درصد است، در حالی‌که در شرایط تغییر اقلیم و تحت سناریوهای مختلف افزایش دما به ۱/۸-۱ درصد کاهش می‌یابد. مقادیر متناظر برای صادرات کشاورزی به‌ترتیب ۲/۷۵ و ۱/۸-۰/۵۵ درصد است. افزون بر این، مشخص گردید در شرایط تغییر اقلیم بخش مهمی از تجارت کشاورزی را واردات غلات تشکیل می‌دهد. هم‌چنین نتایج نشان داد تجارت کل اقتصاد ایران به سمت کالاهای غیرکشاورزی بیش‌تر متمایل خواهد شد.

واژه‌های کلیدی: تجارت کشاورزی، تغییر اقلیم، داده-ستانده

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Research Article
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Assessing the Impact of Adopting the Rutete Rice Variety on Rice Farmer Productivity: A Case Study of Rutete Variety Introduced by IRRI in Gihanga, Burundi

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Abstract

Burundi, like other countries, invests in agricultural research and development. The adoption of the most productive varieties is one of the ways of increasing agricultural yields. Rice, because of its high productivity, is among the cereals which occupy an important place in the food security strategy in Burundi. This study aims to identify the effect of the adoption of this variety on the productivity of rice farmers. Using random sampling technique was used to select the respondents to fill the questionnaires, data were collected from 524 rice farmers spread across the five villages, namely Buringa, Murira, Nyeshanga, Ninga and Bwiza of the Gihanga commune in Bubanza, Burundi. The analysis of the determinants and the quasi-experimental method based on propensity score matching was used in the estimation of the results of the effect of adoption of the rutete variety on the productivity of rice farmers and estimate the results. The study found that the average rice yields for adopted and non-adopted farmers were respectively 9754 and 9912 kg/ha. Also, if non-adopting farmers decide to adopt the variety, their counterfactual rice yield would be 7931 kg/ha for adopters and for non-adopters reached 7927 kg/ha. The average effect of the treatment on the rice yield of the adopters was 1823 kg/ha and significant ($p<0.01$). The decision to adopt for non-adopting rice farmers could increase the average yield by 1984 kg/ha. The results imply the positive role of the adoption of the rutete rice variety on the performance of rice farmers in Gihanga. It is recommended that the government and research institutions involved in the agricultural sustainable development support rice farmers by increasing agricultural research innovation with the aim of increasing the yield of crops.

Keywords: Propensity Score Matching, Rutete Rice, Rice yields

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Introduction

In sub-Saharan Africa, rice is a fundamental source and component in the diet of rural and urban households. From 2014 to 2018, the rice production increased by 22.4 million tonne in 2014, against 28.3 million tonne in 2018 (26 percent increase). The rice consumption has exceeded 37 million tonne in 2017 and should be around 39 million tonne in 2018, either 25 percent of the cereals consumed (Jégourel, 2019).

In Burundi, the rice demand has generally risen sharply due to population growth, urbanization and changing consumption patterns (MINAGRI, 2014). To respond to the rice production deficit, the government resorted to imports, especially from Tanzania and Zambia. In addition, the International Rice Research Institution (IRRI) has contributed to the promotion of the rice sector through the introduction of new rice varieties that are highly productive, resilient, and adaptive to biotic and abiotic stresses for rice-growing areas in the aim of reducing poverty and hunger, improving the health and well-being of rice farmers and consumers (IRRI, 2020). Thus, rice imports are gradually decreasing due to research agricultural technology innovation and adoption. In 2017, rice imports were estimated at 10,995.9 tonne and fell sharply down to 3,219.1 tonne in 2018 (ISTEEBU, 2018). In 2019, expenditure was estimated at 27,118.9 million Fbu and 15,346 million Fbu in 2020. Although the rice production in high and low land has reduced rice imports, Burundi is still depending on the imports. This evidence castigates that the ultimate objective of achieving potential production and food self-sufficiency in rice is far to be reached. Furthermore, there is a low level of rice yields in Burundi compared to that of the other African countries, ranging from 3.5 to 7 tonne /ha (FAO, 2016). Productivity is estimated at 4 tonne per hectare (ISTEEBU, 2015) but irrigated rice production offers a higher yield potential due to better water control. The inability to produce enough rice to meet demand is attributed to several constraints such as reliance on traditional farming techniques, land degradation caused by over-exploitation, limited access to additional services such as extension, agricultural credit (UNDP, 2012) as well as the low adoption of present agricultural technologies proposed by research centers, results of the low financial means of rice farmers (Tene *et al.*, 2013).

In Burundi, where production resources (especially land) are extremely scarce, the adoption of new agricultural technologies by farmers is the best complement to all the efforts made for self-sufficiency in terms of rice production. Moreover, Zeller *et al.* (1998) reveal that increasing agricultural yield is a difficult task and increasingly depends on the adoption of technologies with high added value. It is within this framework that support programs for the rice sector have been set up in Burundi, emphasizing the dissemination of productive varieties and related techniques that can help to significantly improve rice yields. The introduction of improved varieties of rice has been advocated in the various rice production zones. Among these, we have the varieties such as rutete, kazosi, mugwiza, gwizumwimbu, komboka, developed by IRRI in Gihanga and Hybrid rice developed by Chinese cooperation, in collaboration with Institute of Agronomic Research in Burundi (ISABU), Ministry of Environment, Agriculture and Livestock (MEAE) and Imbo Regional Development Community Tmpagny (SRDI).

This paper seeks to evaluate the contributions of IRRI research in Gihanga rice irrigation scheme and measure the impact of the adoption of the rutete rice variety on the yield of rice farmers, by estimating the difference between the yields of adopting and non-adopting households. Highly yielding rice was one of the factors that farmers chose to adopt improved varieties. Zomboudre (2017) shows that this decision is the process centered on the mental journey of the individual from the first information to the adoption. It produces change in a farmer's situation. Autissier & Moutot (2007) define change as “a rupture between an

obsolete existing and a future synonymous with progress". The rupture is a transformation from one state to another to stimulate the driving force of evolution, it is a passage from a state of imbalance to another more progressive one.

In the literature, several studies have found positive effects of technology adoption on farmers' yields (Wiredu *et al.*, 2010; Arouna & Diagne, 2013; Ogunniyi & Kehinde, 2015; Blaise, 2016; Issoufou *et al.*, 2017). The adoption of technology is anticipated to influence crop yield. Historically, impact evaluations have commonly utilized non-experimental designs. Among these approaches, propensity score matching (PSM) is frequently employed to estimate the effect of agricultural technology adoption. PSM aims to mitigate bias by matching treated and untreated groups with similar or identical observable characteristics, thus ensuring balance between the two groups based on their observable covariates. It is non-parametric tool which highlights the common support problem (Dehejia & Wahba, 1998; Smith & Todd, 2000; Sibilia & Sanofi, 2013).

Results contribute to the existing literature and serve as a basis to give a better understanding on the adoption and diffusion of the agricultural technologies in all the rice-growing areas of the country. The remaining parts are the following: The first part presents the methodology of the study; the second part presents the main results and discussion after which a conclusion and recommendations are drawn.

Methodology

The study area

The study was carried out in the rice irrigation scheme of Gihanga located in the south-western part of the province of Bubanza, Burundi, where the SRDI, launched a program by which rice producers receive both agricultural inputs (mainly seeds, water and fertilizers) and other essential agricultural services on credit (Fig. 1).

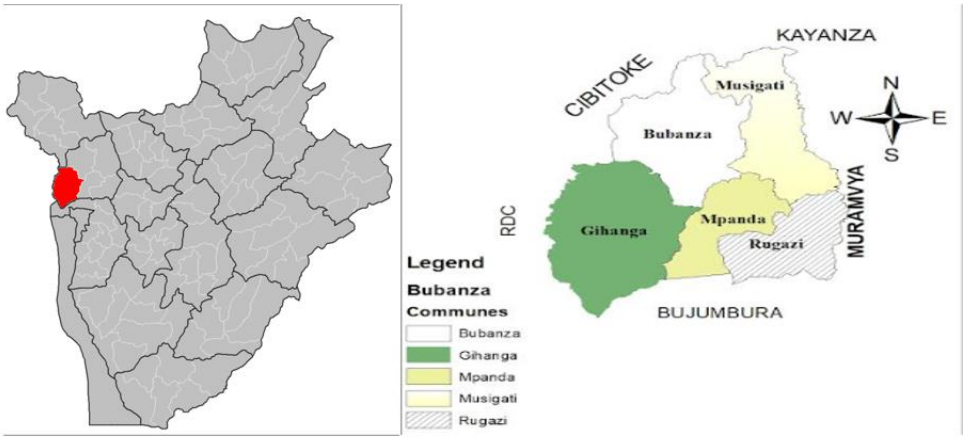

Figure 1- Map of Gihanga
Source: Extract from PDCD Report of Gihanga

The Gihanga irrigated scheme is located in the Imbo plain where most rice is produced in Burundi. Therefore, evaluating the effect of adoption of agricultural technologies in the rice sector based on the most productive varieties sheds light on the importance of rice varieties and provides useful information for research, agricultural policy and practice. Also, a large number of varieties from IRRI have been introduced in this commune than elsewhere. The data on rice production in the Gihanga irrigated scheme are realistic and updated to be consistent with the study. The institute IRRI provided most needed information on their contribution in the area and the challengers hampering the achievement of the goal of rice self-sufficiency and import-substitution.

Conceptual and theoretical frameworks

The conceptual framework of adoption (Fig. 2) and its associated factors is illustrated in the figure below. We believe that adoption is influenced by demographic (age, gender, marital status, level of education, household size, number of household workers), socioeconomic (farm size, farming experience, possession of a mobile phone) and institutional (Credit access, extension, Membership in an association). These factors can have effects on the adoption and yield of rice farmers (Table 1).

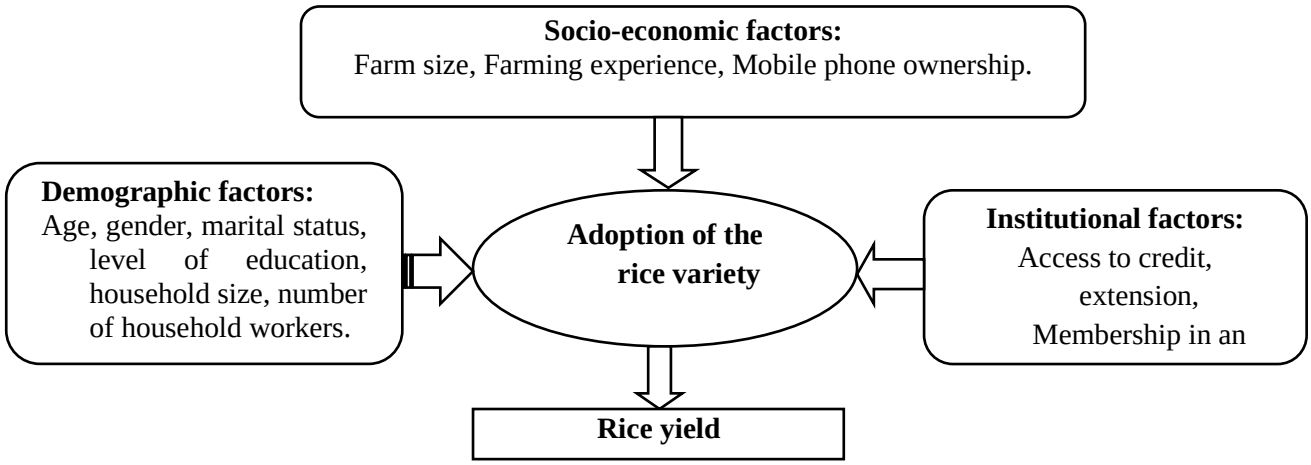

Figure 2- Conceptual framework of the study

The adoption of agricultural improved varieties is influenced by a range of factors (Muluken *et al*., 2021; Ngando *et al.*, 2022; Ouma *et al*., 2013): socio-economic, institutional and demographic factors (Fig. 1). If a farmer or institutions assisting to rice technology adoption are thriving to reconsider such factors, the crop yield will be definitively improved.

The theoretical framework borrows heavily from the theory of impact evaluation measuring whether improved rice yield is attributed the introduction of agricultural technology. We based ourselves on the theory of change which analyzes the situation of a farmer from his decision to adoption to a new situation. We apply the propensity score matching approach introduced by Rosenbaum and Rubin in 1983 to estimate the average treatment effect.

Therefore, participation in the treatment of a dissemination program of the rice variety rutete is represented by a random variable T. for each individual i, we have:

$$\begin{cases} T_i = 1 \; if \; rice \; farmers \; adopt \; the \; variety \; of \; rutete \; rice \; T_i \\ T_i = 0 \quad Otherwise \end{cases}$$

The effectiveness of the program is measured by the result variable $Y_i$which is a latent variable:

$$\begin{cases} Y_{T_i} if \; the \; rice \; farmer \; receives \; the \; improved \; variety \; of \; rutete \; type T = 1 \\ Y_{NT_i} Otherwise \;\; T = 0 \end{cases}$$

These two variables correspond to the potential results. They are never simultaneously observed for the same rice farmer. A treated rice farmer Y_{T_i} is observed while Y_{NT_i} is unobserved.

Yield levels of rice farmers were used as outcome variables to understand the real effect of adopting the rutete variety. However, we have shown what the yield of rice farmers would be if they only participated in the use of the rutete rice variety. We then compared the means of these results found for these variables with the observed results to identify the differences that were very important in our conclusions.

Based on the return equations of two groups (groups of adopters and group of non-adopters), we estimate the effect of adoption. We compare:

- The average of the expected results of rice farmers who decided to cultivate the rutete rice variety ($E(Y_i^1 |T_i = 1)$ compared to those who decided not to cultivate it ($E(Y_i^0 |T_i = 0)$);
- The average of the expected results of the counterfactual cases: the results that the rice farmers cultivating the rutete rice variety would have if they decided not to cultivate it ($E(Y_i^0 |T_i = 1)$); the results that rice farmers who do not grow the rutete rice variety would have if they decided to grow it ($E(Y_i^1/T_i = 0)$).

These different estimates lead us to make a significant comparison between the two treatment groups. The comparisons will tell us the average of the average effect of adoption on the yield of the adopting rice farmers:

$$EMTT = E(Y_I^1 - Y_i^0|T_i = 1) = E(Y_i^1/T_i = 1) - E(Y_i^0|T_i = 1) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

And the average of the average effect of adoption on the yield of non-adopting rice farmers if they adopted:

$$EMTNT = E(Y_i^1 - Y_i^0|T_i = 0) = E(Y_i^1/T_i = 0) - E(Y_i^0|T_i = 0) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

To estimate the results, the nearest neighbor matching method with replacement was used because it gives individuals from the adopters' group a better chance of finding their matches in the non-adopters' group to whom they can compare themselves.

Table 1- Description of the covariates used in the study

Dependent and Independent variables	Type of variables	Description
Rutete rice variety	Qualitative	Dependent variable: 1 if the rutete variety is adopted and 0 if not
Yield of rice farmers	Quantitative	The ratio of production and sown area of a rice farmer
Age of head of household	Quantitative	Number of years of the head of operations
Gender of head of household	Qualitative	1 if the individual is a man and 0 if not
Marital status of head of household	Qualitative	1 if the individual is married and 0 if not
Household head's level of education	Qualitative	The level of study was categorized as follows: 0= no level; 1 = primary level; 2= secondary level; 3= university level
Household size	Quantitative	The number of people living in the household
household labor	Quantitative	Number of farming people in the household
The sown area	Quantitative	Expressed in hectare
Agricultural experience of the head of household	Quantitative	Number of years of experience of a rice farmer
Possession of a mobile phone	Qualitative	Binary variable: 1 phone user and 0 if not
Membership in an association	Qualitative	Binary variable: 1= if the farmer belongs to an association; 0= no
Access to extension services	Qualitative	Binary variable: 1=if the farmer has access to extension services and 0=no
Access to credit	Qualitative	Funding for the farmer from microfinance institutions.
Market access	Qualitative	Binary variable: 1= if the farmer has access to the market and 0 if not

Data

Buringa (V1), Murira (V2), Nyeshanga (V3), Ninga (V4) and Bwiza (V6) villages. bwa Ninga (V5) villages having benefited from IRRI's program to disseminate different varieties of rice. The area of intervention and the various improved varieties of rice popularized by IRRI were drawn from its office located in Bujumbura. In addition, information on the variety of rutete rice was captured through interviews with rice farmers during the days of the pre-survey. We surveyed 105 rice farmers per village to cover the 524 adoptive and non-adoptive rice farmers of the rutete rice variety.

The sample size was calculated using Rea's formula and Parker (1997) as follows:

$$n = \frac{t_p^2 * p(1-p) * N}{t_p^2 * (1-p) + (N-1) * \gamma^2}$$

Where n = sample size; N =represents the population of rice farmers in the study area, it is equal to 8224; t_p= value of the Student index at

the significance level of 5%, it is therefore equal to 1.96; p = proportion of a given variable; γ= margin of error of the estimate of the main indicator.

Among the rice farmers surveyed, many of them are members of cooperatives supervised by the SRDI. Thus, members of SRDI cooperatives and non-members were interviewed using a well-structured questionnaire. This methodology allowed us to have fairly similar populations on average to be able to compare their results. In each village, rice farmers were randomly selected and all village residents had an equal probability of being sampled. This sampling took into account the gender aspect (men and women heads of households). The data collected are cross-sectional data and were collected following semi-structured interviews. These data grouped the demographic, socioeconomic and institutional characteristics of the households. Data were collected using KoBoCollect v1.28.0 software and analyzed with STATA 15.1 software.

Results

The following results emphasize the effect of the adoption of the rutete rice variety on the yield of rice farmers who participated in our sample.

Rice Production and Socio-Demographic Characteristics

The categorization of these induced variables in the model allows us to make an overall analysis of the rice producers in the study area. It is the analysis of quantitative and qualitative variables grouped into the demographic, socioeconomic and intentional characteristics of the respondents.

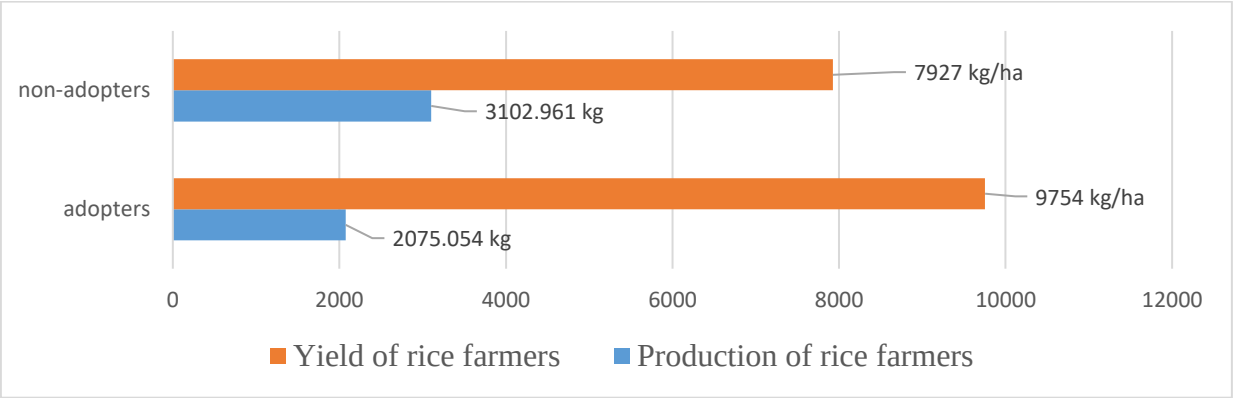

Figure 3- Production and yield of rice farms

On the performance, Rutete rice variety produces high quantities both in terms of production and yield compared to rice farmers practicing other varieties. However, given that the planting areas of non-adopters is greater than that of the adopters, the total production of the former is higher than their counterpart.

The analysis also shows that the households surveyed are mainly headed by men with 80.15 % against 19.85% of women (Table 2).

Table 2- Gender and Marital Status of Respondents

Variables	Terms	Adopters (n=152)		Non-adoptors (n=372)	
		Freq	%	Freq	%
Gender	Women	22	4.2	82	15.65
	Male	130	24.81	290	55.34
Marital status	Single	8	1.53	19	3.63
	Married	144	27.48	353	67.37

The analysis also shows that the households surveyed are mainly headed by men with 80.15

% against 19.85% of women. Men adopting and those not adopting are respectively 24.62% and 55.53% while among women, they are respectively 4.2% and 15.65%. This situation justifies that in the study area, agricultural households are largely headed by men. There is a big gender disparity in rice production.

Furthermore, marital status is an important socio-demographic factor with possibility of affecting the adoption of agricultural technology. Among the rice farmers surveyed, there were more married respondents (94.85 %) than single ones (5.15 %). However, non- adopters had a higher percentage of married respondents than adopters. It emerges from the analysis that the non-adoptors who are married represented 67.37 % of the sampled population while the adopters were 27.48 %. However, there were few single respondents: 3.63 % of non-adoptors and 1.53 % of adopters.

Table 3- Education of Respondents

Household Head Education						
Variables	**Adopters (*n=152)***		**Non-adopters (*n=372)***		**Total *(n=524)***	
	Frequency	**%**	**Frequency**	**%**	**Frequency**	**%**
No education	41	7.82	145	27.67	186	35.50
Primary School	68	12.98	158	30.15	226	43.13
Secondary School	38	7.25	68	12.98	106	20.23
University	5	0.95	1	0.19	6	1.15

As for the level of education, the study revealed that about 35.50% of the farmers had no level of education, 43.13% of the farmers had a primary education, 20.23% had a secondary education while 1.15 % of the farmers had a university education (Table 3). By adoption status, the statistics revealed that the non-adopters of all education levels are respectively represented by 27.67% of rice farmers with no level, 30.15% of rice farmers with primary level, 12.98% of rice farmers with secondary level and 0.19% of rice farmers with university level while the adopters are respectively represented by 7.82% of rice farmers with no level, 12.98% of rice farmers with primary level, 7.25% with secondary level and 0.95% with university level.

Table 4- Age, household size and family labor of respondents

Variables	**Adopters (n =152)**	**Non-adoptors (n =372)**
Age of head of household (years)	45	45
Household size (persons)	8	8
family labor (person)	2	2

The results in Table 4 show that the entire population sampled represents the average age of 45 years. It emerges from this result that the adopters and non-adopters of the rutete rice variety have both an average of 45 years and average of 8 individuals in each household. The figures remain in both groups given that the selection has been done at random without any prior bias.

In addition, the results also show us a small average of family labor (2 individuals). Adopter and non-adoptor households have the average household size of 2 and 2 respectively. The gap between household size and family labor force is relatively large. The respondents opined that they used much more hired labor in their rice farming system. In addition, the household heads surveyed found that men are much more responsible for rice farming while women are responsible for other agricultural activities.

Economic characteristics of respondents

This part presents the socio-economic characteristics of rice producers, focusing mainly on the possession of a mobile phone,

access to the market, the area sown for rice cultivation and the producer's experience in rice-growing activities.

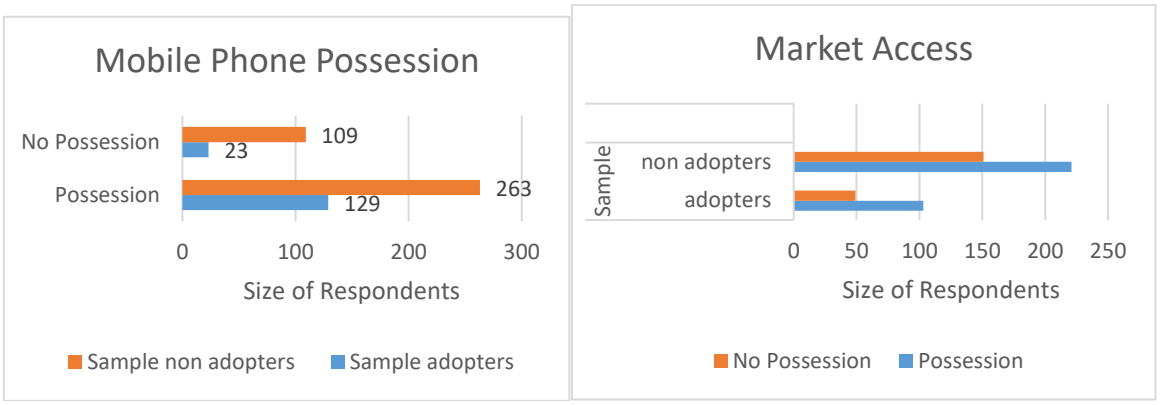

Figure 3- Mobile Phone possession and market access of respondents

Mobile phone is regarded as the necessary tool for communication in rural area. In the study area, the distribution of respondents based on mobile phone usage reveals that a majority are mobile phone users (74.62%), with the remaining 25.38% classified as non-mobile phone users. Among the adopters of rice farming technology, only 24.62% own mobile phones, while 4.39% do not. Conversely, among the non-adopters, 50.00% of respondents are mobile phone users, while 20.99% do not use mobile phones. The mobile phone plays an important role in the agricultural technology adoption. Cole & Fernando (2016) found that the communication tool helps in information access and awareness of agricultural technology innovation. In their study, mobile phone service was effective in nudging farmers to adopt a number of recommended agricultural technology.

Smallholder farmers often face serious difficulties in accessing markets to sell their produces in marketplace or buy crucial agricultural inputs (IFAD, 2015). The statistics also show 83.78% of respondents who have access to the market against 16.22% of respondents who do not have access to the market. This justifies that the rice cultivation practice in Gihanga is largely market oriented. According to the surveyed rice growers, a portion of the production obtained must be sold to repay debts contracted during the operating period, while another part is reserved for consumption. Based on adoption status, 25.19% of rice farmers with access to the market have adopted the rutete rice variety, whereas 58.59% of them have not adopted it. Additionally, 3.83% of rice farmers without market access have adopted the rutete rice variety, compared to 12.40% of rice farmers without market access who have not adopted it. In addition, among the rice farmers with access to the market, 25.19% have adopted the rutete rice variety while 12.40% of them have not adopted it.

The results also show that the average household in the study area has an average area of 27.71565 acres. The results in Table 9 show us that the non- adopters have an average area of 25.91 acres while the adopters have an average of 32.14 Ares. The average agricultural experience of rice farmers in the study area was 15 years. Descriptive statistics revealed an average of 16 years for the adopters while for the non-adopters the average experience was 15 years.

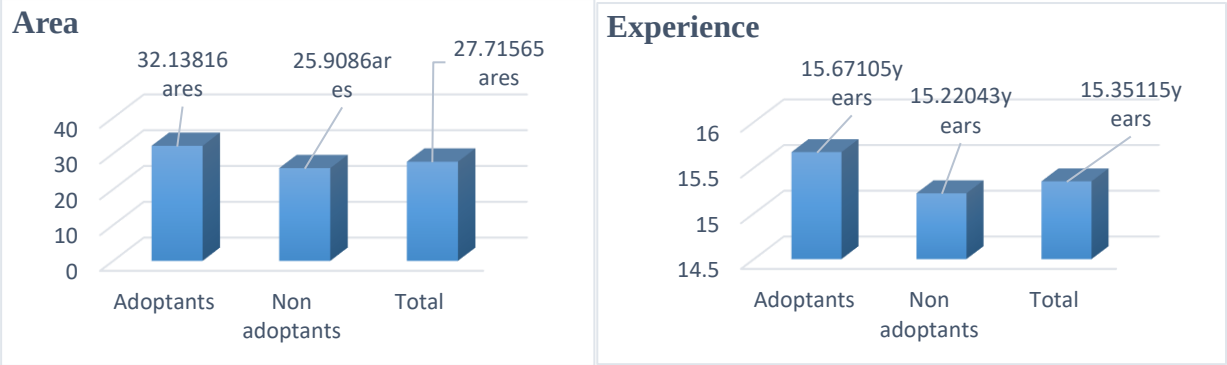

Figure 4- Area and agricultural experience among respondents

Features of Financial Institutions, Farmers'Associations and SRDI's Extension Service

In the population surveyed, farmers obtain agricultural credit through SRDI cooperatives, local lenders, and micro-finance institutions. Credits from the SRDI are often seeds and pesticides. These the latter are supposed to be repaid after the harvest. The rice farmers complain that the price recorded by the SRDI on the loan payment is so low (1300 Burundi Francs) compared to that of the local market (2200 Burundi Francs). Also, local lenders demand loan repayments at a high rate that rice farmers are unable to pay. However, we based ourselves on credit in monetary terms.

Table 5- Institutional characteristics

Variables	Terms	Adopters (n=152)		Non-adoptors (n=372)	
		Freq	%	Freq	%
Access to credit	Access to credit	101	19.27%	220	41.98%
	No access to credit	51	9.73%	152	29.01%
Popularization	Access to extension	99	18.89%	171	32.63%
	No access to extension	53	10.11%	201	38.36%
Membership in an association	Membership	121	23.09%	254	48.47%
	Not membership	31	5.92%	118	22.52%

In this study, information on access to credit was collected. Table 5 shows the number of respondents who requested agricultural credit during the last season of the year 2022 and others who did not request it. In the population surveyed, 61.26 % of farmers had access to credit against 38.74 % of farmers who did not have access to credit.

By adoption status, among the adopters, 19.27% of adopting rice farmers had access to agricultural credit against 9.73% of rice farmers who did not have access to agricultural credit. However, 41.98% of non- adopters had access to agricultural credit against 29.01% of rice farmers who did not have access to agricultural credit.

As for membership in an organization, the statistics showed 71.56% of the respondents who belong to a rice farmers' association and 28.44% of the respondents who do not belong to any rice farmers' association. By adoption status, 23.09% of adopters belong to an association against 5.92% of adopters who do not belong. In addition, 48.47% of non-adoptors belong to an association against 22.52% of non-adoptors who do not belong to any association. An extension service to rice farmers is an incentive for the adoption of improved rice varieties. In the study area, 48.47% declared that they did not benefit from these services from the extension agents while in the counterpart, the number who benefited from at least one extension agent was only 51.53%. By adoption status we noticed 18.89% of adopters who received at least one extension worker against 10.11% of adopters who did not. On the side of non-adopters, 32.63% benefited from extension services while 38.36%

answered that they never benefit from them. These services are supposed to be provided by SRDI agents as said the farmers. Those who said they don't get the extension service reveal of their non-participation in workshop or field demonstration the lack of extension services has been linked to inefficient production agricultural. Since the aftermath of the civil war in Burundi, the delivery of extension services has declined due to the dwindling of the number of extension workers and lack of funds to access at least private extension service.

Adoption Impact Analysis

First of all, we carried out matching quality tests that justify the use of the quasi-experimental method based on propensity score matching in estimating the results.

Table 6- Standardized bias control of the independent variables

Sample	PS R2	LR chi2	*p* >chi2	Average Bias
Unmatched	0.091	57.19	0.000***	16.2
Matched (nearest neighbor)	0.022	9.20	0.757	6.4

Note: *** significant at 1%

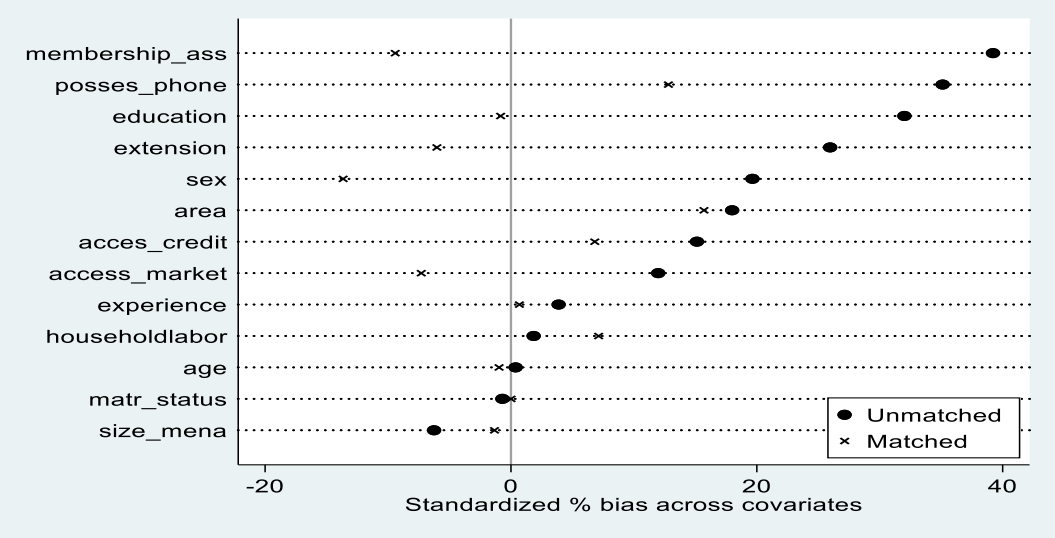

Figure 5- Standardized bias before and after matching

This Table 6 relates the observable differences between rice farmers adopting and non-adopting improved varieties of rutete rice. The results indicate a good quality of the pairing of the rice growers of the surveyed population. Indeed, the pseudo R2 decreases significantly after the pairing going from a value of 9.1% to a value of 2.2%. In addition, the matching quality test before and after the matching of the covariates considered in the study shows a satisfactory balance after the match between the adopting and the non-adopting groups used in the match, The standardized mean difference for the overall covariates used for the matching reduced from 16.2% before matching to 6.4% after matching. In addition, the joint significance test of the variables after matching [1] is rejected (P-value greater than 5%), which justifies the effectiveness of the PSM method for estimating results without bias. In other words, the unobserved characteristics do not have significant effects on the yield of rice farmers.

The graph shows us a considerable reduction in the selection biases because after matching, the biases are concentrated very close to zero or

1- Maximum likelihood tests are rejected before matching but not after

even negative.

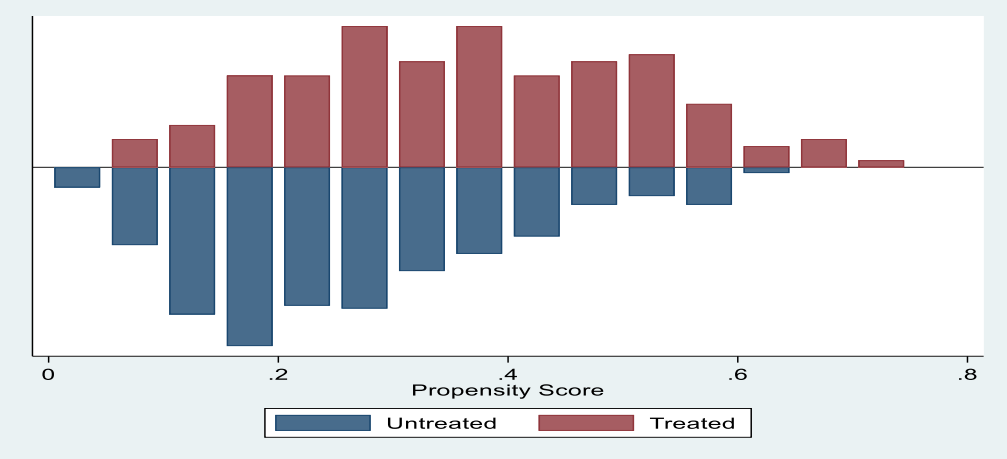

Figure 6- Distribution of propensity scores and common support

We define the "Untreated" to refer to non-adopters (the control group) and "Treated" refer to adopters (treatment group) who are in the common carrier. Adopters who should be outside of the common support are not present. This means that all adopters have related matched from the control group with identical or nearly similar characteristics with which they can compare. This justifies a good quality of the pairing. These results indicate that the required balancing property of the propensity score distribution is satisfied and that the estimated results are reliable and unbiased.

The various matching quality assessment criteria were met by the model. The common support is respected, which therefore makes it possible to calculate the Mean Treatment Effect on the Treated (the EMTT) and the Mean Treatment Effect on the untreated (EMTNT).

These results are estimated using the nearest neighbor matching technique with replacement.

Table 7- Results of estimation of the effect of adopting the rutete rice variety

Algorithm type	Variable	Effects on types of rice-growing households	Adopters	Non-adoptors	Average treatment effect	Prob
nearest neighbor	Yield(kg/ha)	Households of adoptive rice farmers (EMTT)	9754 kg/ha	7931 kg/ha	1823 kg/ha	0.000***
		Household of non-adopting rice farmers (EMTNT)	9912kg/ha	7927 kg/ha	1984 kg/ha	

Note: *** significant at 1%

The interpretation of this Table is made in three categories. First, the average yield for rice farmers who adopted the rutete variety is 9754 kg/ha, while those who did not have an average of 7927 kg/ha. Second, adopting households if they decided not to adopt this variety, their counterfactual rice yield would be 7931 kg/ha, while non-adopting rice farmers if they decided to adopt, their counterfactual rice yield would be 9912 kg/ha. Third, the average effect of the treatment on the rice yield of the adopters corresponds to 1823 kg/ha and it is positive and significant ($p<0.01$). The decision to adopt for non-adopting rice farmers could increase the average yield by 1984 kg/ha. The results indicate that the yield of households that adopted the rutete rice variety increased relatively compared to those that did not. This implies the positive role of the adoption of the rutete rice variety on the performance of rice farmers in Gihanga. This could be interpreted as the result of technical change brought about by the adoption of the rutete rice variety and IRRI's agronomic research on the most

productive varieties that have multiple benefits for rice farmers in Burundi. Moreover, knowing that farmers are financially poor, the results found reveal that the multiplication of the most productive improved varieties of rice from IRRI plays a key role in improving the yield of low-income rice farmers. Furthermore, the adoption of the most productive variety of rice contributes to the reduction of poverty and hunger, enhances the health and well-being of rice farmers and consumers alike. Similar results were found by Zegeye *et al.* (2022) in their study on the impact of agricultural technology adoption on wheat productivity in Ethiopia. More Awotide *et al.* (2012), reported that the adoption of improved rice varieties has a positive and significant impact on productivity (358.89 k/ha) in Nigeria. For its part, FAO (2013) specifies that an increase of more than 25% in yield can be obtained if producers in Niger use improved varieties of millet and cowpea. In Benin, Arouna & Diagne (2013) showed that seed multiplication of improved varieties allows rice farmers to increase their rice yield by 1924 kg/ha. Tesfaye *et al*. (2016) in Ethiopia highlighted that an increase of 1 to 1.1t/ha can be obtained if wheat producers use new varieties resulting from agronomic research.

The results of our study allow us to conclude that the multiplication and knowledge of the most productive rice varieties (rutete) in the region plays an indispensable role in increasing farmers' yields.

Conclusions and Recommendations

In this study, we were motivated to analyze the adoption of the improved rice variety rutete. The objective was to assess the effect of adopting the rutete rice variety on the yield of rice farmers in Gihanga. The study shows that adopters are different from non-adopters in terms of characteristics such as sex, age, marital status, education of household head, household size, household labor force, area, experience, access to credit, market access, association membership, access to extension services and mobile phone ownership. In the estimation procedures, we used the propensity score matching method, which allowed us to eliminate selection bias that could lead to biased results estimates. The observation is that the decision to adopt this variety allows rice growers to increase their yield by 1.823 kg/ha. Rice farmers who did not adopt this variety, if they decided to adopt it, could produce higher yields than the adopters, i.e. increase their yield by 1.984 kg/ha. The adoption of the most productive varieties could therefore constitute an important instrument of agricultural policies aimed at food security and the sustainability of production. It therefore becomes urgent that political decision-makers and organizations working in the Burundian agricultural sector can intensify actions to popularize improved varieties of rice accompanied by modern agricultural techniques and dissemination of IRRI varieties in rural areas in order to increase rice yields.

One of the shortcomings of the study is that it does not distinguish between the different varieties introduced into the study area in order to detect the real effect of each of them. In addition, the use of other non-experimental methods that can take into account unobserved characteristics, could produce good results in future research. In the end, other similar studies of this one are necessary in Burundi to have a general view of the country as to the importance of the agricultural technologies popularized on the yields of the farmers. The results could influence policy makers from organizations in charge of agricultural sector development to make decisions.

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ارزیابی تأثیر پذیرش رقم برنج اصلاح شده بر عملکرد کشاورزان در بروندی: مطالعه موردی رقم معرفی شده توسط مؤسسه بین‌المللی تحقیقات برنج در منطقه گیهانگا کشور بروندی

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چکیده

کشور بروندی مانند بسیاری دیگر از کشورها در تحقیقات و توسعه کشاورزی سرمایه‌گذاری زیادی می‌کند و کاربرد ارقام بذر پرمحصول یکی از مهم‌ترین روش‌ها برای بهبود عملکردها در کشاورزی است. محصول برنج به دلیل راهبرد امنیت غذایی در بروندی از اهمیت بیش‌تری در میان سایر غلات برخوردار است. هدف این مطالعه شناسایی تأثیر کاربرد رقم بذر اصلاح شده برنج بر بهره‌وری کشاورزان است. داده‌های این مطالعه با استفاده از روش نمونه‌گیری تصادفی و پرکردن پرسشنامه از ۵۲۴ کشاورز برنج کار در پنج روستای بورنیا، موریرا، نیشانگا، نینگا و بوئیزا واقع در منطقه گیهانگا، بوهانزا، انجام شد. این مطالعه برای تخمین تأثیر رقم بذر اصلاح شده برنج بر متغیرهای هدف از روش جورسازی نمره گرایش استفاده کرده است. نتایج نشان داد متوسط عملکرد برای کشاورزان تحت تیمار و کشاورزان شاهد، به‌ترتیب، ۹۷۵۴ و ۷۹۲۷ کیلوگرم در هکتار بود. اگر خانوارها تیمار شده تصمیم به عدم استفاده از بذر اصلاح شده بگیرند، عملکرد این خانوارها به ۷۹۳۱ کیلوگرم در هکتار کاهش می‌یابد. همچنین، اگر کشاورزان شاهد تصمیم به استفاده از رقم بذر اصلاح شده بگیرند عملکرد برنج آن‌ها به ۷۹۳۱ کیلوگرم در هکتار افزایش می‌یابد. تأثیر متوسط تیمار بر عملکرد برنج برای گروه تیمار ۱۸۲۳ کیلوگرم در هکتار و معنی‌دار است. به همین ترتیب، تصمیم برای پذیرش رقم بذر اصلاح شده برای کشاورزان شاهد متوسط عملکرد را تا ۱۹۸۴ کیلوگرم در هکتار افزایش می‌دهد. این نتایج به نقش مثبت استفاده از رقم برنج اصلاح شده بر عملکرد کشاورزان در گیهانگا اشاره دارد. از توصیه‌های این مطالعه آن است که دولت و مؤسسه‌های پژوهشی دست‌اندرکار توسعه پایدار کشاورزی از تحقیقات نوآورانه در راستای افزایش عملکرد کشاورزان حمایت کند.

واژه‌های کلیدی: رقم اصلاح شده برنج، روش جورسازی، عملکرد برنج، نمره گرایش

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