FACTORS INFLUENCING THE SUCCESS POTENTIAL IN SMALLHOLDER IRRIGATION PROJECTS OF SOUTH AFRICA: A PRINCIPAL COMPONENT REGRESSION

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Abstract:

The objective of this paper is to examine the role of the factors expected to influence the success potential of smallholder irrigation projects as they apply in the South African context. The study was conducted in six smallholder irrigation schemes in three provinces namely: Eastern Cape, Limpopo and Mpumalanga. The principal component regression (PCR) tool was used to analyze the data and deal with the problem of multicollinearity, transforming the explanatory variables into principal component estimators. There were fourteen explanatory variables. Out of the eight statistically significant variables, six have the expected sign. These are access to information, training, market access, planning, transport and extension all significant at the 1% level. The study has shown which areas should receive specific attention to improve the success potential in South African smallholder irrigation projects.

Key words: success potential; smallholder; South Africa; irrigation projects; principal component regression

JEL Classification: *D1; O13; Q1*

1. Introduction

The performance of smallholder irrigation projects in South Africa is continually underscoring the expectations of those involved in their development. This is in spite of substantial reforms to improve the performance of this sub-sector. Currently, the government is involved in land reform processes to redress past imbalances and meet its objectives of poverty alleviation and economic growth. The land reform process mainly involves restitution, redistribution and tenure reforms. Recipients are expected to engage in entrepreneurial activities and improve their living standard. It is clear therefore that the government attaches a lot of weight to land based strategies in helping it to achieve its objectives.

This continued under-performance provides a good basis for exploring factors that could possibly affect potential success of smallholder irrigation projects in general and look at how South African smallholders compare. Understanding these characteristics will contribute to a better understanding of the essential elements of the farmers' environment. This knowledge would benefit farmers themselves and those working with them like providers of extension services, capital providers and trade partners. This line of thinking is supported by van Rooyen (1984) when he says that effective agricultural production should start with the farmer and his farming system.

The study was conducted in six smallholder irrigation schemes in 3 provinces of South Africa: Eastern Cape (Melani, Qamdobowa, Roxeni and Somgxada), Limpopo (Sepitsi) and Mpumalanga (Hereford). Eastern Cape and Limpopo provinces are where most of

the smallholder irrigation schemes are found in South Africa. These are also classified as the poorest provinces in the country (SSA, 2001).

2. Factors influencing potential success in smallholder irrigation projects

Even though various scholars focus on different issues that have a potential influence on success of smallholder irrigation projects, there are those that seem to be consistently acknowledged commonly. A complex combination of factors has a role in influencing the potential success of these activities. Lipton (1996) identified what he referred to as the four reforms that have helped many developing countries to increase growth in farm output and employment. They involve land distribution, agricultural research, rural infrastructure and markets. He goes further to say that labor-intensive farm growth tends both to increase nearby rural non-farm growth and to improve food availability. De Lange (1994) identifies several issues that are important for the success of small-scale irrigators in South Africa. These issues are identified as appropriate technology, sufficient irrigation, organization and management and training.

Market access is one of the driving forces of agricultural commercialization. In their study, Muhammad *et al.* (2004) included the following factors as having potential to influence level of success: size and type of farm operation, sources of information, importance of farm labor and off-farm income, use of information technology, marketing practices and research, extension and education needs. In addition, they also examined the plans for the future of the respondents. Their results showed that more successful

farmers use production systems that are diverse, adopt measures to control costs and use marketing strategies that seek the highest level of profit.

In their study (Hau and von Oppen, 2002) present an analysis of the impact of market access on agricultural productivity. Results provided evidence for the importance of investments in physical and institutional infrastructure of agricultural markets. They assert that an improvement in market access can help stimulate market driving forces and in turn maximize the potential benefits of agricultural commercialization by increasing incomes and improving living standards in the rural areas of many developing countries. There seems to be a general view therefore that market access is one of the critical factors that determine success of smallholder farming projects. This is an acceptable view even among professional working in developing countries. For example, presenting results of an expert survey, Gabre-Madhin and Haggblade (2001) found that the main views on determinants of success in African agriculture include technology, collaboration, markets and a favorable policy environment and management. In this study, social scientists chose markets and favorable policy environment as the most prominent determinates of success.

3. Data and methodology

3.1 The variables

The preceding discussion makes it very clear that there is a complex set of factors that influence the success potential of smallholder irrigators. To get a better understanding of the success potential therefore, we need to analyse many possibilities. This is a difficult task because problems arise when a large number of factors is analysed. More often, the

problem of multicollinearity crops up. This is a situation where the explanatory variables (in this case factors affecting success potential) are highly correlated, and multicollinearity can lead to biased parameter estimates.

To develop a proxy for the dependent variable, a cluster analysis was carried out that grouped farmers based on individual characteristics. This separated the farmers into two groups that were referred to as more successful (MS) or less successful (LS). This yielded a discrete variable with values either 0 for LS or 1 for MS. The continuous explanatory variables include family labor, planning level, off-farm income and extension visits. Discrete explanatory variables include nature of access to land (private land tenure), infrastructure availability, information, training, research and development, farmer organization, market access, transport and credit.

3.2 The Model

A decision was taken to fit the following model because of the dichotomous nature of the dependent variable:

$$\ln\left(\frac{P}{1-P)}\right) = a_0 + \sum_{i=1}^{k} a_i c_i \ or \ as \left(\frac{P}{1-P}\right) = e^{(a_0 + \sum_{i=1}^{k} a_i c_i)} \qquad [1]$$

Where, P_i represents the probability of small irrigator i being more successful, χ_i are the set of explanatory variables determining smallholder irrigators' potential for success. Denoting $a_0 + \sum_{i=1}^{k} a_i x_i$ as Q, equation 1 may be written to give the probability of success potential of irrigator i as:

$$P_i = \frac{1}{1+e^{-Q_i}} \qquad [2]$$

From equation 2, the probability of an irrigator being unsuccessful is given by $(1 - P_i)$ as

$$(1 - P_i) = \frac{1}{1+e^{Q_i}} \qquad [3]$$

The odds ratio, i.e., $P_i / (1 - P_i)$ is given as

$$\left(\frac{P_i}{1-P_i}\right) = \frac{1+e^{Q_i}}{1+e^{-Q_i}} = e^{Q_i} \qquad [4]$$

The natural logarithm of equation 4 gives rise to equation 5.

$$Ln\left(\frac{P_i}{1-P_i}\right) = a_0 + \sum_{i=1}^{k} a_i + e_i \qquad [5]$$

Rearranging equation 5, with the dependent variable in log odds, the logistic regression can be manipulated to calculate conditional probabilities as

$$P_i = \frac{e^{\left(a_0 + \sum_{i=1}^{k} a_i x_i\right)}}{1 + e^{\left(a_0 + \sum_{i=1}^{k} a_i x_i\right)}} \qquad [6]$$

Our first attempt to fit equation 5 using maximum likelihood procedure failed. This was attributed to perfect multicollinearity problem by studying correlation coefficient matrix and eigen values[1] of the correlation matrix of explanatory variables. The problem was solved by resorting to principal component regression (PCR) procedure. The methodology we outline next is different from other studies in the way PCR is applied. Here we apply PCR within maximum likelihood estimation framework.

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[1] The smallest eigen value calculated is 0.002833. The sum of the reciprocals of the eigen values is 395 which is 28 times the number of variables.

The correlation matrix C^2 using both standardized and unstandardized variables was used to calculate eigen values $\lambda_1, \lambda_2, ... \lambda_K$ and corresponding eigenvectors v_i respectively as

$$|C - \lambda I| = 0, \quad |C - \lambda_j I| v_j = 0 \qquad [7]$$

The eigenvectors v_j were then arranged to give matrix V in equation 8.

$$V = \begin{bmatrix} v_{11} & v_{12} & . & . & . & v_{1k} \\ v_{21} & v_{22} & . & . & . & v_{2k} \\ . & & . & & . & \\ . & & & . & . & \\ . & & & . & . & \\ v_{k1} & v_{k2} & . & . & . & v_{kk} \end{bmatrix} \qquad [8]$$

The matrix V is orthogonal as its columns satisfy the conditions $v_i' v_i = 1$ and $v_j' v_i = 0$ for $i \neq j$.

$$Z = X^S V \qquad [9]$$

Where X^s is n $\times$ k matrix of standardized variables; V is eigenvector matrix as defined in equation 9. There are k principal components as there are k variables[3].

After the principal components (PC) are calculated and PCs with the smallest eigen values are eliminated (see Table 1 for remaining eigen values), equation 10 was fitted to determine PCs having significant impact on the probability of success:

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[2] The independent variables were standardized as $(x_i - \bar{x_i}) / s_{x_i}$

[3] These new set of variables (principal components) unlike the original variables are orthogonal i.e. they are uncorrelated.

$$Ln\left(\frac{P}{1-P}\right) = a_o^s + X^s VV \hat{\jmath}^s + e \qquad [10]$$

After insignificant PC from equation 11 are identified and eliminated, we get equation 12 in terms of the retained principal components.

$$Ln\left(\frac{P}{1-P}\right) = b_o^s + Zg + e^{\circ\circ} \qquad [11]$$

Where, $Z = X^S V$ & $g = V'a^s$. Z is an $n \times \ell$ matrix of retained principal components, V is a $k \times \ell$ matrix of the eigenvectors corresponding to the ℓ retained components, g is ℓ x ℓ vector of coefficients associated with the ℓ components. Standard errors of the estimated coefficients g are represented by an ℓ x 1 vector

$$Var(\hat{g}) = \hat{d}^2 (Z'Z)^{-1} = \hat{d}^2 diag(l_1^{-1}, l_2^{-1}, \dots l_l^{-1}) \qquad [12]$$

Where $\hat{d}^2$ is variance of residuals from equation 12. Therefore standard error of γ may be given by

$$k^s = \left(s.e._{\hat{g}_1} \; s.e._{\hat{g}_2} \dots s.e._{\hat{g}_\ell}\right) \qquad [13]$$

Results obtained using equation 11 may be transformed back to the principal component estimators of standardized variables as follows:

$$
\begin{bmatrix} a^{s}_{1,pc} \\ a^{s}_{2,pc} \\ \cdot \\ \cdot \\ \cdot \\ a^{s}_{k,pc} \end{bmatrix} = \begin{bmatrix} v_{11} & v_{12} & \cdot & \cdot & \cdot & v_{1l} \\ v_{21} & v_{22} & \cdot & \cdot & \cdot & v_{2l} \\ \cdot & & & & & \cdot \\ \cdot & & & & & \cdot \\ \cdot & & & & & \cdot \\ v_{k1} & v_{k2} & \cdot & \cdot & \cdot & v_{kl} \end{bmatrix} \times \begin{bmatrix} \hat{g}_{1} \\ \hat{g}_{2} \\ \cdot \\ \cdot \\ \cdot \\ \hat{g}_{\ell} \end{bmatrix} \qquad [15]
$$

Where $\hat{g}_i$ is estimator of g_i in equation 12. The constant $a^{s}_{0,pc} = \bar{y}$. The standardized coefficients evaluate the relative importance of the explanatory variables in determining the success potential of irrigators.

Following Fekedulegn, Colbert, Hicks & Schuckers (2002), variance of the principal component estimators in standardized variables is given by:

$$
Var\left(a^{s}_{pc}\right) = \Psi^{s}_{\ell} K^{S} \qquad [16]
$$

Where Ψ^{s}_{l} contains the squares of the elements of V^{s}_{l} in equation 8, and K^{s} contains the squares of the elements of the matrix of standard errors of the coefficient matrix of g in equation 11. The corresponding standard errors for the estimators of principal components of standardized variables are given by:

$$
s.e.\left(a^{s}_{pc}\right) = \left[Var\left(a^{s}_{pc}\right)\right]^{\frac{1}{2}} \qquad [17]
$$

Following Fekedulegn, *et al*, (2002), we transformed standardized coefficients $a^{s}_{j,pc}$ of standardized variables X^{x}_{j} back to unstandardized coefficients $a_{j,pc}$ of X_{j}

$$a_{j,pc} = \frac{a^s_{j,pc}}{S_{xj}}, j = 1, 2,\dots, k \qquad\qquad [18]$$

and

$$a_{o,pc} = a^s_{o,pc} - \frac{a^s_{1,pc}\bar{x}_1}{S_{x_1}} - \frac{a^s_{2,pc}\bar{x}_2}{S_{x_2}} - \dots - \frac{a^s_{k,pc}\bar{x}_k}{S_{xk}} \qquad\qquad [19]$$

Where S_{xj} is the standard deviation of the jth original variable X_j & $a^s_{o,pc}$, $a^s_{1,pc}$ pc, $a^s_{2,pc}$, $a^s_{k,pc}$ are coefficients of the standardized variables. Variance of the principal component estimators in standardized variables is given by:

Partial effect of the continuous individual variables on potential success of irrigators may be computed by the expression

$$\frac{\partial P_i}{\partial x_{ij}} = P_i(1 - P_i)a_{j,pc} \qquad\qquad [20]$$

The" partial" effects of the discrete variables are calculated by taking the difference of the probabilities estimated when value of the variable is set to 1 and 0 $(x_i = 0, x_i = 1)$, respectively.

4. Results and discussion

As it can be seen in Table 2, out of the thirteen variables, eight were highly significant at the 1% level. Six of the significant variables have the expected direction of relationships with the dependent variable. The two variables that are significant in a direction opposite the expected one are: nature of access to land and membership to a farm organization. The goodness of fit of the model is 87.6%.

It is difficult to explain why these variables have an inverse relationship with success potential because as discussed earlier, they are both supposed to improve the success potential. Their signs do not make economic sense in this case. In the case of farm organization, perhaps the understanding of the fact that the existing organizational structure does not translate to any real returns can explain the situation. It does not necessarily translate to any benefits in terms of, e.g. marketing association and also the fact that only a small number (about 30%) of the surveyed farmers belong to a farm organization. The nature of access to land is the difference between the more prevalent permission to occupy (PTO) and private ownership or lease contract. Results of this study show that success favours farmers who have PTO. Perhaps because of the fact that this is the more prevalent tenure system and that only 20% of the surveyed farmers have private lease contracts.

According to the standardized coefficients of the remaining six other variables, information has the biggest impact. Salient and timely information is key to improving success potential. This is usually the biggest source of transaction costs for smallholder farmers in general. Smallholder farmers are seldom in a position to understand what to produce, when and in what quantities or quality requirements. They usually also lag behind in terms of technology as a result of this. This makes it difficult to enter the more lucrative markets for their produce. Following information is the level of planning which is very important in farming enterprises. This is because of the volatile nature of agricultural production and the time lag between investment and harvesting. Therefore farmers who have more detailed plans have a higher potential for success.

The above variables are closely followed by training, transport, market access and extension. Transport availability is key in accessing both input and output markets. It is therefore not surprising that together with market access they are significant and have a positive relationship with success potential. Market access is important because farmers can generate income to use for household needs and re-invest in the farming enterprise.

Extension has also been shown in numerous studies as a very important aspect in improved smallholder irrigation management. This is mainly how the results of the R&D exercise reach the farmers. For some farmers, extension officers are the only contact farmers have with the government department of agriculture. In other areas, extension officers play a role larger than just dissemination of information but assisting farmers in acquiring the factors of production including assistance in credit acquisition.

The estimates of the partial effects are calculated by re-scaling the estimated coefficients using a scaling factor (0.24849) produced in the regression analysis for continuous variables an. The estimated partial effects are as follows: For information, it is 0.06065; for market access it is 0.0025; for training, it is 0.60023; for transport, it is 0.582841; for planning, it is 0.5267 and for extension, it is 0.008052. These could be interpreted as meaning that a unit improvement in each variable will increase the probability to be more successful by the corresponding coefficient.

5. Summary and conclusion

Understanding success potential of smallholder irrigation projects is critical because it aids in proper planning. The common understanding is that smallholder irrigation projects have a potential to provide multiple livelihood sources for the rural poor. Beyond serving the purpose of fulfilling subsistence needs, surplus production has a potential to improve household incomes. These improvements would feed right into the government's imperatives of poverty alleviation and economic growth.

In this paper the method of Principal Component Regression (PCR) is used to understand the myriad of factors hypothesized to influence success potential in smallholder irrigation projects. This technique combats co-linearity by transforming the original variables into a new set of orthogonal or uncorrelated variables called principal components. At the end of the procedure we were able to obtain principal component estimators. These are coefficients of the transformed variables.

Results of this PCR show that of the eight significant explanatory variables, six have the expected signs and are statistically significant. Access to information, training, market access, planning, transport and extension are all significant at the 1% level.

This elucidates the complexity of the task that faces those that deal with smallholder irrigation management. In addition to the farmers themselves, these include extension service providers, capital providers and trade partners. This study has tried to provide

guidelines on which areas should receive attention when dealing with smallholder irrigation management. Some implications of these results are discussed below.

Access to information has been shown to be a critical area in improving the success potential of the farmers and needs to improved. One way of doing that is to ensure that farm specific information is available through media that are accessible to the smallholder farmers. The other complementary approach is to focus on improving the extension services. Extension is shown to be highly significant as one of the factors that influence success in smallholder irrigation projects. This suggests that more focus should be directed at improving the effectiveness and efficiency of the extension services. It might be necessary to improve the training levels of the extension officers so as to be able to deliver a better service to the farmers. Also, the capacity of the farmers themselves should receive attention through targeted training as training has shown to be a significant factor in improving the success potential.

A majority of farmers only make rough plans (about 55%). In some schemes, there are farmers who admit to not making any plans at all. This situation is usually attributed to the highly uncertain environment under which smallholders operate. These uncertainties relate to variability in the availability of resources for farming operations like capital and inputs. A combination of improved access to information regarding potential demand for various markets and quality requirements together with capacity building through specific training may solve part of the problem.

 The implication of the results regarding market access is that in designing irrigation projects, market access should be included in the planning process and not as an additional aspect, late in planning. In other words, it should not come after assessments regarding physical suitability have been conducted but should be an integral part of the initial planning stages. For existing irrigation schemes, an assessment could be made and market access ruled out first when the project is encountering problems.

Studies on how to develop the critical links between policymakers, donors, researchers, and the private sector are necessary. These would contribute to improving the probability of realizing more successful smallholder irrigated agriculture in a sustainable manner.

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7. Tables

Table 1: : Remaining principal components and eigenvalues

Principal component	Eigenvalue	%variability
PC$_1$	3.674	28.26
PC$_2$	2.562	19.71
PC$_3$	1.654	12.72
PC$_4$	1.170	9
PC$_5$	1.018	7.83
Sum	**10.078**	**77.53**

Table 2: Summary of results

Variables	Standardized Coefficient	Unstandardized Coefficient
Nature of access to land	-1.04574 (0.213846)***	2.57217 (0.525991)*
Infrastructure	0.00661 (0.294122)	0.030324 (1.349232
Information	1.617806 (0.23913)***	3.318946 (0.490578)*
Training	1.108553	3.349972

	(0.22161)***	(0.669691)*
Family labor	0.356419 (0.219566)	0.333503 (0.205449)
Access to Research & Development	0.096961 (0.08292)	0.200728 (0.171661)
Membership to farm organization	-1.06852 (0.211361)***	-2.2768 (0.45037)*
Market access	0.782917 (0.233998)***	1.583379 (0.47324)*
Planning	1.498991 (0.239327)***	2.119601 (0.338412)*
Off farm income	0.047676 (0.204184)	2.67E-06 (1.14E-05)
Transport	1.077983 (0.241693)***	3.089256 (0.692638)*
Extension	0.835903 (0.238204)***	0.032404 (0.9234)*
Credit	-0.35272 (0.245609)	-0.84365 (0.587466)
Constant	--	-15.4064*
Number of Observations		121
Goodness of fit		87.6%
Pesaran-Timmermann test		7.4459[.000]

***, ** and *= 1%, 5% and 10% respectively; Numbers in brackets are standard errors

Table 3: Parameter estimates of logistic regression

Variables	Coefficient (α)	Standard error	T-ratio	Probabilities
Constant	0.15585	0.31864	0.48912	0.626
PC_1	2.7941	0.52039	5.3692	0.000***
PC_2	0.55672	0.35689	1.5599	0.122
PC_3	1.5314	0.45160	3.3911	0.001***
PC_4	-0.53615	0.30608	-1.7517	0.083*
PC_5	0.79102	0.31474	2.5133	0.013**

***, **& * = 1% , 5% and 10% respectively