Fertilizer Application and Agricultural Growth in Rural China: Co-integration Estimation and Granger Causality Test

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ABSTRACT

Application of Chemical fertilizer contributes significantly to the production of food and agricultural growth worldwide. This paper estimates the short and long-run effects of fertilizer consumption and agricultural growth by adopting unit root tests and co-integration. The study investigates the effect of fertilizer consumption on agricultural growth by using Fully Modified OLS and Dynamics OLS time series data from 1987 to 2015. The findings indicate the existence of a long-run relationship between the increase in fertilizer application and agricultural growth in PR China. Moreover, there is the presence of long-run causality from fertilizer consumption to the agricultural growth. The empirical findings of FMOLS and DOLS revealed that increase in fertilizer application has a positive and significant effect on the growth of Chinese agriculture. The findings of this study will help to contribute to the current food production challenges and effective application of chemical fertilizer to boost food production.

Keywords: Agricultural Growth; Fertilizer Consumption; Unit Root Test; FMOLS; DOLS; China.

INTRODUCTION

Agricultural growth remains central to poverty reduction, particularly in the poorest countries, where a large share of the population relies on agriculture for their livelihood. Agricultural sector for the past decades has experienced some drastic changes due to global demand for food. The rapid increase in food demand has become necessary as a result of the increase in population growth and incomes, dietary shifts, and high demand for agricultural products (Jervell, 2011). In these circumstances, a study into the use of chemical fertilizer to increase agricultural growth is needed.

The growth in the agricultural sector has been held back in recent years by a number of factors, which include land and water constraints, underinvestment in rural infrastructure and agricultural innovation, lack of access to inputs, and unfavorable weather conditions. However, accelerating economic growth, reducing rural poverty and narrowing rural-urban disparities in most of the agrarian economies is partly through agricultural development. The renewed focus is on ‘new agriculture for development’ framework to benefit economic growth and address the socio-economic dimension of the Chinese economy. The agricultural growth remains a key pillar for economic growth and development in developing agricultural based economies, yet, difficulties remain to integrate rural development, limited arable land, fertilizer application, environmental constraints that have changed in the contest of agriculture’s role (Boserup, 2017). However, with a large growing of human population and the need to increase food production, there is the need to increase fertilizer application by adopting effective strategies (Aker, 2011; Chappell & LaValle, 2011).
According to the report of IFC in just ended lunching of Better Life Farming Alliance (April 2018), the growing of food today uses about 70 percent of the freshwater worldwide, which is a serious challenge to human survival in the future. This problem is even worst in most countries in Africa and Southeast Asia, where the greater number of the smallholder farmers experience low productivity, inadequate farm inputs and seeds, constraint in accessing finance, lack of technological know-how, unavailability of the market and lack of strong government commitment. According to the IFC report, as an effort to develop the agribusiness sector to increase food production and reduce poverty in most of the low-income countries, this corporation is estimating an investment of 140 billion US Dollars globally by 2030 with 90 billion Dollars coming from the private investors and 90 billion from the public sector.

According to Heffer (2009), the consumption of World fertilizer nutrient (N+P₂O₅+K₂O), which was 172 200 000 metric tons (Mt) in 2010-2010/2011 reached 186 900 000 tonnes in 2014, which was an increment of 2.0 percent over the estimated figure in 2013. Therefore, the report from food and Agriculture Organization of the United States, the application of chemical fertilizer worldwide was estimated to increase around 1.8 percent annually from the period of 2014 to 2018. For the next five years, statistics show that there will be a rise in fertilizer products, intermediates and raw materials globally, whereby the demand for nitrogen, phosphate, and potash is expected to have an annual increase by 1.4 to 2.6 percent. L. Li, Li, and Howe (2001), predicted that “In 2030 we have to have at least 72 million tons of NPK fertilizer to meet the demand of food production and agricultural development.”

However, according to Zhu and Chen (2002), the increase in the usage of CF-N has resulted in high nitrogen concentration in ground and well water, which has exceeded the critical value of WHO, 10mg N L⁻¹, in most of the provinces in China. Inasmuch as the application of chemical fertilizer in mainland China has come with many challenges, its contribution to food production for the past decades has been enormous (Ebenstein, Zhang, McMillan, & Chen, 2011). According to Huang and Rozelle (1995), the application of chemical fertilizer in rural China (kilograms per hectare) is almost thrice the of worldwide average. China’s fertilizer production and consumption rank No. 1 in the world. It is imperative to increase fertilizer efficiency and to transform the production pattern of agriculture. Currently, the Chinese government has spent about RMB 20 billion Yuan on fertilizer companies, as part of the national policy, to achieve self-sufficiency in food staples and improve the farmers’ income (Gale, Lohmar, & Tuan, 2005; Kevin Z. Chen, Dr Suresh Chandra Babu, Gautam, & Yu, 2015). The report from Century Business Herald indicates that due to excessive use of chemical fertilizers, the Chinese government has introduced new fertilizers to achieve zero growth of fertilizer application on major crops by 2020.

Several studies conducted in China’s agricultural sector contributed the rapid growth of agriculture to several factors. McMillan, Whalley, and Zhu (1989), investigated into the impact of China’s economic reforms and Agricultural productivity growth. They established that institution of price adjustment policy contributed to productivity growth of agriculture. Wu, Walker, Devadoss, and Lu (2001), employed no-parametric Malmquist procedure to investigate the temporal and spatial nature of agricultural productivity growth over the study period (1988-1995). The study discovered that agricultural productivity growth in mainland China has increased through continuing innovation, the use of modern inputs and competitive market. In this line of research, Huang and Ma (2010) analyzed the determinants of public and farm household capital stock formation and their effects on the productivity growth of agriculture. By using Cobb-Douglas production function, the study revealed that capital investment in agriculture; private capital formation and technological changes have increased agricultural growth whilst fertilization application has had the mild effect on agricultural growth. Lin (1992), using province-level panel data investigated rural reforms and Agricultural growth in rural China. By employing Cobb-Douglas production function,
the author indicated that decollectivization and adjustment in state procurement prices have augmented the growth of agricultural production. Lezin W and Long-bao (2005), explored the impact of production variables used on agricultural productivity growth. However, using 1989-2002 data for Zhejiang Province and employing Cobb-Douglas production function, the study indicates that there is a strong correlation between the production variables and agricultural productivity growth. Yu and Nin-Pratt (2012), also examined the differences between agricultural productivity growth in China and India. They employed Malmquist index and disclosed that the TFP growth accelerated in China outperformed that of India because of China’s fundamental institutional and agricultural policies. Xu (2012), made use of Cobb-Douglas production function to synthesis the empirical literature on the subject Chinese Agricultural growth in post-reform Era. The study reveals that there is a relationship between household responsibility system and agricultural productivity growth. Z. Li (2012), adopted Stochastic Frontier Analysis and employed 1995-2009 village-level data to investigate the effect of China’s Agricultural reforms on productivity changes. The study disclosed that for the past fifteen years, Chinese Agricultural productivity has increased due to the institution of agricultural policies and technological changes. Wang, Zhang, and Tong (2013), also, investigated into the influence of rural infrastructure construction on agricultural GDP. By adopting data of Heilongjiang from 1980 to 2008, the study concluded that the influence of rural road construction on rural GDP is reversed. In VAR model, influences of the first order lag and second-order lag of rural road construction on agriculture are contrary, and both rural effective irrigated areas and rural power consumption has a close relation to agricultural productivity growth. To do this much-needed research for Chinese agricultural growth, this paper aims at analyzing the relationship between fertilizer application and agricultural growth in China. We however, hypothesize that; 

**H1:** There exists a causal relationship between Increase in Fertilizer Application and Agricultural Growth in China.

We, therefore, explained data dimensions and sources, whereby the econometric methodologies used in the study are also explained in the next section.

**Data and Methodology**

This study investigates the dynamic relationship between fertilizer application and Agricultural Growth in China. The dataset for the study consists of a 37-year observation for the period 1978-2015. We obtained the data on agricultural growth in Chinese from World Development Indicators (WDI) and that of fertilizer application from China Statistical Yearbook. We measured Agricultural growth (AG) by agriculture contributions to the national GDP and Fertilizer application (F_A) by the number of chemical fertilizers applied in agriculture in a year, including nitrogenous fertilizer, phosphate fertilizer, potash fertilizer and compound fertilizer. To reduce the heterogeneity of the data between the two variables, we converted the variables into natural logarithms. Stata version 13 and EViews Standard Version 9.0 were used for the statistical estimations.

**Econometric Models**

The study looks at the existence of a long-run equilibrium relationship between fertilizer application and agricultural productivity growth. We utilized both Johansen co-integration approach. We adapted the Vector Autoregressive models (VAR) approach (1991) and the Engle-Granger procedure (1987). We initially tested the stationarity properties of the regression residuals.

To investigate the impact of fertilizer application on Agricultural Growth in China within the study period, we employed the following recent econometric techniques: Semi-parametric Fully Modified Ordinary Least Squares (FMOLS); and Dynamic Ordinary Least Square (DOLS). These recent econometric approaches are more robust and provide better statistical inferences towards policy formulation, guidelines and reforms.
regarding the fertilizer application and agricultural productivity growth in China.

In testing the direction of causality, we followed the three-stage procedure used by Oxley and Greasley (1998) and (Ghosh, 2002). Firstly, we tested for the order of integration by utilizing the Augmented Dickey-Fuller (ADF) or using nonparametric Zt ( ) ε statistics(Phillips & Perron, 1988). In the second stage, we investigated the bivariate co integration by using the VAR model as proposed by Johansen (1988). In the final stage, our study constructed the Granger-type causality test with error correction term.

Below are the estimated equations (equation1-6):

\[ F_{At} = \varepsilon + \sum_{i=1}^{k} \beta_i F_{At-i} + \sum_{j=1}^{v} \rho_j A_{Gi-j} + \alpha_t, \]

(1)

\[ A_{Gi} = \alpha + \sum_{i=1}^{k} \eta_i A_{Gi-i} + \sum_{j=1}^{m} \beta_j F_{At-j} + \nu_t, \]

(2)

Where \( \alpha_t \) and \( \nu_t \) are zero-mean, serially uncorrelated, random disturbances. Moreover, Granger causality test with cointegrated variables apply the I (0) data, with error-correction term i.e.

\[ \Delta F_{At} = \varepsilon + \sum_{i=1}^{k} \beta_i \Delta F_{At-i} + \sum_{j=1}^{v} \rho_j \Delta A_{Gi-j} + \delta ECM + \alpha_t, \]

(3)

\[ \Delta A_{Gi} = \alpha + \sum_{i=1}^{k} \eta_i \Delta A_{Gi-i} + \sum_{j=1}^{m} \beta_j \Delta F_{At-j} + dECM + \nu_t, \]

(4)

Where the error-correction term is denoted ECM.

Furthermore, if the data are I (1) but not cointegrated, Granger-type tests require transformations to induce I (1). The equation can be represented as follows:

\[ \Delta F_{At} = \varepsilon + \sum_{i=1}^{k} \beta_i \Delta F_{At-i} + \sum_{j=1}^{v} \rho_j \Delta A_{Gi-j} + \alpha_t, \]

(5)

\[ \Delta A_{Gi} = \alpha + \sum_{i=1}^{k} \eta_i \Delta A_{Gi-i} + \sum_{j=1}^{m} \beta_j \Delta F_{At-j} + \nu_t, \]

(6)

The optimal lag length \( x, v, k \) and \( m \) in the model are determined based on Akaike’s (AIC) or Schwarz Bayesian (SBC) and log-likelihood ratio test (LR) criterion.

After finding the existence of long run relationship between the two variables, we further employed Fully Modified Ordinary Least Square (FMOLS) and Dynamic Ordinary Least Square (DOLS) proposed by Phillips and Hansen (1988) and Stock and Watson (1993), respectively to have a strong basis for comparing the robustness of the results.

We adopted FMOLS modifies least squares to clarify the serial correlation effect and for the endogeneity in the regressors that arise due to the existence of a cointegrating relationship, provides reliable results for small sample size and provides check for robustness of the results. Moreover, the FMOLS technique utilizes “Kernal estimators of the Nuisance parameters that affect the asymptotic distribution of then OLS estimator(Bashier & Siam, 2014).

Following (Mehmood, Feliceo, & Shahid, 2014), we propose the following model:

\[ K_1 = \hat{\Pi}_{21} M_{1r} + \hat{\Pi}_{21} M_{1r} + \gamma_t, \]

(7)

Or directly from the regressions

\[ \Delta K_1 = \hat{\Pi}_{21} \Delta M_{1r} + \hat{\Pi}_{21} \Delta M_{1r} + \nu_t, \]

(8)

Let \( \phi \) and \( \phi^* \) be the long-run covariance of are long-run covariance matrices, which have been calculated by the use of the residual \( \gamma_t = \left( \gamma_{1t}, \gamma_{2t} \right)' \). Therefore, we can explain the modified data as

\[ \rho^* = \rho_t - \hat{\beta}^{-1}_{12} \hat{\beta}^{-1}_{22}, \]

(9)

An estimated bias correction term

\[ \hat{\beta}^{-1}_{12} = \hat{\beta}^{-1}_{12} \hat{\beta}^{-1}_{22}, \]

(10)

Therefore, the FMOLS estimator can be given as

\[ d = \left[ \begin{array}{c} \beta_t' \\ \alpha_t' \end{array} \right] = \left( \sum_{t=1}^{n} R_t R_t' \right)^{-1} \left( \sum_{t=1}^{n} R_t \beta_t' - p \left[ \beta_0 \right] \right) \]

Where \( R = \left( K', M' \right)' \). FMOLS aims at

constructing long-run covariance matrix estimators $\hat{\Phi}$ and $\hat{\mu}$. However, there is the need to define the scalar estimator.

\[
1_{12} = 1_{11} - 1_{12} \hat{\Phi}_{121121}.
\]  
(12)

This is defined as the estimated long-run variance of $V_t$, conditional on $V_2$. The degree of freedom may be applicable to $1_{12}$.

Stock and Watson 1993, Dynamic Ordinary Least squares (DOLS) provides an alternative approach, advantage over both OLS and the maximum likelihood procedures. DOLS outperforms OLS by coping with limited sample size and dynamic sources of bias. Dynamic Ordinary Least squares has similar asymptotic optimality properties as the Johnson distribution. This method has by adopted to estimate energy demand in Jordan by Al-Azzam and Hawdon (1999), find the cause effect relationship between aviation demand and economic growth in Romania by (Mehmood et al., 2014). However, we adapt and extend the approach here.

Moreover, DOLS comprises augmenting the cointegrating regression with lags and leads of in order for the resulting cointegrating equation error term are orthogonal to the whole idea of stochastic regressor innovations. Following Al-Azzam and Hawdon (1999), we adapt and modify the model below:

\[
P = [\alpha, \beta, \nu, \epsilon], X = [1, R, A, S]
\]
(13)

Where

\[
P = [\alpha, \beta, \nu, \epsilon], X = [1, R, A, S]
\]
(14)

And where, $p$, $v$ and $n$ denote the lengths of leads and lags of the regressions. We assume that if $P$ has revealed to be $I (1)$ and if some variables at the RHS $I (1)$ or $I (0)$, then DOLS estimates are obtained by regression analysis of the equation formulated above.

**Empirical Results**

To begin, we investigated the order of integration of the data. The results of unit root tests, which are in natural logarithms of the levels (V) and the first differences (VI) of the variables through agricultural growth and fertilizer application is presented in table 1. However, this paper adopts Augmented Dickey-Fuller (ADF) and Phillips and Perron (PP) techniques to investigate whether fertilizer application and agricultural growth in China are stationary within the study period. However, in both stationarity test, we adopt ADF and PP with assumptions that $LF_A$ and $LA_G$ in their logarithmic form will show intercept and trend. According to the results from table 1, both variables are stationary at first difference (VI) using ADF and PP test with significant at all levels (1%, 5% and 10%). So $LF_A$ and $LA_G$ variables are stationary at $I (1)$.

<table>
<thead>
<tr>
<th>Table 1: ADF and PP Unit Root tests results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using constant</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>\text{ADF}</td>
</tr>
<tr>
<td>\text{ADF}</td>
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<tr>
<td>\text{ADF}</td>
</tr>
<tr>
<td>\text{ADF}</td>
</tr>
<tr>
<td>\text{PP}</td>
</tr>
<tr>
<td>\text{PP}</td>
</tr>
<tr>
<td>\text{PP}</td>
</tr>
</tbody>
</table>

Note: Null hypothesis is represented at 5% level of significance

Table 2 presents the results of Johansen Juselius Likelihood Cointegrating tests. Cointegration is mainly adopted to show if there is a long-run equilibrium relationship between the variables. However, if the relationship is stationary, it is $I (0)$, zero order of cointegration; on the other hand if their relationship is not stationary it means that data becomes difficult to model because the estimate of the mean and the variance will be changing sometimes.

From table 2, we test the cointegration rank, $\alpha$, of the time series is also tested by the use of different test statistics. Following Ghosh (2002), we denote the number of cointegrating vectors by $\alpha_0$, the maximum eigenvalue ($\rho_{\text{max}}$) test is calculated under the null hypothesis that $\alpha_0 = \alpha$, against the alternative of $\alpha_0 > \alpha$. Therefore, the trace statistics is calculated under the null hypothesis that $\alpha_0 \leq \alpha$, against $\alpha_0 > \alpha$.

Table 2 reports the results of the Johansen-Juselius Likelihood Cointegrating tests. From the null
hypothesis of cointegration between $LF_A$ and $LA_G$, ($\alpha=0$), the maximum eigenvalue statistic is 26.7184 more than 90 percent critical value of 14.2640. This means the null hypothesis of $\alpha=0$ can be rejected at 10 percent significant level. In addition, from the trace statistics represented in table 2, the trace null hypothesis of no cointegration is rejected at 10 percent significant level. Maximal eigenvalue test and Trace tests reveal the existence of one cointegrating vector.

**Table 2: Johnson Co-integration Test**

<table>
<thead>
<tr>
<th>Null</th>
<th>Alternative</th>
<th>Statistics ($LA_G$ and $LF_A$)</th>
<th>Critical Value (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>II</td>
<td>III</td>
<td>IV</td>
</tr>
<tr>
<td>$\alpha=0$</td>
<td>$\alpha=1$</td>
<td>26.7184</td>
<td>14.2640</td>
</tr>
<tr>
<td>Trace test</td>
<td>$\alpha=0$</td>
<td>32.2220</td>
<td>14.4047</td>
</tr>
</tbody>
</table>

Notes: $\alpha$ is the number of cointegrating relations. Optimum lag length is ‘2’, which is selected using Akaike Information Criterion (AIC), Hannan Quinn Information Criterion (HQIC), and Schwarz Bayesian Information Criterion (SBIC).

We also adopted modern econometric models (Fully Modified Ordinary Least Square (FMOLS) and Dynamic Ordinary Least Square (DOLS) to study the existence of a long-run relationship between the variables. Table 3 presents the results of FMOLS and DOLS. The results of FMOLS and DOLS adopted for cointegrating regression are positive and statistically significant at 1% significant level. Therefore, the results of the study show a long-term relationship between agricultural growth and fertilizer application. The results obtain for FMOLS and DOLS estimation imply that a unit increase in fertilizer application increase agricultural growth by 2.893 and 1.214 respectively. The results add up to the various studies conducted on Chinese agricultural growth, which maintain that increase in fertilizer application has helped in promoting agricultural productivity growth.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$D_{A_0}$</th>
<th>$D_{F_A}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{A_0}$</td>
<td>CHS-Q (R$^2$)</td>
<td>0.521</td>
</tr>
<tr>
<td>$D_{F_A}$</td>
<td>CHS-Q (R$^2$)</td>
<td>0.330</td>
</tr>
</tbody>
</table>

Although there is absence of a short run causality fertilizer to increase in agricultural production, there is the presence of a long-run causality from the increase in fertilizer consumption to the growth of Chinese agriculture. In the long-run, table 4, the error term is significantly negative, which shows a speed of adjustment towards long run equilibrium at 33.9%.

**Table 3: Comparison of the Co-integration Regression Estimates**

<table>
<thead>
<tr>
<th>Method Const.</th>
<th>Cow.</th>
<th>v</th>
<th>S.E.</th>
<th>Adj. R$^2$</th>
<th>Long-Run Variance</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>II</td>
<td>III</td>
<td>IV</td>
<td>V</td>
<td>VI</td>
<td>VII</td>
</tr>
<tr>
<td>FMOLS 14.716</td>
<td>2.893</td>
<td>1.214</td>
<td>0.070</td>
<td>0.9569</td>
<td>0.012</td>
<td>0.0012</td>
</tr>
<tr>
<td>DOLS 16.0244</td>
<td>1.214</td>
<td>2.893</td>
<td>0.098</td>
<td>0.9796</td>
<td>0.009</td>
<td>0.0122</td>
</tr>
</tbody>
</table>

From table 4, the results of Granger causality reveal that in the short run, there is a unidirectional causality running from agricultural productivity growth to fertilizer consumption. This implies that as crop, fishery, livestock and forestry production increases consumption of fertilizer also increases in the short run for a country like China.

**Table 4: Results of Granger-causality test.**

**Figure 1:** The correlation between fertilizer application and Agricultural productivity growth from 1978 to 2015. **Source:** Authors construct

The study further explores the relationship between fertilizer application and agricultural productivity growth by the use of correlogram, that is, cross...
correlation. The result from figure 5 reveals a positive effect of fertilizer consumption on agricultural productivity growth reaching the highest point at lag 0. This implies that fertilizer consumption is positively correlated with agricultural productivity growth during the study period. However, the impact of fertilizer consumption on agricultural production is likely to decrease in the subsequent years due to farmers sensitization on the environmental problems associated with chemical fertilization, which includes large emissions and alarming rate of water pollution and not forgetting poor quality of some farm products.

Conclusion
With an average population of 1.4 billion in China, food security has been a major concern for Chinese government. However, to increase food production has called for Chinese government to support fertilizer production through the provision of fertilizer subsidies. The main goal of this paper is to investigate the relationship between increases in fertilizer consumption and agricultural productivity growth in rural China for the period 1978-2015 by adopting unit root tests and test of co-integration. The study also used Fully Modified OLS and Dynamics OLS approach to investigate the effect of fertilizer consumption on agricultural growth. This is measured by the use of Johansen co-integration approach and Engle-Granger procedure, which adopt the use of Vector Autoregressive models (VAR) and also testing the stationarity of the regression residuals respectively. The VAR is constructed either by adopting level of the data or their first differences. The results revealed a short run unidirectional causality running from agricultural productivity growth to fertilizer consumption. This implies that as crop, fishery, livestock and forestry production increases consumption of chemical fertilizer also increases. Moreover, there is the presence of a long run causality from increase in fertilizer consumption to the productivity growth of agriculture. This means that an increase in chemical fertilizer application on farmlands can lead to an increase in agricultural growth in the long-run. The results of FMOLS and DOLS. The results of FMOLS and DOLS approach also showed that the effect of chemical fertilizer application on agricultural productivity growth is significantly positive. Moreover, the results from the correlogram revealed that fertilizer application is positively correlated with agricultural productivity growth, reaching the highest point at lag -1. The study therefore suggests that there should be effective implementation of fertilizer application policy in China. For example, creation of no fertilizer county as proposed by Miyun County Director, “Pesticide and fertilizer are not allowed to be used within 5 km to the sea in Dalian city” as suggested by Dalian Environmental Director and reduction in the use of pesticide and nitrogen fertilizer consumption to 20% in Tai Lake as authorized by Jiangsu Government Director. Therefore, both direct and indirect subsidies of N fertilizers should be given to farmers for food production, without compromising on proper application of the nitrogen fertilizers.

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