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Modeling the Dynamics of Agricultural Investment and Output: A Statistical-Planning Approach to Sustainable Regional Development

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Abstract
This study investigates the direct and indirect effects of key variables influencing agricultural investment and local agricultural output over the period 2004–2024. The research employs the Full Information Maximum Likelihood (FIML) estimation technique, implemented using both *R* and *MINITAB* software packages, to estimate the structural parameters of the proposed econometric model.
By integrating applied statistics with urban and regional planning frameworks, this paper aims to provide a comprehensive understanding of the spatial and economic dimensions of agricultural performance. The results are particularly relevant for planning authorities and policymakers involved in the formulation of sustainable development strategies, as they reveal the responsiveness of the agricultural sector to economic, spatial, and infrastructural factors. This interdisciplinary approach not only enhances the accuracy of statistical inference but also strengthens the alignment between agricultural policy and broader regional development goals.

Keywords: Applied statistics, Full Information Maximum Likelihood, Sustainable development, Economic and spatial factors, R and MINITAB software**.**

Introduction
The agricultural sector holds a prominent position and significant importance in the Iraqi economy. This importance is reflected in its contribution to providing food for the population and meeting some of the needs of the industrial sector, in addition to employing a large number of the workforce. This necessitates giving importance to the study of this sector commensurate with its role and size in the Iraqi economy.
This study addressed the construction of a system consisting of two equations for agricultural investment and agricultural gross domestic product in Iraq by specifying two simultaneous equations. Agricultural investment is described as a function of agricultural gross domestic product, agricultural loans, agricultural fixed capital formation, and the agricultural workforce. Agricultural gross domestic product is described as a function of agricultural investment, chemical technology, mechanical technology, and the agricultural workforce. The Full Information Maximum Likelihood (FIML) method was used in the estimation process due to its efficiency and consistency (Al-Nuaimi, ***2022***).

1. Theoretical Aspect
The basic assumption of the linear regression model is that there is a one-way causation, meaning that there is a set of explanatory variables that affect the dependent variable and are not affected by it. Since most economic relationships are interconnected, they require description by a set of equations (system of equations), the number of which is proportional to the nature of the problem under study. The system of equations is divided into multiple types according to the nature of the relationship that links the variables to each other within one equation and from it to the rest of the variables in the other equations in the system. One of these types is the Simultaneous Equations System and Recursive Equation Systems and Block-Recursive Equation Systems.

A simultaneous equations system contains a set of equations in which the endogenous the variable of one or more of its equations is an exogenous variable in one or more of equations of the system. That is, there is a two-way causation, and therefore, applying the ordinary least squares (OLS) method will lead to a violation of the assumption that the observed values of the explanatory variable are not correlated with the sequential values of the random error, which leads to biased and inconsistent estimators. This requires estimating the parameters of the system using other methods that are appropriate to the diagnostic state of the system equations (Awad, 1998).

1-1 Identification of Simultaneous Equations Systems:

The first step in the statistical analysis of simultaneous models is to perform an identification process, i.e., testing each equation in the system in terms of its formulation on one hand and determining the appropriate methods for estimating the system parameters on the other hand.

To determine the identification status, both the order and rank conditions must be met.

a- Order Condition:

According to this condition, the equation is identified when the number of variables excluded from the equation to be identified and present in the other equations of the structural model is equal to the number of equations in the system minus one. Therefore, the order condition takes the following form:

K-M $\leq$ G-1

Where:

- **K**: The number of endogenous, exogenous, and lagged variables in the structural model.
- **M**: The number of variables in the equation under test.
- **G**: The number of equations in the structural system.

The equation is exactly or just identified. If K-M > G-1, the equation is described as over-identified. If K-M > G-1, the equation is described as under-identified (Kadhim, 2005).

b- Rank Condition:

The necessary and sufficient condition for identifying the equation is the ability to form at least one determinant that is not equal to zero (Awad, 2022). Therefore, according to this condition, the structural parameters of all variables in the system are arranged, and then the parameters corresponding to the missing parameters in the equation to be tested are taken and placed in the form of a matrix. Then, we find the value of the matrix determinant, which has a rank of (G-1). If the determinant value is not equal to zero, the equation is identified. If the determinant value is equal to zero, the equation is not identified. In light of the identification process, the appropriate method for estimating the structural model parameters is selected (Kadhim, 2023).

1-2- Full Information Maximum Likelihood (FIML) Method:

The Full Information Maximum Likelihood method is considered one of the methods for estimating simultaneous equations systems that have the over-identification characteristic, and it is called system methods because the estimates of the structural form parameters are done simultaneously for all equations, not for a single equation (Kadhim, 2023).

To know how to find the estimates using the (FIML) method, let us assume that we have a simultaneous equations system that can be written in the following form:

(1)……………………$YA' + XB' = E$

Where:

- **Y**: Matrix of endogenous variables with dimension n × G.
- **X**: Matrix of exogenous variables with dimension n × K.
- **E**: Matrix of residuals n × G.

The FIML method assumes that the random variables of the structural equations are normally distributed with means (μ) equal to zero, and that the covariance matrix (Σ) is independent of each other. Therefore, the probability density function for row ***i*** of the residual matrix **E** can be written as follows:

(2)……………………$p(\varepsilon_i') = (2\pi)^{(-G/2)} |\Sigma|^{(-1/2)} \exp(-1/2\, \varepsilon_i' \Sigma^{-1} \varepsilon_i)$

To obtain the likelihood function for the structural equation **y *i*** from the matrix **Y**, we need to transform the variables from ε_i' to Y_i'. This transformation step, by substituting ε_i' in equation (2) with $y_i A' + x_i B'$, requires the determinant of the partial derivatives of all ε's with respect to y's. This determinant is the jacobian |A|, and then we can find the likelihood function y as follows:

(3)………………………………$P(y_i'; A, B, \Sigma) = (2\pi)^{(-G/2)} |A| |\Sigma|^{(-1/2)} \exp\{-1/2\, (y_i' A' + x_i B) \Sigma^{-1} (A y_i + B x_i)\}$

Where $y_1', y_2' \ldots\ldots y_n'$ are independent of each other, and the joint density function of Y is:

(4)………………………………$P(Y{:}A, B\, \Sigma) = (2\pi)^{(-nG/2)} |A|^n |\Sigma|^{(-n/2)} \exp\{-1/2 \operatorname{tr} \Sigma^{-1} (y_i' A' + x_i B) \Sigma^{-1} (A y_i + B x_i)\}$

Taking the logarithm to the base e, we get:

(5)……………………..$\ln L = c + n \ln|A| - (n/2) \ln|\Sigma| - 1/2 \operatorname{tr} \Sigma^{-1} (AY' + BX') (YA' + XB')$

Where c is a constant, and:

(6)……………………..$n\sum_{i=1} \operatorname{tr} (y_i' A' + x_i' B')\Sigma^{-1}(Ay_i' + Bx_i') = n\sum_{i=1} \operatorname{tr}\Sigma^{-1}(Ay_i + Bx_i)(y_i' A' + x_i' . B') = \operatorname{tr}\Sigma^{-1}(AY' + BX')(YA' + XB)$

To maximize the likelihood function (**ln L**) for equation (5**),** we take the partial derivatives with respect to **B', A',**

Σ^{-1} and set them equal to zero, using the following partial differentiation rules:

(7)…………………..$\partial tr(AB)/\partial A = B'$; $\partial \ln|A|/ \partial A^{-1} = A'$; $\partial \ln|A|/ \partial A = -A'^{-1}$

We obtain:

(8)………………………..$n/2\ \Sigma\text{-}1/2\ (AY' + BX')(YA' + XB') = 0$

(9)………………………$\partial \ln L/\partial A' = -nA^{-1} - Y'(YA' + XB')\Sigma^{-1} = 0$

(10)……………………$\partial \ln L/\partial B' = -X'(YA' + XB')\Sigma^{-1} = 0$

Solving equation (8) gives us the value of Σ:

(11)……………………$\Sigma = n^{-1}(AY' + BX')(YA' + XB')$

Taking the partial derivatives of ln L with respect to A_i and B_i yields:

$\partial \ln L/\partial A_i = nA^i – Y_i'(YA' + XB')$ (ith column of Σ^{-1})

(12)…………………..$=nA_i\text{-}Y_i' \Sigma (y_j\text{-}Y_jA_J\text{-}X_Jb_j)\ \partial^{ji}= 0$

(13)…………………..$\partial \ln L/\partial b_i = -X_i' \Sigma \Sigma (y_j\text{-}Y_jA_J\text{-}X_Jb_j)\ \partial^{ji}= 0$

To arrive at the Full Information Maximum Likelihood (FIML) estimators, A_i and B_i can be combined into a single column vector, denoted as Ⓐ, for both equations according to the following formula:

(14)……………………δi - [$\partial \ln L / \partial \delta 1$: $\partial \ln L / \partial \delta_G$] = $\partial \ln L / \partial \delta = f(\delta) = 0$

To solve the system of nonlinear equations, the Newton-Raphson method is used, starting with an initial value, δ^o, as follows:

(15)……………………...$f(\delta) = f(\delta^o) + (\partial f/\partial \delta')_{\delta^o} (\delta - \delta^o) = 0$

Since the Newton-Raphson method is iterative, it starts with an initial value, δ^o, to solve equation (15) and obtain δ. This value is then used in the subsequent iteration to obtain δ, and so on, until convergence is reached, where the subsequent value is equal to the previous value. This convergence indicates reaching the Full Information Maximum Likelihood (FIML) estimators, which are efficient and consistent (Chow, 1983).

2. Practical Aspect

The task of building an econometric model, whether a single equation or a system of equations, should be consistent with economic theory, as well as the statistical tests related to the model in terms of significance and explanatory power. Additionally, tests are required to ensure that the model does not suffer from problems resulting from the violation of some assumptions, such as autocorrelation, multicollinearity, and heteroscedasticity, etc. Conducting the necessary treatments is a very difficult task, if not impossible, in practice, especially when the studied economic phenomenon relates to the agricultural sector in Iraq during the period (2004-2024), given that this period witnessed the eight-year war, as well as years of economic embargo which negatively affected the economy on one hand, and the process of completing the database and its accuracy on the other hand.

The primary source of data relied upon by the researcher is the data used in Zeidan's master's thesis (2005). The thesis relied on two equations: the first is the agricultural investment function in Iraq and its relationship with agricultural loans, agricultural fixed capital formation $\mathbf{X_1}$, gross domestic product $\mathbf{X_2}$, trade balance $\mathbf{X_3}$, chemical technology $\mathbf{X_4}$, mechanical technology $\mathbf{X_5}$, agricultural labor force $\mathbf{X_6}$, and agricultural gross domestic product X_7. Thus, the agricultural investment function was described by the following formula:

(16)…………………..$Y_1 = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6$ + β<0xE2><0x82><0x87>X<0xE2><0x82><0x87> + U_1

The second equation is the agricultural growth rate equation G and its relationship with the estimated agricultural investment Y_1. Therefore, the agricultural growth rate equation took the following formula:

(17)………………….$G = \beta_0 + \beta_9 Y + U_2$

The researcher stated that she used the Two Stage Least Squares (2SLS) method to find the estimators (Zeidan, 2015).

The two equations above were reformulated and made simultaneous equations in line with economic theory and the nature of available data in order to provide a basis for analyzing the agricultural sector in a way that helps derive some characteristics of this sector.

The research addressed building a system consisting of two equations: agricultural investment and agricultural gross domestic product in Iraq, by describing two simultaneous equations and their relationship with some economic variables that have a direct or indirect impact. Agricultural investment means developing physical means of production and working to improve them and raise their productive efficiency (Katad, 2022), or it is the part of current production that is directed towards the agricultural financial capital, both material and human, aims to increase the country's agricultural capacity through machinery, equipment, installations, irrigation and drainage networks, land reclamation, transportation means, and trained agricultural personnel. For the agricultural sector to be able to meet the development requirements in developing countries, productivity in this sector must be increased. This, in turn, necessitates increasing the level of investments in the agricultural sector and directing them to serve social capital, represented by dams, reservoirs, and canals. Additionally, investments aimed at increasing the use of chemical fertilizers, pesticides, improving seeds, establishing agricultural extension stations, and improving the level of fixed agricultural capital are needed (Muhaidi, 2010).

From the above, it is noted that there is a reciprocal influence between agricultural investment and the growth of the agricultural sector, Zeidan (2015). Agricultural investment can be described as a function of agricultural gross domestic product $\mathbf{Y_2}$, agricultural loans $\mathbf{X_1}$, fixed capital formation $\mathbf{X_2}$, and the agricultural labor force $\mathbf{X_5}$. Based on this, the agricultural investment function is:

(18)………………..$\mathbf{Y_1 = f(Y_2, X_1, X_2, X_5)}$

The agricultural gross domestic product can be described as a function of agricultural investment Y_1, chemical technology X_3, mechanical technology X_4, and the agricultural labor force X_5 (for details on the variables' description, see Zeidan (2015)). Therefore, the agricultural gross domestic product function is:

(19)…………………$\mathbf{Y_2 = f(Y_1, X_3, X_4, X_5)}$

It is noted from the above two equations that there is a mutual dependence between the variables. The two variables Y_1 and Y_2 are endogenous variables, appearing sometimes as dependent variables and sometimes as explanatory variables, indicating a two-way causality. This is known as a system of simultaneous equations. Applying ordinary least squares (OLS) to a system of simultaneous equations will lead to a violation of the assumption that the observed values are not correlated with the error terms.

For the explanatory variable with successive values of the random error, which leads to biased and inconsistent estimates (Dhrymes, 1974), other methods are required to estimate the system of simultaneous equations, which will be determined based on the system's diagnosis.

The diagnosis for the two equations above was conducted, and it was found that they are over-identified. Therefore, the Two Stage Least Squares (2SLS) method and the Three Stage Least Squares (3SLS) method can be used, as well as the Full Information Maximum Likelihood method to find the estimates.

Since the research emphasizes the importance of achieving the best statistical representation of the economic relationships in the phenomenon under study, the Full Information Maximum Likelihood method was used because it is considered one of the advanced methods in reaching consistent and efficient estimates. Therefore, this method was used on various types of functions (linear, semi-logarithmic, double logarithmic, reciprocal, reciprocal logarithmic, and square root) for the original data. It was observed that there were significant differences between the estimates resulting from data inconsistency. Therefore, estimates that align with economic theory and pass the required standard tests were not reached. The next step was to eliminate volatility and instability in the data by processing it using Moving Average (MA(1), MA(2), MA(3), MA(4)). This method is used to eliminate the impact of seasonal, cyclical, and random changes, as the opposing changes tend to decay and disappear. Additionally, the Single Exponential Smoothing method and the Double Exponential Smoothing method were used (for more details, see Makridakis, 1998). (See Figures 1 to 7, which represent the original series graphs with the smoothed series using the Double Exponential Smoothing method). The linear function for the data smoothed by the Double Exponential Smoothing method was chosen as the best statistical representation of the simultaneous equations system for agricultural investment and gross Agricultural product in Iraq, and this is due to its success in statistical and econometric tests on one hand, and its consistency with reality and economic theory on the other hand.

Fixed capital and agricultural labor were excluded from the agricultural investment equation due to their insignificance and being the main cause of multicollinearity. Mechanical technology and agricultural labor were also excluded from the agricultural gross domestic product equation for the same reason.

Tables (1), (2), and (3) represent a summary of the results, which were characterized by the best values obtained from the agricultural investment and agricultural gross domestic product equations for the (2004-2024) series of data smoothed using the Double Exponential Smoothing method.

2-1. Discussion of Results

2-1-1. Agricultural Investment Equation

It is noted from Table (1) that the estimated parameter for agricultural gross domestic product (Y_2) appeared as negative and was (-0.065249). This contradicts economic theory, but it reflects the actual reality of the agricultural sector in Iraq. The factor that explains the imbalance between the volume of investments and the growth of agricultural gross domestic product is that the majority of agricultural investment is government spending rather than private, and most of it is directed towards infrastructure projects with indirect and non-short-term impacts on production development (Ministry of Planning, 2012). As for the estimated parameter for agricultural loans (X_1), it is consistent with economic theory, indicating the responsiveness of the agricultural sector to agricultural loans. An increase of one unit in agricultural loans leads to an increase in agricultural investment by (0.313440) units. Regarding the value of the intercept, it can be considered a mathematical value with no statistical significance.

The statistical analysis of the results clearly shows the significance of the estimated coefficients of the equation's variables and their statistical reliability. The calculated t-value indicates that the estimated parameters in the equation are significant at the 5% significance level. When examining the significance of the equation as a whole through the F-value, it is clear from Table (3) that the calculated F-value is greater than the tabulated F-value at the 5% and 1% significance levels and degrees of freedom (2,18). The Farrar-Glauber test, based on the chi-squared statistic, indicates the absence of multicollinearity among the explanatory variables, as the calculated chi-squared value (0.0066987) is less than its tabulated value with 1 degree of freedom and 5% and 1% significance levels. The DW test indicates the absence of correlation between the random errors, as the DW value falls within the acceptance region at the 5% and 1% significance levels and degrees of freedom (2,12). It is also noted that the explanatory variables in the equation explain 0.440513 of the variations in agricultural investment, while these variables fail to explain 0.559487 of the variations. This is either due to the exclusion of some variables due to multicollinearity or the presence of other explanatory variables that were not included in the system.

Table (1): Structural Equation for Agricultural Investment Estimated by Full Information Maximum Likelihood.

Variable	DF	Parameter Estimate	t-test
Intercept	**1**	79.128704	1.537
Y_2	**1**	-0.065249	-2.031
X_1	**1**	0.031344	3.431

2-1-2. Agricultural Gross Domestic Product Equation

The estimation results in Table (2) show that the intercept coefficient is negative, reaching (-1826.831558). The estimated parameter for agricultural investment (Y_1) was (3.970685), which is consistent with economic theory, indicating that agricultural gross domestic product is positively affected by an increase in agricultural investment, meaning that increasing rates of Government and private agricultural investment lead to the development of agricultural efficiency and increased productivity. As for the mechanical technology parameter (X_4), it is noted that it is positive, reaching (0.757697), which is also consistent with economic theory. An increase in the rates of using agricultural machinery and increasing the training capacities of agricultural workers on technological means, as well as modernization and development factors, lead to increased efficiency and productivity.

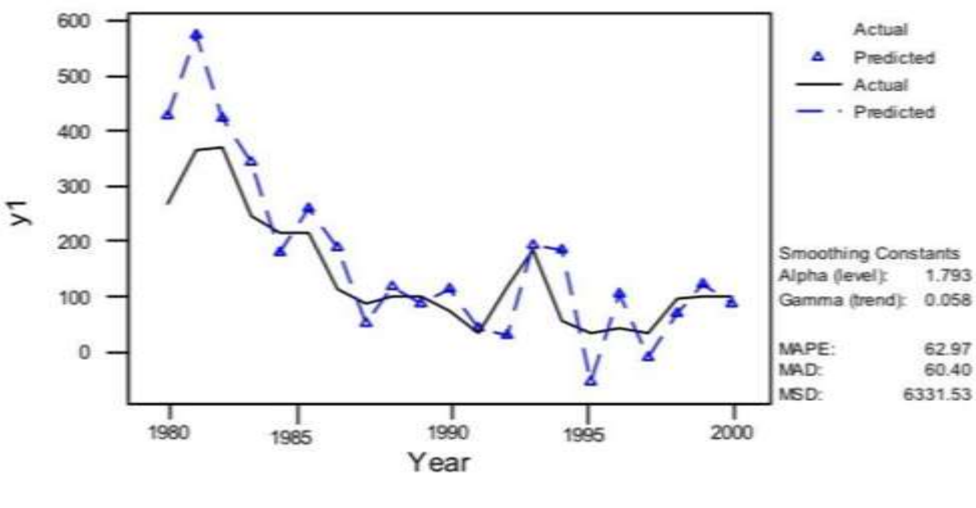
Table (2): Structural Equation for Gross Domestic Product Estimated by Full Information Maximum Likelihood.

Variable	DF	Parameter Estimate	t-test
Intercept	**1**	-1826.831558	-2.673
Y_2	**1**	3.970685	1.982
X_1	**1**	0.757697	5.211

As for the statistical test results, the calculated t-value indicates that the estimated parameters in the equation are significant for the two variables (agricultural investment and mechanical technology) at the 5% significance level and degrees of freedom (18). From Table (3), it is noted that the explanatory variables in the estimated equation explain 0.778633 of the variations in the gross domestic product equation. The calculated F-value for the equation indicates that it is highly significant at the 5% and 1% significance levels and degrees of freedom (2,18). The Farrar-Glauber test also indicates that there is no multicollinearity problem, as the chi-squared value (5.4619242) is less than its tabulated value with 1 degree of freedom and 1% significance level. The DW value indicates that the equation is free from autocorrelation of random errors, as the calculated DW value falls within the region where there is no autocorrelation with degrees of freedom (2,12) and at the 1% significance level.

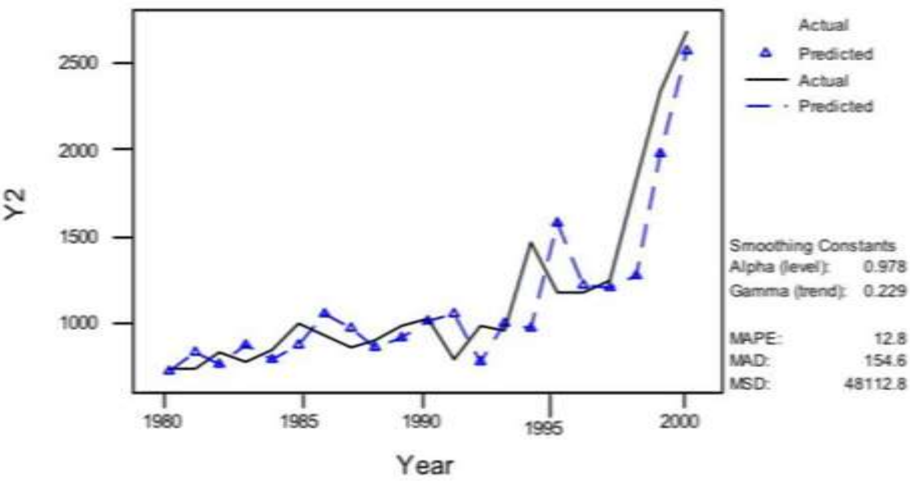
Table (3): Standard Tests that the Agricultural Investment and Agricultural Gross Domestic Product Equations Passed.

EQ	F-Test	R^2	R^2-adjusted	DW	Farrar-Glauber
Agricultural Investment Equation	7.08616	0.440513	0.37834	2.074	$\chi^2 = 0.0066987$
Agricultural Gross Domestic Product Equation	31.6565	0.778633	0.754036	1.296	$\chi^2 = 5.4619242$



(Graph) (1) Plotting the original series with the smoothed series using the exponential smoothing method Multiplier.

Double Exponential Smoothing for y2



(Illustration Diagram) (2): Graphing the original series 2 with the series smoothed using the exponential smoothing method Multiplier.

Conclusions and Recommendations

Conclusions

Among the most important conclusions reached by the research are:

1. Estimates were derived that align with the actual reality of agricultural investment and agricultural gross domestic product in Iraq. The statistical analysis showed the significance of both equations and their parameters, as well as the absence of autocorrelation and multicollinearity.
2. The results showed an inverse relationship between agricultural investment and agricultural gross domestic product. The reason may be that the majority of investment is government spending rather than private, and therefore, it is far from the agricultural crop market.
3. The results showed the responsiveness of the agricultural sector to agricultural loans and mechanical technology. An increase in agricultural loans leads to an increase in agricultural investment. An increase in the rates of using agricultural machinery and increasing the training capacities of agricultural workers on technological means, as well as modernization and development factors, lead to increased efficiency and productivity.
4. Some economic variables were excluded due to multicollinearity, which negatively affected the ability to determine the impact of these variables in the system of simultaneous equations.

Recommendations

1. Work on building detailed standard models for the agricultural sector and use advanced methods in estimating these models, in a manner that is appropriate for the nature of the model.
2. The fundamental factor in improving productivity levels is the continuous development of agricultural production means and technology. This requires the dissemination of agricultural mechanization in a manner that aligns with the decline in the labor force in this sector.

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