Does the structure of agricultural science and technology policy system matter in developing country agricultural productivity growth trends? Evidence from Kenya and Uganda

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Abstract

Despite the acknowledged importance of agricultural science and technology (AS&T) in enhancing agricultural productivity growth, little is known about the structure of AS&T policy system in developing countries. The structure of this policy system in developing countries was analysed using a "system components-shift effects" framework, with Kenya and Uganda as case studies. The framework was incorporated into the second step technical inefficiency effects translog stochastic frontier model. Food and Agriculture Organisation data for years 1970-2002 were used as input-output data. Important AS&T policy system determinants were identified to include: research expenditures, human capital development, domestic research output, farm-level literacy, intellectual property rights regime, degree of economic openness and access to agricultural extension information.

Key words: Agricultural science and technology, policy system, developing countries

JEL Classification: C22; O12; O33

1. Introduction

Developing countries are characterised by high population pressure and low agricultural productivity. The declining productivity growth has been occasioned by among others, inefficient use of resources and low technology development and use. Policy advocates have argued that contrary to Boserup's hypothesis that suggests population pressure is a sufficient condition for inducing productivity growth, governments need to play a pro-active role through enactment of supportive policies (Lele and Stone, 1989).

Agricultural science and technology (AS&T) policy is one such tool that can stimulate agricultural productivity growth (World Bank-FAO-WHO-UNEP, 2003). AS&T comprises those resources bearing public good characteristics albeit with high social returns, but whose provision is neither excludable nor rivalrous (Omamo et al., 2005). This makes it difficult for the private sector to make profits from them and therefore tend to under-invest and undersupply such goods. In this regard, the public sector needs to offer incentives to make markets for such goods not to fail. This offers motivation to investigate the functioning of AS&T policy (Byerlee and Alex, 1998).

Empirical work on AS&T policy system is limited. More intriguing is that its definition is even difficult to locate in literature. Earlier works in this area have either focused on agricultural research policy (Pardey et al., 1991; Omamo et al., 2000) or on agricultural science policy (Alston et al., 1995; Alston et al., 2001). The broad focus of these studies has been on identification of how investments in and policies for improving agricultural education, research, and extension can efficiently promote agricultural productivity. To contribute to this apparent gap in knowledge, Omamo et al. (2005) proposed a preliminary definition for AS&T policy system as '*comprising the structures and processes for setting priorities; specifying agendas; and financing,* *organising, delivering, monitoring, evaluating, and assessing impacts of agricultural research, extension, education and transboundary technology transfer*'. Two salient features of this definition are that, first it recognises that the policy system encompasses four system components: research, extension, education and transboundary technology transfer. Second, it recognises the need to investigate impact brought about by innovations within these key components.

Several studies have investigated the impact of some of these key components of the policy system on agricultural productivity in developing countries. Craig et al (1997) showed that agricultural research expenditures were significant in explaining cross-sectional differences in labour productivity across 67 developing countries. Lusigi and Thirtle (1997) found that conventional inputs and research expenditures together explained almost three-quarters of variation in production across 47 African countries between 1961 and 1991. Block (1994) suggested that expenditures for agricultural research and improved macroeconomic policies together explained two-thirds of measured productivity growth in 39 sub-Saharan African (SSA) countries during 1983-88. Thirtle et al (1995) established that investments in infrastructure, agricultural extension, and the level of real protection on international agricultural markets were significant in explaining efficiency change, while research and education explained the variation in technical progress. Although the precise effects of the different AS&T policy system functional components on the agricultural productivity vary from one study to the next, one broad pattern is clear - policy reform, infrastructure, and agricultural research make important contributions to productivity, although the estimated magnitude of these contributions is sensitive to the precise ways in which these variables are measured and analysed. Therefore, what is lacking in these past studies is a consistent framework for outlining the structure of

AS&T policy system when analysing its impact on productivity. This study endeavoured to fill the void by adopting and empirically testing a preliminary framework for delineating the structure of the AS&T policy system suggested by Omamo et al (2005) using Kenya and Uganda as case studies for the years between 1970 and 2002.

2. Methodology

2.1 Theoretical framework

This was grounded in two conceptual underpinnings derived from posits of Omamo et al. (2005). First, the AS&T policy system is composed of four functional components, i.e. research, extension, education, and transboundary technology acquisition and exchange. These comprise the policy 'system-components'. The influence of these components on productivity is modified by the second set of determinants, the 'shift effects' namely policy environment; institutional arrangements; and micro-level conditions. Based on the arguments of Davis and North (1971), Edwards (1983) and Williamson (1994), the interaction of the system components and the shifts effects give rise to the 'system components-shifts effects' framework that can be presented as a 3x4 matrix (Table 1). This matrix together with their internal interactions comprised the 'potential structure' of the AS&T policy system.

[Insert Table 1 here]

The potential determinants of the policy system structure were related to the estimated performance indicator (agricultural productivity) through a functional relationship:

$$P = \alpha_i + \beta_i(\text{System Components})(\text{Shift Effects}) + \Phi_i(\text{non-policy variables}) + e \qquad (1)$$

where P is the agricultural productivity (or performance); and α_i, β_i, and Φ_i are vectors of estimated parameters, and e is vector of error terms.

Four progressively disaggregated estimation scenarios are envisaged as being discernible from Equation 1 and the choice of which to apply in the analysis of structure and performance depends on the data available. These include:

a) Undifferentiated system and shift variables;
b) Functionally specific system effects with undifferentiated shift variables;
c) Functionally specific system effects with differentiated shift variables; and
d) Functionally specific system effects interacting with differentiated shift variables.

(a) Undifferentiated System and Shift effects:

Under this scenario, it is hypothesised that there are no differences between the system components and consideration is not given to the implication of the shift effects. Thus, under these circumstances, sector-wide system variables (like aggregate public expenditure) together with non-policy variables (e.g., rainfall) can be regressed on performance indicators. In effect, Table 1 collapses to a single box— no columns or rows.

(b) Functionally Specific System Effects with Undifferentiated Shift Effects:

The second scenario is envisaged to recognise the four AS&T policy system components—research, extension, education, and transboundary technology acquisition and exchange—but disregard the impact of the shift effects. Thus under this scenario, the functionally specific policy system components together with non-policy variables can be regressed on agricultural productivity measures. In this scenario, Table 1 would have four columns but only one row.

(c) Functionally Specific System Effects with Differentiated Shift Effects:

The third scenario is thought to explicitly capture not only the functional aspects of policy systems components, but also their modification by the shift effects – policy, institutional, and micro features. Table 1 therefore has four columns and three rows, but in this case, the column- and row-effects are captured independently of each other.

(d) Functionally Specific System Effects Interacting with Differentiated Shift Effects:

The fourth scenario is thought to assume a similar degree of disaggregation in system and shift dimensions as in the third scenario, but also allows for interaction between these aspects. Table 1 therefore has four columns and three rows, but now with each of the column- and row-effects captured in an integrated manner. This framework was applied in the analysis of the structure and performance of the policy system.

2.2. Relation between the 'systems components-shifts effects' framework with other systems frameworks

Even though this paper uses a different approach in the evaluation of AS&T policy system, it is informed by other system oriented frameworks that have been used to investigate various elements within science and technology. The systems perspective—that is, the study of sets of interrelated actors who interact in the creation, exchange, and application of agriculture-related technologies under varying social, economic and institutional contexts that conditions their actions and interactions has become an important method of analysing policy systems (Spielman and Birner, 2008). The systems approach has evolved to encapsulate the dynamics of developing-country agriculture. Three distinct forms of systems frameworks can be traced in literature, *viz*. the National Agricultural Research Systems (NARS), the Agricultural Knowledge and Information Systems (AKIS), and the Agricultural Innovation Systems (AIS) frameworks.

The NARS framework, was developed during the 1970s, and was informed by neoclassical economics and the inherent failures in the market for agricultural research in developing countries. The private benefits of research were often limited leading to undersupply of research products. This required that public investment in research be undertaken to address the chronic undersupply (see among other studies Anderson, et al. 1994; Alston, et al. 1995). The NARS framework thus focused on ways of optimising the investment in public research organisations as a means of developing technologies to foster agricultural productivity.

Limitations inherent within the NARS approach resulted in a broader approach to the study of drivers of agricultural productivity growth – i.e. the agricultural knowledge and information systems (AKIS) framework of the 1980s. Inspite of its broad definition (see Röling, 1990), the AKIS framework was mainly applied in a narrower sense, recasting agricultural research as one point of a "knowledge triangle" that also included agricultural extension and education, and placed the farmer in the middle of this triangle. This framework succeeded in refocusing the study of agricultural productivity growth on the dissemination and diffusion of knowledge and information, emphasising specifically the importance of knowledge and information flows between researchers, extension agents, educators, and farmers.

The NARS and AKIS frameworks were largely focused on the role of education, research, and extension as sources of new knowledge and technology to the farmer. This predisposition was found limited leading to development of the agricultural innovation system (AIS) approach at the end of the 1990s. The AIS thus extended beyond the creation of knowledge to encompass the factors affecting demand for and use of knowledge in novel and useful ways (World Bank, 2006a). The AIS has therefore developed to include the farmer as part of a complex network of heterogeneous actors engaged in innovation processes, along with the other institutions and the policy environment that influence these processes. It's important to note that the AIS drew on the concept of a "national system of innovation," which emerged in evolutionary economics in the 1980s (see among others Freeman 1987; Edquist, 1997). The approach was introduced to the analysis of developing-country agriculture mainly as a critique of the "linear" or "pipeline" model of agricultural research that was prominent in the earlier frameworks (Clark 2002).

Spielman and Birner (2008) have observed that the applications of the AIS framework to date have been primarily used to describe innovation processes that underlie the introduction of a given technology. Investigations that describe and assess entire national agricultural innovation systems have been scarce in the literature to date, particularly in developing countries of Africa. This gap in knowledge is the main focus of this study, where in essence we apply a modified version of the AIS framework to investigate the structure of the AS&T policy systems in Kenya and Uganda. Two main modifications are made. First, the business and enterprise domain of the AIS framework is replaced by the micro-level conditions, to effectively capture the conditions of generated technologies and knowledge together with the prevailing institutional arrangements at the micro-level. Second, one additional component – transboundary technology transfer is added as an important contributor to increased agricultural knowledge and technologies besides research, extension and education. In addition, the farmer ceases to be implied in the framework, but rather a focal player. This is achieved through incorporation of indicators that capture the interface between the developed knowledge and technologies and the farmer at the micro-level.

2.3. Performance indicators for the AS&T policy system

Technical efficiency was selected as a measure of agricultural productivity. The technical efficiency of a decision making unit (DMU) is defined as the degree to which it is able to convert its inputs efficiently into outputs – relative to best practice (Rao et al., 2004). AS&T policy contributes to improved technical efficiency in a number of ways. First, it leads to productions of technologies and knowledge, either through research or from transboundary acquisition; and secondly, it creates an environment that fosters the learning by DMUs in application of these technologies, thereby leading to improved efficiency (Malerba, 1992). This framework presupposes that the prevailing AS&T policy promotes learning by DMUs, leading to enhancements in the stock of knowledge and technological capabilities, and increased efficiency.

2.4. Data

Technical efficiency was derived based on the FAO input and output data for the years 1970 to 2002 (FAOSTAT, 2006) using the Battese and Coelli (1995) model. Output was net production at 1999-2001 international dollar prices derived using a Geary-Khamis formula for the agricultural sector (PIN) (Rao et al., 2004). Inputs were agricultural land, agricultural labour, capital, fertilizer and livestock. Agricultural land referred to the share of land area that is arable, under permanent crops, and under permanent pastures. Labour entailed the number of people economically active or searching for employment in agriculture. Fertilizer comprised the total consumption in nutrient equivalent terms of nitrogen, potash and phosphates consumed by a country and expressed in tones. Livestock comprised the aggregate sheep equivalent that were derived as a weighted sum of different livestock species including camels, cattle, pigs, sheep, and goats using the weights suggested by (Rao et al., 2004). Capital was a simple aggregate number of tractors in use at national level with no quality adjustment. The technical inefficiency variables that formed the potential structure of AS&T policy system were:

(i) Agricultural research capital (AG_RE_CAP) – Was computed as a ratio of the lagged total agricultural research expenditure to full time researcher equivalent using a method suggested by Huffman and Evenson (2004). Data were obtained from the Agricultural Science and Technology Indicators - ASTI (2006), supplemented with expenditure estimates from the ministries of finance from the study countries. Expenditures included salaries, operating costs, and capital from all sources (government, donors, private, civil society) reported in *constant 1993 US dollars*. It covered key sectors including crops, livestock, forestry, fisheries, natural resources, use of agricultural inputs as well as the socioeconomic aspects of primary agricultural production.

(ii) Human capital stock (HUM_CAP) - Was derived from expenditures on education by applying a lagging approach similar to research capital and then dividing by total enrolment in primary, secondary and higher education to obtain the human capital stock per student. Data was derived from the World Bank online database (World Bank, 2006), supplemented with expenditure estimates from the ministries of finance from the study countries. Expenditures included salaries, operating costs, and capital from all sources (government and donors) for primary and secondary education, and tertiary education. They were reported in *constant 1993 US dollars*.

(iii) Degree of economic openness (ECO_OPEN) - Was computed as the ratio of imports and exports of goods and services to GDP. This ratio indicated the level at which the economy is 'open' to allow the flow of transboundary technologies (Rao et al., 2004). Data was obtained from the World Bank online database (World Bank, 2006b).

(iv) Annual scientific journal articles published (JOURNAL). This was taken as the best available proxy denoting output of research. It incorporated publications in all fields, under the assumption that this was an indicator for the level of research output in agriculture, since agricultural studies dominate most publications in the study countries (Kenya, 2002; Uganda 2004). Data was obtained from the World Bank (2006) database, the Kenya National Bibliography (Kenya, 2002) and the National Bibliography of Uganda (Uganda, 2004). It had been envisaged that the actual technologies developed would be a suitable indicator. However, application of this variable was constrained by: (a) absence of a complete catalogue of technologies developed in Uganda in plant and animal health and production, soil science and biotechnology; (b) lack of the corresponding years of inception for each of the identified technologies in Kenya.

(v) Literacy level (LITERACY)**.** Literacy level in population over 15 years was used as the micro-level indicator of investments in education. Literacy level data was obtained from the World Bank online database, supplemented by review of records from the Uganda Bureau of Statistics in Kampala and the Kenya Bureau of Statistics in Nairobi.

(vi) Road density (ROAD). This was measured as total length of paved road per square km of agricultural land and acted as a proxy for the transaction costs that may be incurred in obtaining technologies at farm level. Data was obtained from the Uganda Bureau of Statistics, the Kenya Bureau of Statistics, and from the World Bank online database.

(viii) Telephone connection per 1000 economically active population (TELEPHONE). This comprised total telephone lines per 1000 people and was used as a proxy for transaction costs in accessing agricultural information. Household with access to telephone services have been shown to be more likely to access extension services than those without (Mugunieri and Omiti, 2007). Data was obtained from the Statistical abstracts (various) and the World Bank online database.

(ix) Institutional arrangements: Four regulatory systems were included in the model, i.e.: (i) agricultural research regulatory system (REG_AG_RES) that was represented by the presence of legislation that consolidated research under the National Science and Technology Act; (ii) agricultural extension (REG_AG_EXT) representing the switch from centralised to decentralised extension services; (iii) property rights (REG_PAT) representing the presence of legislation that conferred intellectual property rights within the economy; and, (iv) transboundary trade regime (REG_ECO_OPEN) that was used represented by economic liberalisation. These were represented as dummy variables. Policies that enhanced access to education (universal education) were not included as they were implemented in 1997 in Uganda and 2002 in Kenya.

All the above variables were used in the stochastic frontier technical inefficiency model (Table 2). In addition time trend was also included to capture the linear change in technical efficiency over time. Similarly, other variables like investment in irrigation (IRRIGATE), life expectancy (LIFE) and rainfall (RAIN) which might influence performance of the AS&T policy system (but are not elements of the framework) were also included. Irrigation was computed as the ratio of net irrigated area to net-cropped area and captured the influence of irrigation on productivity above and beyond its value as an input (Rosegrant and Evenson, 1995). Data used was obtained from FAO (FAOSTAT, 2006). Life expectancy at birth was included to capture the quality of the agricultural labour force. Rain was included due to its importance in determining the level of agricultural production realizable in a country in a given season. Rainfall data was obtained from the IFPRI database, where a single rainfall entry was derived to represent rainfall-level for the whole country.

[Insert Table 2 here]

2.5 The Empirical Model

In the empirical estimation, the stochastic frontier production function was conceptualised as a general translog functional form incorporating the possibility of non-neutral technical change[1]:

$$\ln y_{it} = \alpha + \sum_k \beta_k \ln x_{kit} + 0.5 \sum_k \sum_j \beta_{kj} \ln x_{kit} \ln x_{jit} + \sum_k \xi_k \ln x_{kit} t + \zeta_t t + \zeta_{tt} t^2 + u_{it} + v_{it} \quad (2)$$

where y_{it} represented output for country i in year t (i.e. the Agricultural PIN); x_{kit} represented the k-th input of country i in year t (for all inputs – land, labour, livestock, capital and fertiliser); t reflected the time technical change; α, β_k, β_{kj}, ξ_k, ζ_t, and ζ_{tt} were parameters to be estimated; u_{it} was the time variant technical efficiency (time variant technical efficiency was assumed because it would be imprudent to assume that technical efficiency would remain constant over an extended period of time, particularly when the environment is competitive); and, v_{it} was statistical noise.

This form of the stochastic frontier was adopted with the knowledge that a number of other functional forms were nested within it. Specifically, by restricting $\xi_k = 0$, the model reduced to a translog frontier production function with neutral technical change. By setting $\beta_{kj} = 0$, the model condensed to a Cobb-Douglas frontier production function. These specifications were formally tested.

[1] The utilization of fairly long panel data in this study necessitated the inclusion of technical change since it is less likely that technology would remain constant. One approach in which this is done is by inclusion of time among the regressors as a proxy for technical change, and doing so causes no unusual problems in the estimation process (Kumbhakar and Lovell, 2000).

The rate of technical change is defined from Equation (2) as the percentage change in output due to a unit change in time, that is,

$$TC_{it} = \partial y_{it} / \partial t = \zeta_t + \zeta_{tt} t + \sum_{j}^{J} \xi_{jt} x_{jit} \quad (3)$$

Neutral technical change is given by the first two terms of Equation (3) and non-neutral technical change is given by the third term (Hesmati, 1996). If ζ_t is positive/negative then there is technical progress/regress over the period. The sign on ζ_{tt} determines whether or not technical change is taking place at an increasing or decreasing rate. Technical change is said to be input-using in the j^{th} input if the sign on ξ_{jt} is greater than zero and input-saving in the j^{th} input if ξ_{jt} is less than zero.

The v_{it}s in Equation (2) were assumed to be independent and identically distributed normal random variables with mean zero and variance, σ_v^2; and, the u_{it}s were at the onset taken as non-negative random variables, which were assumed to be independently distributed, such that u_{it} was truncated (at zero) of the normal distribution with mean, μ_{it}, and variance σ^2 (appropriateness of this choice was empirically tested), and μ_{it} was defined by:

$$\mu_{it} = \delta_0 + Z_{it}\delta_{it} + t \quad (4)$$

where Z was a vector of specific variables comprising the potential structure of AS&T policy system and δ were the unknown parameters to be estimated. By including a time trend in Equation (4) it was possible to capture the linear change in technical efficiency over time (Battese and Coelli, 1995).

Prior to estimation of the model, a Chow test was done to determine whether the full set of regression parameters (the intercepts and slopes taken together) differed across the two countries (Chow, 1960). Two Chow tests were done, first for the input-output data, and second for the data on indicators of potential structure of the AS&T

policy system. In both cases, the test established that there were no significant differences making the estimation of the pooled model statistically sound. A dummy variable (COUNTRY) to distinguish between the two countries was included in the model.

3. Results and discussion

The first step regarding the suitable stochastic frontier model tests revolved on the validity of the translog over the Cobb-Douglas specification within the maximum likelihood (ML) specifications. The log likelihood test was used, that is $LRI = 1 - \ln L_o / \ln L$, where $\ln L_o$ is the log-likelihood value for the model computed with only the constant term and $\ln L$ is the log-likelihood function value for the model having all the regressors (Greene, 2003). The null hypothesis that $\beta_{ij}=0$, $\forall\ i \leq j = 1, 4$ was rejected. Therefore, the translog production technology was considered to be a better representation of metaproduction function technology than the Cobb-Douglas specification. The second stage of testing used log likelihood tests to examine the alternative specifications of technical change within the family of ML translog models. The null hypothesis that there was neutral technical change was rejected in each case against the alternative hypothesis of non-neutral technical change. The third stage of testing that focused on the null hypothesis that there were no technical inefficiency effects in the model, that is, the one sided error $\gamma = 0$, was strongly rejected.

The final stage of testing concerned the distribution of the inefficiency effects. The null hypothesis that the technical inefficiency effects have a half-normal distribution (i.e., $\mu=0$), was rejected against the null that the technical inefficiency effects have a truncated normal distribution ($\mu = 0.12$; $p<0.002$). Given these results, the translog with non-neutral technical change was chosen as the best representation of Kenyan and Ugandan agricultural technology given the alternative specifications considered. The maximum likelihood estimates of this stochastic frontier production function model were obtained using STATA 8.2. The results are shown in Table 3.

[Insert Table 3 here]

The coefficients on the time trend variable showed that there was positive neutral technological progress. The stochastic frontier metaproduction function, evaluated at the first observation, was moving upward at an annual rate of about 3.7%. The coefficient on γ implied that 99.99% of the two components disturbance term was represented by technical inefficiency. Labour had the highest production elasticity. The production elasticities estimated in this study were quite similar to those found in Kawagoe et al. (1985) who estimated respectively a metaproduction function for 38 and 43 developed and underdeveloped countries. Progress in technical change was found to be labour saving. The important determinants of AS&T policy system included agricultural research expenditures per FTE, public education expenditure per student, domestic research output, farm level literacy, presence of a regulatory framework for intellectual property rights, increased economic openness and access to extension information. Non-policy determinants included quality of labour and precipitation.

All key macroeconomic indicators like public expenditures (in education, research and extension) and level of economic openness are expected to be positively related to agricultural productivity, provided there are no substantial urban biases in these expenditures (Rao et al, 2004). This aphorism was valid only for education and research but not economic openness. Since transboundary trade leads to importation of foreign goods, and in the process allows a country to access foreign technology, it is expected to contribute to improved technical efficiency. The opening up of the economies was associated with increased inflow of agricultural products, heralding additional competition against local produce, probably against a background of an under-developed private sector. It is apparent that such a private sector was yet to be stimulated to establish trading networks needed for proper functioning of a liberalised economy. Furthermore, the risks associated with adopting a more exposed position in a highly competitive global agricultural market presented countries with smaller economies with some serious difficulties (Badiane and Mukherjee, 1998). Therefore, it can be argued that a combination of the impact of liberalisation policies and partial reform of the rules governing international trade that led to reduction in the prices of primary commodities exported by developing countries and an increase in imports of agricultural products from more competitive (and perhaps subsidised) producers had a negative effect developing economies. However, it is anticipated that as these economies develop and the role of the private sector becomes more prominent, the effect of open trade is bound to be significant in the long term. This is based on the argument that agricultural reforms, reductions in trade barriers and entrenchment of intellectual property rights (IPR) regulations are envisaged to help farmers both in the industrialised and developing worlds get a better deal in a more cost-effective way (Monika, 2005). The fact that enactment of IPR regulations is an important policy system determinant attests to this line of argument.

Another important finding of this study is the significance of increased literacy levels. The significance of the literacy level is depended upon whether the technologies in use are complex and knowledge intensive (Rosegrant and Evenson, 1995). Such technologies could be derived from domestic research. Indeed domestic research was found to be significant signifying the relevance of research in facilitating rapid growth in productivity.

6. Conclusion

The main objective of this paper was to suggest an approach for delineating the structure of AS&T policy system in developing countries using data set from the Kenyan and Ugandan agricultural sectors as case studies. Important determinants were identified to include: research expenditures, human capital development, domestic research, literacy level, intellectual property rights, economic liberalisation and access information. Although important determinants of AS&T policy system have been presented, is worthwhile to note that this analysis utilised conventional agricultural inputs without taking into account quality adjustments, which is likely to affect efficiency measures (Suhariyanto and Thirtle, 2001). Nevertheless the results provide some useful insights on policy areas where AS&T policy interventions are likely to have significant positive impacts contingent on the level of economic development of a country.

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Table 1: Potential structure of AS&T policy system – 'systems components-shifts effects' framework

		AS&T Policy System Components			
		Research	Extension	Education	Trans-boundary Technology Transfer
AS & T Policy System Shift Effects	Policy Environment	Research capital	Extension financing priorities	Human resource capital	Degree of economic openness
	Institutional arrangement	Coordination of agricultural research	Extension delivery systems	Education access and quality control systems	Intellectual property rights regulatory regime
	Micro-conditions	Technologies developed	Farmer-extension agent contact intensity	Literacy level within the agricultural labour force	Transaction costs in accessing technologies

Source: Adapted with modification from Omamo et al. (2005)

Table 2: Variables used in the model

Input-Output data	***n = 66***
Inputs (Means)	
FERTILIZER (NPK-nutrient tones)	47,216.15 (52,126.61)
LABOUR (000' people)	7,442.55 (2,148.71)
LAND (000' Ha)	18,594.41 (7,306.32)
LIVESTOCK (sheep equivalent)	7.6(E+7) (3.26E+07)
CAPITAL (Tractor numbers)	6,177.83 (3,350.30)
Output (Means)	
Agricultural PIN (1999 international dollars)	72.68 (18.06)
Potential determinants of AS&T policy system	***n = 66***
Potential policy-level determinants (means)	
AG_RE_CAP	27705.39 (7459.59)
HUM_CAP	345.79 (113.00)
ECO_OPEN	30.47 (8.82)
Potential micro-level determinants (means)	
JOURNAL	144.84 (114.05)
TELEPHONE	14.55 (18.46)
ROAD	2.23 (0.86)
LITERACY	58.32 (13.57)
Potential non-policy determinants (means)	
RAIN	1006.77 (254.53)
IRRIGATE	0.13 (0.09)
LIFE	51.01 (4.60)
Potential institutional arrangement determinants (frequencies)	
REG_AG_EXT	
Centralised	78.8%
Decentralised	21.2%
REG_PAT	
Not well regulated	80.3%
Act enacted and made operational	19.7%
REG_AG_RES	
S&T Act not available	47.0%
S&T Act available and operational	53.0%

Figures in parentheses are standard deviations.

Table 3: The stochastic production frontier estimation - Dependent variable

Agricultural PIN

Variable	*Coefficient*	*Standard Error*
ln LIVESTOCK	0.299***	0.100
ln LABOUR	5.326***	0.165
ln LAND	0.358***	0.053
ln CAPITAL	0.527***	0.056
ln FERTILISER	0.014*	0.010
ln LABOUR*TIME	-0.079***	0.006
ln FERTILISER*FERTILISER	0.001**	0.0001
TIME	0.037***	0.002
TIME*TIME	0.004***	0.001
Constant	43.305***	0.001
Inefficiency effects		
ln PU_AG_RE	-0.603***	0.164
ln HUM_CAP	-0.082**	0.011
ln ECO_OPEN	-0.063	0.061
ln JOURNAL	-0.160**	0.092
ln LITERACY	2.280***	0.790
ln LIFE_EXP	-1.532**	0.780
ln ROAD	-0.036	0.175
ln TELEPHONE	-0.505***	0.159
REG_AG_RES	-0.040	0.072
REG_AG_EXT	-0.018	0.258
REG_PAT	-0.64**	0.318
REG_ECO_OPEN	0.441***	0.127
ln IRRIGATE	-0.074	0.128
ln RAIN	-0.098**	0.050
GENERATION	0.196	0.300
TIME	-0.101***	0.022
Constant	5.047**	2.821
μ (mu)	0.121***	0.040
lnsigma2	3.850	0.033
Ilgtgamma	15.153	5.813
σ^2_v	5.61e-09	3.26e-08
σ^2_u	0.022	0.001
σ^2	0.022	0.001
γ	0.999	1.53e-06

Notes: Figures in parentheses are standard errors).

*** p<0.01; ** p<0.05; * p<0.10