Role of Agricultural Research and Extension in Enhancing Agricultural Productivity in Punjab, Pakistan

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Abstract

In this study long run relationship between agricultural research and TFP (total factor productivity) is estimated by using Cointegration technique for 1970-2005. The results of the long run relationship between TFP and agricultural research indicate that agricultural research has a significant and positive impact on TFP. The estimated coefficient of research is 0.571 and it is significant at 1 percent level of significance. Granger-causality tests show a bidirectional relationship between research and productivity. The estimate of marginal internal rate of return (MIRR) to research is found to be 73 percent, indicating that Punjab agricultural research system remained productive.

Keywords: Productivity, TFP, Cointegration, MIRR, Granger Causality.

1. Introduction

Despite of decreasing share of agriculture towards GDP form 53.2 percent in 1949-50 to 21.8 percent in 2008-09, agriculture sector is still the dominant sector of the economy with profound impact on rural economy. Its forward and backward linkages particularly with the industrial sector, gives it central place as a useful tool for the economic development of Pakistan.

In face of increasing population growth especially in developing countries, limited possibilities of further extension of cultivated land (Chang and Zepeda, 2001), increasing resource degradation (Murgai *et al*. 2000) and wide gap between potential and national average yield (Government of Punjab, 2007), productivity growth takes an important place to face the challenges of the future to combat against food insecurity.

Productivity enhancement issue has been focused for every country of the world so as to increase the agricultural supply. Pakistan has obtained an average annual growth of 4 percent since the last four decades. The growth was attributed to technological progress along with investment in agricultural related physical infrastructure and agricultural research and extension (Ali, 2005). During Green Revolution, most of the countries in Asia experienced the pivotal role of technological change in enhancing agricultural productivity. Among all types of agricultural expenditures, agricultural research and development is the most important in increasing agricultural productivity and ensuring food security (Evenson and Rosegrant, 1993; Byerlee, 1994).

Various studies in the empirical literature has explored the relationship between public investment and agricultural productivity by employing different methodologies. Most among those studies focused on investment on agriculture research, agriculture extension and combined effect of research and extension [for example, Chavas and Cox (1992), Fernandez-Cornejo and Shumway (1997), Evenson *et al.*(1999), Makki *et al.*(1999), Schimmelpfenning *et al.* (2000), Fan (2000), Hall and Scobie (2006), Jin *et al.* (2001), Ahearn *et al. (*2002), Fan *et al*. (2002,2004), Fan and Rao, (2003), Thirtle *et al.* (2004), Jongeneel and Ge (2005), Ananth *et al*. (2006), Mullen, (2007)]. In case of Pakistan few attempts have been made to determine the relationship between agricultural research and agricultural output / TFP [for exemple, Khan and Akbari (1986); Nagy (1991); Evenson and Bloom (1991); Rosegrant and Evenson (1993); Ali (2005)] with the conclusion that agriculture research has a positive and significant impact on agriculture productivity and yields high rate of return. As most of these studies have used time series data, however, most time series are trended overtime and regression between trended series may produce significant, but spurious results (Granger and Newbold, 1974). This casts doubts on the validity of these previous results. Moreover, none of the studies has done analysis at Punjab province level. The present study been planned to fill this gap by estimating the effect of investment in agricultural research and extension on Punjab's agricultural productivity. The paper is organized as follows: Section 2 presents the empirical framework, Section 3 discusses the empirical results, while Section 4 concludes.

2. Empirical Framework

2.1: Data and Variable Specification

The data on agriculture research and extension consist of both development and non-development expenditures. Data on development expenditures were collected form the various issues of Annual Development Plan and non development data from annual budget copies. The data were collected for the period ranging from 1970-2005. It is worth mentioning that data on both investment variables (agriculture research and agriculture extension) were collected on the basis of actual utilization rather than budget allocation because while data collection we observed a considerable difference between budget allocation and actual utilization. Govereh *et al.* (2006) has also pointed out this difference. The data on agricultural total factor productivity (TFP) were taken for Nadeem *et al*. (2010).

The data on research and extension were deflated with GDP deflator to convert into real terms. The series of GDP deflator is only available at country level. Therefore, relay has to be made on the GDP deflator because of non availability of GDP deflator data at the Provincial level. Moreover, it is more convincing because the province of Punjab has the largest share in the GDP of Pakistan.[1] All data series were transformed into logarithmic form.

2.2: Conceptual Model

In the context of Pakistan the relationship between productivity and investment in agriculture research can be specified as:

$$TFP_t = A.\prod_{i=0}^{n} RES_{t-i}^{\alpha_{t-i}}.\varepsilon \tag{1}$$

where

TFP_t= is Total Factor Productivity of the Punjab's agriculture sector in time t.
RES = is the real agricultural research and extension expenditures;[2]

α_{t-i} = are the partial productivity coefficients of research investment in period t-1

ε = is the error term.

2.3: Estimation Procedure

2.3.1: Unit root, Johansen's Cointegration and Granger Causality Analysis

[1] See (Government of the Punjab, 2007).

[2] We combine research and extension because they are strong complements whose separate contributions are not easily sorted out (Makki et al. 1999).

We begin by testing for the presence of unit roots in the individual time series of each model using the augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1981), both with and without a deterministic trend. The number of lags in the ADF-equation is chosen to ensure that serial correlation is absent using the Breusch-Godfrey statistic (Greene, 2000, p.541). The ADF equation is required to estimate the following by OLS.

$$\Delta Y_t = \alpha_3 + \beta_3 t + (\phi_3 - 1)Y_{t-1} + \sum_{i=1}^{k} \theta_i \Delta Y_{t-i} + u_t \qquad (2)$$

Where Y_t is the series under investigation, t is a time trend[3] and u_t are white noise residuals. We do not know that how many lagged values of the dependent variable to include on the right-hand side of (2). There are several approaches but we use the Lagrange Multiplier (LM) test (Holden and Perman, 1994, p.62).

If two series are integrated of the same order, Johansen's (1988) procedure can then be used to test for the long run relationship between them. The procedure is based on maximum likelihood estimation of the vector error correction model (VECM):

$$\Delta z_t = \delta + \Gamma_1 \Delta z_{t-1} + \Gamma_2 \Delta z_{t-2} + \cdots + \Gamma_{p-1} \Delta z_{t-p+1} + \pi z_{t-p} + \Psi x_t + u_t \qquad (3)$$

where z_t is a vector of I(1) endogenous variables, $\Delta z_t = z_t - z_{t-1}$, x_t is vector of I(0) exogenous variables, and π and Γ_i are ($n \times n$) matrices of parameters with $\Gamma_i = -(I - A_1 - A_2 - \ldots - A_i)$, ($i = 1, \ldots, k-1$), and $\pi = I - \pi_1 - \pi_2 - \ldots - \pi_k$. This specification provides information about the short-run and long-run adjustments to the changes in z_t through the estimates of $\hat{\Gamma}_i$ and $\hat{\pi}$ respectively. The term πz_{t-k} provides information about the long-run equilibrium relationship between the variables in z_t. Information about the number of cointegrating relationships among the variables in z_t is given by the rank of the π-matrix: if π is of reduced rank, the model is subject to a unit root; and if $0 < r < n$, where r is the rank of π, π can be decomposed into two ($n \times r$) matrices α and β, such that $\pi = \alpha\beta'$ where $\beta' z_t$ is stationary. Here, α is the error correction term and measures the speed of adjustment in Δz_t and β contains r distinct cointegrating vectors, that is the cointegrating relationships

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[3] The rationale for having a trend variable in the model is that as most of the series are trended overtime. So it is important to test the series for unit root having a stochastic trend against the alternative of trend stationary.

between the non-stationary variables. Johansen (1988) uses the reduced rank regression procedure to estimate the α- and β-matrices and the trace test statistic is used to test the null hypothesis of at most r cointegrating vectors against the alternative that it is greater than r.

If cointegration is established, then Engle and Granger (1987) error correction specification can be used to test for Granger causality. If the series TFP and RES are both I (1) and cointegrated, then the ECM model is represented by the following equations.

$$\Delta TFP = \alpha_0 + \sum_{i=1}^{n} \beta_i \Delta TFP_{t-i} + \sum_{i=1}^{n} \beta_j \Delta RES_{t-i} + \delta\, ECT_{t-i} + \mu_t \quad (4)$$

$$\Delta RES = \phi_0 + \sum_{i=1}^{n} \sigma_i \Delta RES_{t-i} + \sum_{i=1}^{n} \sigma_j \Delta TFP_{t-i} + \lambda\, ECT_{t-i} + \varepsilon_t \quad (5)$$

where Δ is the difference operator, μ_t and ε_t are the white noise error terms, ECT_{t-i} is the error-correction term derived from the long-run cointegrating relationship, while *n* is the optimal lag length orders of the variables which are determined by using the general-to-specific modelling procedure (Hendry and Ericsson, 1991). Our null hypotheses are as follows. *RES* will Granger cause *TFP* if $\beta_j \neq 0$ in (4). Similarly, *TFP* will Granger cause *RES* if $\sigma_j \neq 0$ in (5). There will be bidirectional causality if $\beta_j \neq 0$ and $\sigma_j \neq 0$. To implement the Granger-causality test, *F*-statistics are calculated under the null hypothesis that in Eqs. (4) and (5) all the coefficients of β_j, σ_j =0.

2.3.2: Measurement of Internal Rate of Return

In order to determine the rate of return associated with research investment, standard methodology widely used in the literature e.g. (Nagy, 1991; Fernadez-Cornejo and Shumway, 1997; and Evenson *et al*, 1999) is employed. Marginal internal rate of return can be estimated from the elasticities calculated from the model given in equation (1).

$$\eta_i = \frac{\partial \log TFP_t}{\partial \log RES_{t-i}} = \frac{\partial TFP_t}{\partial RES_{t-i}} . \frac{RES_{t-i}}{TFP_t} \quad (6)$$

After rearranging the above equation, it can be written as

$$\frac{\partial TFP_t}{\partial RES_{t-i}} = \eta_i .(\frac{TFP_t}{RES_{t-i}}) \quad (7)$$

Replacing $\frac{TFP_t}{RES_{t-i}}$ by the means of these variables and using discrete approximations leads to:

$$\frac{\Delta TFP_t}{\Delta RES_{t-i}} = \eta_i \left(\frac{\overline{TFP}}{\overline{RES}_{t-i}}\right) \qquad (8)$$

Productivity change can be converted into a change in the value of output when both sides of the above equation is multiplied by the average increase in the net value of output (Y) caused by a one index point increase in productivity.

$$\frac{\Delta TFP_t}{\Delta RES_{t-i}} \cdot \frac{\Delta Y_t}{\Delta TFP_t} dTFP_t = \eta_i \left(\frac{\overline{TFP}}{\overline{RES}_{t-i}}\right) \cdot \frac{\Delta Y_t}{\Delta TFP_t} dTFP_t \qquad (9)$$

From this the value marginal product of research in period (t-i) can be written as:

$$VMP_{t-i} = \frac{\Delta Y_t}{\Delta RES_{t-i}} = \eta_i \left(\frac{\overline{TFP}}{\overline{RES}_{t-i}}\right) \cdot \frac{\Delta Y_t}{\Delta TFP_t} \qquad (10)$$

With the value of output $\frac{\Delta Y_t}{\Delta TFP_t}$ and $\left(\frac{\overline{TFP}}{\overline{RES}_{t-i}}\right)$ that have been calculated as averages, η_i varies over the lag period providing a series of marginal value products resulting from a unit change in research expenditures. The marginal internal rate of return can be estimated from these annual flows of value benefits from a unit change in research investment with the following fallow formula:

$$\sum_i^n \left[\frac{VMP_{t-i}}{(1+r)^i}\right] - 1 = 0 \qquad (11)$$

3. Empirical Results

3.1: Unit root, Cointegration and Granger-Causality results

Table 1 presents the results of unit root analysis, which reveals that both the variables i.e., TFP and agricultural research are non stationary at one percent level of significance, both in non trended and trended models, as in both the models calculated value for the variables is less than the critical value. Therefore, we can not reject the null hypothesis of unit root. However, their first difference is stationary at one percent level of significance. The results suggest that both the variables are integrated of degree one.

Table: 1 Results of the Unite Root Test

Variables	Non Trended		Trended		Conclusion
	Level	First Difference.	Level	First Difference.	
LTFP	-0.14	-8.15	-2.28	-8.09	1(1)

LRES	-2.0	-6.81	-2.52	-6.90	1(1)
	C.V At 1% -3.65 At 5% -2.95 At 10% -2.62		C.V At 1% -4.27 At 5% -3.56 At 10% -3.21		

Note: C.V means Critical Values.

Next we proceed with the multivariate Cointegration tests. Applying the AIC criterion, we estimate the "best" lag length of the underlying vector auto regression (VAR) of Punjab agricultural productivity and research investment to be eight years. Although longer lags have been found for research investment and productivity impact in Pakistan, our results for the optimal lag compare well with the results obtained for other countries. The shorter lag length estimated for Punjab may be related to the nature of agriculture sector and the age of agricultural research system in Pakistan. Shorter lag may be appropriate due to following reasons. Firstly, Pakistan's and especially Punjab research system is very young as compared to advanced countries. Also prior to 1960 research investment and research capacity were very limited and hence there was very small impact on today's production, if any. Secondly, mostly all agricultural related research is adaptive in Pakistan (Khan and Akbari, 1986), as evident from the experience of Green Revolution. Shorter lag length for other countries have also been estimated e.g, Bouchet *et al.* (1989), Pray and Ahmed (1991) and Fernandez-Cornejo and Shumway (1997) have calculated five, seven and seven years lag length for France, Bangladesh and Mexico respectively.

Table 2: Cointegration with restricted intercepts and no trends in the VAR

Cointegration LR Test Based on Maximal Eigenvalue of the Stochastic Matrix

List of variables included in the cointegrating vector:

LTFPT LRE Intercept

Null	Alternative	Statistic	95% Critical Value	90% Critical Value
r = 0	r = 1	19.8388	15.8700	13.8100
r<= 1	r = 2	5.3156	9.1600	7.5300

Table 3: Cointegration with restricted intercepts and no trends in the VAR

Cointegration LR Test Based on Trace of the Stochastic Matrix

List of variables included in the cointegrating vector:

LTFPT LRE Intercept

Null	Alternative	Statistic	95% Critical Value	90% Critical Value
r = 0	r>= 1	25.1544	20.1800	17.8800
r<= 1	r = 2	5.3156	9.1600	7.5300

The second step in the Johansen procedure is to test for the presence and number of cointegrating vectors among the series in the model. The results are presented in Table 2 and 3. The Johansen results in Tabel 2 based on maximum eigenvalue statistics imply that the model has one cointegrating vector (i.e., a unique long-run equilibrium relationship exists) because we reject the Ho: r=0 at 5 percent level of significance. Similarly, the results shown in Table 3 based on Trace test also indicate the presence of one cointegrating vector having rejected Ho:r=0 at 5 percent level of significance. Johensen's method also provides the equation for the unique long-run relationship between Punjab agricultural productivity and research spending. The estimated long-run, cointegrating relation (L reflects logarithmic form, standard errors in parentheses) is as follows:

LTFP = 1.29 + 0.571 LRES

(0.347) (0.053)

The average long-run elasticity of Punjab agricultural productivity to research investment is 0.571. That is, in the long run, a 1% rise in research investment would increase total factor productivity by 0.571%.

Pair-wise Granger-causality tests are conducted between agricultural research and TFP where the variables are in logarithmic form. To test causality from RES to TFP, F=5.11 [p-value: 0.003]; and to test causality from TFP to RES, F=2.77 [0.04]. We conclude therefore that there is bidirectional causality from RES to TFP i.e., agricultural research has a positive and significant impact on agricultural TFP. Conversely, TFP does also significantly contribute towards agricultural research.

3.2: Estimation of Marginal Internal Rate of Return

The marginal internal rate of return to research is estimated from productivity elasticities. The estimated rate of returns is at 73 percent, which is high in relation to what can be earned on alternative investments. This high rate of return is a strong indicator of underinvestment in research and extension for Punjab's agriculture.

The finding of this study is comparable to the study of (Ali, 2005; Evenson and Bloom, 1991) who estimated IRR 88 percent for investment on research and extension and agricultural research respectively. The results also conform to the study of Fernandez-Cornejo and Shumway (1997) who's calculated IRR 64 percent..

4. Conclusions and Policy Implications

By employing Cointegration analysis, we conclude a unique long-run relationship between total factor productivity and agricultural research and extension investment. A 1 percent increase in research and extension expenditures increases TFP by 0.571 percent in the long run. Granger-causality tests show that there is bidirectional relationship between agricultural research and agricultural productivity. The estimated marginal rate of return to agricultural research and extension in Punjab over the 1970-2005 is about 73 percent. High rate of MIRR suggests that agricultural research and extension has been underinvested in Punjab province. This fact has also been stated in the report of Government of Pakistan (1988) and other studies conducted at Pakistan level like Ali (2005) and Evenson and Bloom (1991). Low crop yield per hectare in Punjab and Pakistan for the major crops as compared to other countries with similar conditions and the yield levels on experiment stations (Government of Punjab, 2007), implies continuing high return to research and extension investments in Punjab and Pakistan. To get benefits from these potential gains, the research and extension institutions would have to play their role for the sustainable development of agriculture sector. On the other hand

Government would have to ensure adequate financial resources to these institutions so that they could work under constrained free environment.

Besides that due to huge investment in this sector, private sector should also be encouraged to invest in agricultural research by eliminating all types of constraints e.g. legal, administrative and bureaucratic in this regard. Moreover, having long run impact of research on TFP, the study suggests that investment in research and development must be on consistent basis so as to save from future shocks/decrease in aggregate productivity.

References

Ahearn, M., J. Yee. and W. Huffman. 2002. The Impact of Government Policies on Agricultural Productivity and Structure: Preliminary Results. Paper Prepared for Presentation at the American Agricultural Economics Association Meetings Long Beach, California July 28-31.

Ali, S. 2005. Total Factor Productivity Growth and Agricultural Research and Extension: An analysis of Pakistan's Agriculture, 1960-1996. *The Pakistan Development Review*, 44 (4): 729-746.

Ananth, G. S., P. Chengappa and A. Janaiah. 2006. Impact of research investment on technology development and total factor productivity in major field crops of peninsular India. Contributed poster paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia, August 12-18.

Araji, A. A., F. C. White and J. F. Guenthner. 1995. Spillovers and Returns to Agricultural Research for Potatoes. Journal of Agricultural and Resource Economic 20(2): 263-76.

Boucher, F., D. Orden and G.W. Norton. 1989. Sources of Growth in French Agriculture. Amer. J. Agr. Econ. 71 (May 1989): 280-93.

Byerlee, D. 1994. Agriculture Productivity in Pakistan: Problems and Potential. Background Paper for World Bank Agricultural Sector Review.

Chang, H. and L. Zepeda. 2001. Agricultural Productivity for Sustainable Food Security in Asia and the Pacific: The Role of Investment. In Agricultural Investment and Productivity in Developing Countries. FAO Economic and Social Development Paper 148. Edited by Lydia Zepeda, Department of Consumer Science, University of Wisconsin-Madison USA.

Chavas, J. P. and T. L. Cox. 1992. A Non-Parametric Analysis of the Influence of Research on Agricultural productivity. *American Journal of Agricultural Economics*, 74(3): 583-91.

Dickey, D. A. and W. A. Fuller. 1981. Likelihood Ratio Statistics for Autoregressive Time Series with Unit Roots. *Journal of Econometrica*, 49: 1057-72.

Engle, R. F. and C. W. J. Granger. 1987. Cointegration and Error Correction: Representation, Estimation and Testing. *Journal of Econometrica* 55: 251-276.

Evenson, R. E, C. E. Pray and M. W. Roregrant. 1999. Agricultural Research and Productivity Growth in India. Research Report No.109, International Food Policy Research Institute.

Evenson, R. E. 1980. A Century of Agricultural Research and Productivity Change, Research Invention, Extension and productivity Change in U.S. Agriculture: A Historical Decomposition Analysis. Research and Extension Productivity in Agriculture, ed. A. A. Araji. University of Idaho.

Evenson, R. E. 1984. Benefits and Obstacles in Developing Appropriate Agricultural Technology. In C. Eicher and J. Staatz, Eds., Agricultural Development in the Third World. John Hopkins University Press.

Evenson, R. E. and E. Bloom. 1991. Research and Productivity in Pakistan Agriculture. *In Agricultural strategies in the 1990's: Issues and Policies*, eds., Haider, A.S., Z. Hussain., R. McConnen and S. J. Malik. Pakistan Association of Agricultural Social Scientist, Islamabad.

Evenson, R. E. and M. W. Rosegrant. 1991. Determinants of productivity growth in Asian agriculture. Pa per presented at the 1993 American Agricultural Economics Association pre conference work shop, Post- Green- Revolution Agricultural Development Strategies in the Third World: What Next?, Orlando, Fla.

Fan, S. 2000. Research Investment and the Economic Returns to Chinese Agricultural Research, *Journal of Productivity Analysis,* 14:163-182

Fan, S. and N. Rao. 2003. Public Spending In Developing Countries: Trends, Determination, And Impact. EPTD Discussion Paper No. 99. Environment and Production Technology Division, International Food Policy Research Institute.

Fan, S., L. Zhang and X. Zhang. 2002. Growth, Inequality, and Poverty in Rural China: The Role of Public Investment, Research Report No.125. International Food Policy Research Institute, Washington, D.C.

Fan, S., S. Jitsuchon and J. Methakunnavut. 2004. The importance of Public Investment for Reducing Rural Poverty in Middle Income Countires: The Case of Thailand. DSGD Discussion Paper No.7, International Food Policy Research Institute.

Fernandez-Cornejo, J., and C. R. Shumway. 1997. Research and Productivity in Mexican Agriculture. *American Journal of Agricultural Economics* 738–752.

Govereh, J., J. J. Shawa, E. Malawo and T. S. Jayne. 2006. Raising The Productivity of Public Investments in Zambia's Agricultural Sector. FSRP Working Paper No. 20 Available at http://www.aec.msu.edu/agecon/fs2/zambia/index.htm

Government of Pakistan. 2007. Agricultural Statistics of Pakistan 2006-07. Ministry of Food, Agricultural and Livestock, Economic Division, Islamabad.

Government of Pakistan.1988. Report of the National Commission on Agriculture. Ministry of Food and Agriculture, Islamabad.

Government of Punjab. 2007. Punjab Economic Report, Government of the Punjab, Lahore

Government of Punjab. Various Issues. Annual Development Plans and Budget Copies. Lahore.

Government of Punjab. Various Issues. Punjab Development Statistics. Bureau of Statistics, Government of the Punjab, Lahore.

Granger, C. W. J and P. Newbold. 1974. Spurious Regressions in Econometrics. *Journal of Econometrics*, 2: 111-20.

Greene, W. H. (2000) *Econometric Analysis*. New Jersey: Prentice-Hall, Inc.

Hall, J., and G. Scobie. 2006. The Role of R&D in Productivity Growth: The Case of Agriculture in New Zealand: 1927 to 2001. New Zealand Treasury, Working Paper 06/01

Hendry, D. F., and Ericson, N.R. (1991). Modelling the Demand for Narrow Money in the United Kingdom and the United States, *European Economic Review*, 35(4), 833-886.

Hansen, H. and K. Juselius. 1995. Cats and Rats Cointegration Analysis of Time Series. Estima, Evanston, Illinois.

Holden, D. and Perman, R. (1994). Unit Roots and Cointegration for the Economist, in Rao, B. B., *Cointegration for the Applied Economists*, St. Martin's Press, New York.

Jin, S., J. Huang, R. Hue, and S. Rozelle. 2001. The Creation and Spread of Technology and Total Factor Productivity in China's Agriculture. Centre for Chinese Agriculture Policy CCAP, Beijing, China, Working Paper No. 01-014.

Johansen, S. 1988. Statistical Analysis of Cointegrating Vectors. *Journal of Economic Dynamics*: 2/3, 231-254.

Johansen, S. and K. Juselius. 1990. Maximum Likelihood Estimation and Inference on Cointegration- With Application on Demand for Money. *Oxford Bulletin of Economics and Statistics*, 52: 170-209.

Jongeneel, R. and L. Ge. 2005. Explaining Growth in Dutch Agriculture: Prices, Public R & D and Technological Change. Prepared for presentation at the XIth International Congress of the EAAE, 'The Future of Rural Europe in the Global Agri. Food System', Copenhagen, Denmark, 24-27 August.

Khan, M. H., and A. H. Akbari. 1986. Impact of Agricultural Research and Extension on Crop Productivity in Pakistan: A Production Function Approach. *World Development* 14:6.

Makki, S. S., Cameron, S. T., and L. G. Tweeten. 1999. Returns to American Agricultural Research: Results from a Cointegration Model. *Journal of Policy Modelling* 21(2):185-211

Mullen, J. 2007. Productivity growth and the returns from public investment in R&D in Australian broadacre agriculture. *The Australian Journal of Agricultural and Resource Economics,* 51: 359–384

Murgai, R., M. Ali and D. Byerlee. 2000. Productivity growth and sustainability in post-green revolution agriculture in Indian and Pakistan Punjab. World Bank Research Observer in Press.

Nadeem, N., M. S. Javed, S. A. Adil and S. Hassan. 2010. Estimation of Total Factor Productivity Growth in Agriculture Sector in Punjab, Pakistan: 1970-2005. *Pak. J. Agri. Sci., Vol.47(1), 1-6; 2010 ISSN (Print) 0552-9034, ISSN (Online) 2076-0906*

Nagy, J. G. 1991. Returns from Agricultural Research and Extension in Wheat and Maize in Pakistan. In *Research and Productivity in Asian Agriculture,* eds., R. E. Evenson and C. E. Pray. Ithaca and London: Cornell University Press.

Pray, C.E. and Z. Ahmed. 1991. Research and Agricultural Productivity Growth in Bangladesh. Research and Productivity in Asian Agriculture. R. E. Evenson and C. E. Pray, eds, Ithaca NY: Cornell University Press.

Rosegrant, M. W. and R. E. Evenson. 1993. "Agricultural Productivity Growth in Pakistan and India: A Comparative Analysis." *Pakistan Development Review,* 32: 433-51.

Schimmelpfenning, D., C. Thirtle, J.V. Zyl, C. Arnade, and Y. Khatri. 2000. Short and Long-Run Returns to Agriculrure R & D in South Africa, or Will the Real Rate of Return Please Stand up?. *Journal of Agriculture Economics,* Vol.23, pp. 1-15.

Thirtle, C., L. Lin, J. Holding, L. Jenkins, and J. Piesse. 2004. Explaining the Decline in U.K. Agricultural Productivity Growth. *Journal of Agricultural Economics*, 55(2): 343-366.