Assessment of the Effects of the Fertilizer Support Programme on Maize Productivity: A Chow-test approach

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ABSTRACT

In an effort to alleviate poverty and increase the incomes of millions of rural Zambia that depend on agriculture, the Zambian government has been implementing the Fertilizer Support Programme since 2002. Since then, the allocations to the FSP have been increasing despite claims that the programme has not been achieving the intended objectives. Unlike other studies conducted on the subject, this study used time series data to assess the effects of the fertilizer support programme on maize productivity. The methodology involved the use of tests of structural breaks (Chow-test) as a device for identifying discontinuities in the data which potentially represent treatment effects. The paper used data from the FAO database on national production and area under production between 1990 and 2010 (a period that covers the pre – FSP period (1990 – 2001) and post – FSP (2002-2010).

The results showed that there has been a significant difference in the marginal productivity of land between the two periods (1.857 tons/hectare for the pre – FSP period compared to 2.219 tons/hectare for the post – FSP period) at the five percent significant level. The conclusion is that even though the FSP has resulted in significant increase in marginal productivity over the period in question, the question still remains whether the cost of the programme can be justified by the observed increase in marginal productivity.

INTRODUCTION

Since 2002, the government has been distributing an increasing amount of subsidized fertilizer through the Fertilizer Support Programme (FSP) which is currently known as Farmer Input Support Programme (FISP). This has raised a lot of questions from various quarters of society. For instance, the Agricultural Consultative Forum and the Food Security Research Project[1] shows that the programme which was aimed to be a gradual subsidy for a three-year period now accounts for more than a third (about 38 percent) of the national agricultural budget and the resources allocated to it have continued to increase (see table 1). For the year 2011, the budgetary allocation for the FISP was raised to 485 billion from 435 billion in 2010. This, according to the budget speech[2], is based on the success of the programme in 2010 when the nation recorded an unprecedented bumper harvest. In view of the ever increasing resources allocated to the FSP which is a recurrent subsidy at the expense of other investments such as research, irrigation and extension among others and also in view of the recently recorded 2008/09 and 2009/10 maize bumper harvests[3], there have been debates from various sections of society as regards the impact of the FISP on the development of the agricultural sector in general and specifically its impact on maize production/ productivity. For instance, some sections of society have attributed the maize bumper harvests to government policies on agriculture such as the FISP, while others attribute this to increased use of good farming practices such as conservation agriculture while others attribute this to favorable weather.

In the light of these debates, there have been attempts by researchers to provide some insights on the factors that could have contributed to these bumper harvests, consequently evaluating the impact of the FISP on maize production and productivity. In an effort to explain the 2009/2010 bumper harvest, the Food Security Research Project[3] carried out a study, using the Crop Forecast Survey (CFS) data, that aimed at measuring the contribution of various factors to the jump in maize production in 2010 with the aim of providing policy makers and other stakeholders an empirical foundation for future discussions in Zambia about the importance of government programmes and other factors in driving the recent maize production growth. The results showed that the factors that were responsible for the bumper harvest includes good weather (61 percent), increased usage of fertilizer (32 percent) and also use of hybrid seed (5 percent). However, earlier analysis of the impact of the FISP on maize productivity using cross sectional data by Minde *et al*[4], CSPR[5] and the World Bank[6] show that maize yields per hectare have remained low despite the programme. The Agricultural Consultative Forum[7] shows that although the programme aimed at increasing smallholder farmer's yields per hectare to about 3 tons, estimates show that the average yields hover around 2 tons per hectare, a factor that has been attributed to poor agronomic practices, untimely application of fertilizer and weed infestation among others.

This study will add a new dimension to the existing body of literature on the FISP by use of time-series data to determine the (productivity) relationship between area under maize

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cultivation and total maize produced. In contrast to cross-sectional data that has been used in earlier studies (Burke *et al.*,[3]; World Bank[6]; Miinde *et al.*,[4]; CSPR[5]) time-series analysis is appealing because it is able to provide information on longer run impacts of the programme on maize productivity. The goal is to contribute to better evidence to inform policy towards improved spending in the agricultural sector, while the main objective is to assess the impact of the FISP on maize productivity.

ANALYTICAL FRAMEWORK

Time-series analysis can and has been used is estimating treatment effects. Piehl[8] shows that this involves the use of tests for structural breaks as a device for identifying discontinuities in the data which potentially represent treatment effects. As Lee and Suardi[9] shows, the idea involves modeling the dependent variable of interest using a time series model, and using a structural break test to determine if the timing of changes in policy coincides with statistically significant discontinuities in the data series of the dependent variable. From an evaluation perspective, an important advantage of the structural break approach is that it can even be used in the case when there are no obvious or appropriate comparison groups, as is the case with FSP programme in Zambia. Considering that the aim was to evaluate the impact of the FSP/FISP programme whose commencement date is known (2002), the paper uses the Chow test for structural change. Chow as cited in Gujarati[10] proposes an *F*-test for a one-time structural change in one or more estimated regression coefficients when the date of the break is known. The chow test has been mostly used for testing parameter instability, which is a common form of misspecification. Basically, what the test does is to test whether the same relationship held over the whole sample period. As a hypothesis-testing problem, this can formally be expressed as follows, considering a linear model

$$Y = X\beta + \Sigma \qquad (1)$$

It can be shown that if there are two subsamples, (1) and (2), in which the parameters are not necessarily the same, then the equation (1) above can be written as

$$y_1 = \begin{cases} X_i\beta_1 + \varepsilon_i & i\epsilon(1) \\ X_i\beta_2 + \varepsilon_i & i\epsilon(2) \end{cases} \qquad (2)$$

And the hypothesis to be tested can be stated as

$$H_0: \beta_1 = \beta_2 \qquad (3)$$

The total number observation is $n = n_1 + n_2$ and the number of parameters is *k*. According to literature, there are two methods for testing this hypothesis, (i) the sum of squares test, (ii) and the dummy variables test, both which give the same numerical answers.

In this study, the sum of squares test was used. Under this test, if the null hypothesis *isn't true*, then the correct procedure is to estimate two separate regressions, i.e. let $\hat{\beta}_1 \, and \, \hat{\beta}_2$ be the parameters estimated from these regressions, with residuals $\hat{\varepsilon}_1 \, and \, \hat{\varepsilon}_2$ and sum of squares $RSS_1 = \hat{\varepsilon}_1\hat{\varepsilon}_1 \, and \, RSS_2 = \varepsilon_2'\varepsilon_2$. The unrestricted sum of squares for the whole data set will be $RSS_U = RSS_1 + RSS_2$, which has $(n_1 - k) + (n_2 - k) = n - 2k$ degrees of freedom. On the other hand, if the null hypothesis is true then the correct procedure is to determine a single regression from all the data. In this case we denote the parameter estimate as $\hat{\beta}$, the residuals by $\hat{\varepsilon}$ and the *restricted* sum of squares $\hat{\varepsilon}'\hat{\varepsilon}$ as $RSS_R \; with \; n - k$ grees of freedom. The assumption is that under the null hypothesis, there should be no significant difference between RSS_{UR} and RSS_R. A formal test is performed by calculating the F-Statistic.

$$F = \frac{\dfrac{RSS_R - RSS_{UR}}{k}}{\dfrac{RSS_{UR}}{n_1 + n_2 - 2k}} \sim F_{[k, (n_1+n_2-2k)]} \qquad (4)$$

In short the Chow test statistic for a particular break date involves splitting the sample at that break date and estimating the model parameters separately on each sub-sample, as well as for the whole sample. The respective residual sum of squares (RSS) are computed and used to calculate the Wald statistic using equation (2) above where, RSS_R is the residual sum of squares for the whole sample. The subscripts 1 and 2 denote the first and second sub-samples and *k* is the number of regressors in the sub-sample regression

Agriculture productivity is measured as the ratio of agricultural outputs to agricultural inputs. It is commonly known[11] that agricultural productivity is very important in that aside from providing more food, increasing farm productivity affects a nation's prospects for growth and competitiveness on the agricultural market, income distribution and savings, and labor migration. Furthermore, increases in agricultural productivity leads to agricultural growth and can help alleviate poverty in less developed countries where agriculture employs the majority. By definition, productivity can be considered as a measure of output from a production process, per unit of input. For this paper, land productivity is typically measured as a ratio of output (total maize produced) per (hectare of land) input. In order to assess whether land productivity (measured as a ratio of maize produced in metric tons to land input in hectares) has changed as a result of introduction of the FISP, a simple production function that relates production *(Y)* to area under maize cultivation *(X)* was estimated, i.e.:

$$Y = f(X) \qquad (5)$$

From the above function relating area under cultivation *(X)* to maize output *(Y)*, we can get the marginal productivity of land by differentiating with respect to maize output (where the marginal product or marginal physical product of an input (factor of production) is the extra output that can be produced by using one more unit of the input, assuming that the quantities of other inputs to production do not change. This is given by the slope as shown below

$$MP_x = \frac{\partial y}{\partial x} = Slope \qquad (6)$$

In order to estimate the parameters, the chow test comes in handy. Since we have the data for maize production (output) from 1990 to 2010 *(Y)* and also for area cultivated *(X)* for the same period, we can obtain an OLS regression of *Y* on *X*. However, as Gujarati[10] points out, by doing that, we are maintaining that the relationship between output and area under cultivation remained the same over this period. The implication of this is that the fertilizer support programmes have had no impact on the productivity of land. Considering the amounts of resources spent on the programmes and the recently observed bumper harvests as well as the pronouncements about the contribution of the FSP to maize production, we assert that due to the fertilizer support programmes, the relationship between maize production and area under production should not have remained the same over this time span. In short, introduction of the fertilizer support programme must have changed the relationship between production and area under cultivation as claimed by many. To see if this happened, we employ the chow test for structural stability (breaks). To test for structural breaks, we divided the data into two time periods: 1990 – 2001 and 2002 – 2010, as the pre-FSP and post-FSP periods, giving three possible regressions:

Pre-FSP 1990–2001: $Y_t = \lambda_1 + \lambda_2 X_t + u_{1t}$ $n_1 = 12$ (7)

Post-FSP 2002–2010: $Y_t = \gamma_1 + \gamma_2 X_t + u_{2t}$ $n_2 = 10$ (8)

Entire period 1990–2010: $Y_t = \alpha_1 + \alpha_2 X_t + u_t$ $n_t = (n_1 + n_2) = 22$ (9)

Where: Regression (9) assumes no differences between the pre- and post FSP errors (i.e. assumes there is no structural change despite the FSP programme) which is the null hypothesis:

$$\text{Ho: } \gamma_2 = \lambda_2;\ \gamma_1 = \lambda_1 \qquad (10)$$

Regressions (7) and (8) assumes that there is structural change i.e. regressions in the two time periods are different (both the slopes and intercepts are different).

To formally test the null hypothesis that there no structural break, we use the chow test to test for structural stability of regression (9). In the context of this paper, finding of a structural break that coincides with the implementation of the Fertilizer Support Programme shall be interpreted as evidence supporting that there has been a change in land productivity. On the other hand, a failure to find structural breaks coinciding with the implementation of the FSP shall imply that we cannot reject the null hypothesis that the FSP has had no impact on land productivity.

The chow test works under three main underlying assumptions, which were tested before the test was undertaken. These are:

(1) The error terms in the sub-period regressions are normally distributed and similar

(2) The two error terms are independently distributed

(3) The time of the break is known

After testing these assumptions and finding that they had not been violated, the chow test was run following the steps outlined below:

(1) The residual sum of squares (RSS) for equation (9) was estimated. This was denoted as RSS_R or the restricted residual sum of squares[10]

(2) The RSS for equation (7) and that for equation (8) denoted as RSS_1 and RSS_2 respectively were also estimated

(3) Then the two RSS's (i.e. $RSS_1 + RSS_2$) were added to get the Unrestricted Residual Sum of Squares (RSS_{UR})[1]

(4) The null hypothesis (no structural change) was tested using the ratio:

$$F = \frac{\dfrac{RSS_R - RSS_{UR}}{k}}{\dfrac{RSS_{UR}}{n_1 + n_2 - 2k}} \sim F_{[k, (n_1+n_2-2k)]} \qquad (11)$$

The assumption was that if the null hypothesis could not be rejected, then the RSS_R and RSS_{UR} should not be statistically different using the ratio in equation (11). By comparing the computed F-value with the critical F-value, it was possible to reject or not to reject the null hypothesis.

The likely major limitation of the approach is that even though it enables evaluation of the FISP without the need to have a comparison group to represent a plausible counterfactual, the implications of not having a comparison group is that even when a break is identified, this does not constitute conclusive evidence that the break is solely due to the implementation of the program as many other factors could have occurred simultaneously. However, institutional knowledge can be useful in this case to aid in determining if such breaks are solely due to the effects of one policy change, or plausibly due to other exogenous shocks. For instance, introduction of the Food Reserve Agency which buys maize from farmers at prices which sometimes tend to be above the market price could also have contributed to the increase in maize production and contribute to the structural break observed. However, considering that government activities in maize marketing dates back before 2002 (i.e., through institutions such as National Agricultural Marketing Boards (NAMBOARD)) for purposes of this study, the impact of the FRA is considered to be almost constant in the period under review. The other limitation lies in the smallness of the number of observations. However, considering that all the available observations after the FISP have been included, it was the best that could be done.

Source of Data

In this paper, the impact of the FSP was evaluated by analyzing annual time-series data on maize production and area under maize cultivation in Zambia for the period 1990 to 2010. For the case of Zambia agriculture, 2002 is an important year because it was the year that the Zambian government introduced the Fertilizer Support Programme (FSP), a programme that aimed at reducing poverty through increased access by small-scale but viable farmers to maize seed and fertilizer. The data for the period 1990 to 2008 was obtained from the 2010 *Food and Agriculture organization (FAO)*

[1]Addition of RSS1 and RSS2 is permissible due to assumption of independent samples.

online database published by the FAO[12]. From this database, national annual maize production (in metric tons) data from 1991 to 2008 was obtained together with total area under maize production (in hectares) for the same period. Maize production data and area under cultivation for 2009 and 2010 was obtained from reports by Zambia National Farmers Union (ZNFU) [13]. The sample period was selected because it enabled the study to achieve its objective of analyzing the impact of farmer FSP on maize yield in Zambia because it covers the periods before (1991 – 2001) and after implementation of the FISP (2002 – 2010).

Analytical Process

The analysis process involved a number of steps with the first being testing for the assumptions under which the chow test relies. This included testing for normality of the error terms as well as equality of variance for the sub-samples. This was followed by testing for independence of distribution of the error terms for the subsamples. After testing these assumptions and finding that they had not been violated, the chow test was run following the steps outlined under the theoretical framework section.

RESULTS

Testing for Underlying Assumptions

The first assumption tested was that of equality of the error variances in the two sub-periods using the estimates of the error variances from the respective residual sum of squares in regressions (7) and (8) for each of the sub-periods as shown in equations (12) and (13)

$$\hat{\sigma}_1^2 = \frac{RSS_1}{n_1 - 2} = \frac{886{,}663{,}759{,}114}{9} = 98{,}518{,}195{,}457 \quad (12)$$

$$\hat{\sigma}_2^2 = \frac{RSS_2}{n_2 - 2} = \frac{287{,}129{,}769{,}519}{6} = 47{,}854{,}961{,}586 \quad (13)$$

If the two variances in equations (12) and (13) are the same as assumed by the Chow test, then it can be shown that:

$$\frac{(\hat{\sigma}_1^2/\sigma_1^2)}{\hat{\sigma}_2^2/\sigma_2^2} \sim F_{(n_1-k),(n_2-k)} \quad (14)$$

That is the ratio in (14) follows an F distribution with the shown degrees of freedom. The ratio in (14) is equivalent to computing F as in (15) below:

$$F = \frac{\hat{\sigma}_1^2}{\hat{\sigma}_2^2} = \frac{98{,}518{,}195{,}457}{47{,}854{,}961{,}586} = 2.059 \quad (15)$$

By comparing the computed F in (15) with the appropriate degree of freedom, a decision could be made to reject or not to reject the null hypothesis that the two variances in the sub-populations are the same. If the null hypothesis is not rejected, then the Chow test could be used. According to the data, the calculated F-value in equation (15) was 2.059 with 9 and 6 degrees of freedom while the tabulated were 4.10 and 7.98 at the 1 and 5 percent respectively, implying that the null hypothesis of equal variances for the sub-samples could not be rejected. This implied that the Chow test could be used as the first assumption was not violated.

To test the second assumption, the error terms in the sub-period regressions are normally distributed and similar, the Kolmogorov-Smirnov and Shapiro-Wilk testes were used. These compare the scores in the sample to a normally distributed set of scores with the same standard deviation and degrees of freedom (Field, 2005). If the test is not significant *(p>0.05)* it shows that the distribution of the sample is not significantly different from a normal distribution. Table 2 shows the results of the results *(p=0.200>0.05)* implying that the distribution was not significantly different from a normal distribution. This implied that the data did not violate the normality assumption either and the Chow test could be conducted.

Model Results

Restricted regression model (Pre-FISP period 1990-2001)

Model 1 gives the restricted model which assumes that there is no structural change for the entire period (1990 to 2010). The regression equation is expressed as $Y_t = \alpha_1 + \alpha_2 X_t + u_t$. The Analysis of Variance (ANOVA) (Table 3) shows that the Restricted Sum of Squares (RSS_{UR}) is 1,333,960,855,162. Table 3 also shows the coefficients for the regression. The results show that every one hectare increase in area under maize results in 2.336 metric tons increase in maize production, holding all other factors constant. These results were significant at the one percent confidence level and the r-squared value of 0.734 was quite high indicating that area under cultivation explained about 73 percent of the observed variation in maize production.

Model 2 gives the restricted model for the pre-FSP period. Table 4 is the Analysis of Variance (ANOVA) table for this regression $Y_t = \gamma_1 + \gamma_2 X_t + u_{2t}$. The residual sum of squares (RSS_R) is 886,663,759,114. Table 4 also shows the coefficients for the regression. A one hectare increase in area under maize resulted in 1.857 metric tons increase in maize production, holding all other factors constant during the period 1990 - 2001. However, these results were not significant even at the ten percent confidence level and the r-squared value of 0.176 was quite low indicating that area under cultivation explained only about 17 percent of the observed variation in production.

Unrestricted Regression Model (Post FISP period, 2002-2010)

Model 3 gives the restricted model for the post-FSP period (2002 – 2010). Table 5 is the Analysis of Variance (ANOVA) table for the restricted regression $Y_t = \gamma_1 + \gamma_2 X_t + u_{2t}$. The residual sum of squares (RSS_R) is 287,129,769,519. Table 5 also shows the coefficients for the regression model. The results show that every one hectare increase in area under maize resulted in 2.211 metric tons increase in maize production, holding all other factors constant during the period

2002 - 2010. These results were significant at one percent confidence level and the r-squared value of 0.910 was quite high indicating that area under cultivation explained about 91 percent of the observed variation in maize production for the period.

Since the two sets of sub-samples are deemed independent, we add RSS_1 and RSS_2 to obtain the Unrestricted Residual Sum of Squares (RSS_{UR}) as shown below:

RSSUR = RSS1 + RSS2 = 886,663,759,114 +287,129,769,519 = 1,173,793,528,633

Results for Step 5 (Hypothesis Testing, i.e. $H_o: \gamma_2 = \lambda_2;\ \gamma_1 = \lambda_1$ (16)

The fifth step involves testing the null hypothesis (no structural change) by using the ratio:

$$F = \frac{\frac{RSS_R - RSS_{UR}}{k}}{\frac{RSS_{UR}}{n_1 + n_2 - 2k}} \sim F_{[k_1(n_1+n_2-2k)]} \quad (17)$$

The results are as follows:

$$F = \frac{\frac{1,333,960,855,162}{2}}{\frac{1,173,793,528,633}{16}} = 9.0916$$

From the tables, for the 2 and 16 degrees of freedom, the 1 percent critical F value was 6.23 therefore; the probability of obtaining an F value as large as 9.0916 was much smaller than 1 percent implying that the Chow test supported the allegation that there has been a change in the area/production regression (i.e. marginal productivity of land since introduction of the FSP).

DISCUSSION

Despite the availability of numerous detailed studies of the effects of the fertilizer support programme on maize farm productivity using various alternative approaches (but relying on cross sectional data), the subject remains highly contentious and politically charged with no clear consensus between the parties. This paper has used a different approach (time-series) to assess if there has been a change in the marginal productivity of land since introduction of the programmes in 2002. By testing for structural breaks to determine if there is a significant relationship between area under maize production and maize production, the paper concludes that there appears to have been a significant structural break in the marginal productivity of land over the period in question. The regression results show that the introduction of the fertilizer support programmes has resulted into changes in the marginal productivity of land from 1.857 tons per hectare in the pre-FSP (1990-2001) to 2.211 tons per hectare in the post-FSP period (2002 – 2010). The large Chow statistic shows that this structural change is significant and the parameters on these two regressions (2.211 and 1.857) are significantly different statistically.

However, when interpreting these results, it is important to bear in mind that the two bumper harvests experienced in the 2008/09 and 2009/20 seasons must have had a huge influence on the results considering the small sample size. However, on average, the results do not contradict the findings of other studies which have estimated yields per hectare for the FSP period at between 2.04 tons for FSP beneficiaries using the 2004 Crop Forecast Survey (CFS) data[7] and 2.219 tons per hectare for FSP beneficiaries using the 2009 CFS data[3]. However, while making these comparisons, it is important to bear in mind that the production data that this study used is total national production (i.e. it includes also production from non-FSP fertilizer).

CONCLUSION

In conclusion, the key message is that even the fertilizer support programmes have not been able to raise productivity to the targeted 3 metric tons per hectare[6] there is still a significant increase in marginal productivities between the two periods, with the marginal productivity for the post – FSP period being higher than that for the pre-FSP. However, the question still remains on whether the costs incurred in implementing the programme can be justified by the observed increases in marginal productivity. This is particularly important in that the resources allocated to the programme keep increasing at the expense of other programmes which have been identified as priority areas in the National Development Plans such as irrigation, agricultural infrastructural development and extension.

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Table 1: Trends in funds allocation to the Fertilizer Support Programme (2006 -2010)

	2006	2007	2008	2009	2010	2011
	K'Bn	K'Bn	K'Bn	K'Bn	K'Bn	K'Bn
Amount Allocated to FISP	199	150.3	185	435	430	485
Percentage Change from Previous Year		-22.5	23.1	135	-1.1	12.8

Table 2: Testing for the Normality Assumption using the Kolmogorov test

	Period	Kolmogorov -Smirnov			Shapiro -Wilk		
		Statistic	Df	Sig.	Statistic	df	Sig.
Production	Pre	0.183	12	.200*	0.964	12	0.841
	Post	0.261	9	0.079	0.902	9	0.262
Area	Pre	0.137	12	.200*	0.963	12	0.823
	Post	0.27	9	0.058	0.874	9	0.135

Table 3: ANOVA and Regression Analysis table for the restricted model (1990-2010)

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	3,948,248,512,708	1	3,948,248,512,708	56.236	0.000
Residual	1,333,960,855,162	19	70,208,466,061		
Total	5,282,209,367,870	20			

Model	B	Std. Error	T	Sig.
Constant	-414,178.638	218,376.924	-1.897	0.073
Area	2.336	0.311	7.499	0.000

Table 4: ANOVA and Regression table for Model two (pre-FSP period, 1990 – 2001)

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	189,581,681, 061	1	189,581,681,061	2.138	0.174
Residual	886,663,759,114	10	88,666,375,911		
Total	1,076,245,440,176	11			

Model	B	Std. Error	t	Sig.
Constant	-185,139.133	798,057.519	-0.232	0.821
Area	1.857	1.270	1.462	0.174