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Returns to Agricultural Public Spending in Africa South of the Sahara

Samuel Benin

Development Strategy and Governance Division

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AUTHOR

Samuel Benin (**s.benin@cgiar.org**) is a research fellow in the Development Strategy and Governance Division of the International Food Policy Research Institute, Washington, DC.

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ABSTRACT

Using data on 34 countries in Africa south of the Sahara (SSA) from 1980 to 2012, this paper assesses the returns to public spending in the agricultural sector, considering expenditures on agriculture as a whole versus expenditures on agricultural research. First, an aggregate production function is estimated using a fixed-effects, instrumental variables estimator to address potential endogeneity of agricultural expenditure and to obtain elasticities of land productivity with respect to total agricultural expenditure and agricultural research expenditure. Different model specifications are used to test the sensitivity of the results to different assumptions. The estimated elasticities are then used to estimate the rate of return to expenditure in different countries and groups of countries.

The elasticity of land productivity with respect to total agricultural expenditure per hectare is estimated at 0.04, and elasticity with respect to agricultural research expenditure per hectare is estimated to be higher at 0.09. The aggregate returns to total agricultural expenditure and agricultural research expenditure in SSA are estimated at 11 percent and 93 percent, respectively. Comparative analysis of the estimates with those of previous studies, as well as across different countries and different groups of countries, is undertaken. Then implications are discussed for maintaining the high returns to agricultural research expenditure and for further studies on the low return to total agricultural expenditure, including more disaggregated analysis of expenditure on other functions besides research to better inform prioritization of agricultural expenditure.

Keywords: agricultural expenditure, agricultural research, Africa, rate of return

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ABBREVIATIONS AND ACRONYMS

2SLS	two-stage least squares
AIC	Akaike information criterion
ASTI	Agricultural Science and Technology Indicators
CAADP	Comprehensive Africa Agriculture Development Programme
FD	first difference
FE	fixed effects
GDP	gross domestic product
IV	instrumental variables
LCU	local currency unit
R&D	research and development
RE	random effects
ReSAKSS	Regional Strategic and Knowledge Support System
ROR	rate of return
SPEED	Statistics on Public Expenditures for Economic Development
TFP	total-factor productivity

1. INTRODUCTION

Raising agricultural productivity and sustaining high agricultural growth rates are major strategic objectives of African governments in their effort to accelerate overall economic development and reduce poverty and hunger in the continent. As part of the Comprehensive Africa Agriculture Development Programme (CAADP), for example, African leaders have committed to increase their annual spending on agriculture to 10 percent of total national expenditure—a commitment popularly known as the Maputo Declaration (AU 2003, 2014). Because of economic inefficiencies due to market failures and because of inequality in the distribution of goods and services due to differences in initial allocation of resources across different groups and members of society, public investment is justified. In the agricultural sector, market failure hinges on, for example, imperfect markets and information asymmetries in agricultural technology generation and adoption. In terms of social inequities, the distribution of goods and services is often biased against the majority of people who live in rural areas, depend on agriculture for their livelihoods, and are poor. As such, the commitment by African leaders to increase their annual spending on agriculture to 10 percent of total national expenditure seems laudable.

But African leaders have also signed on to various charters that demand similar or larger public expenditures—for example, the 2001 Abuja Declaration that calls for spending 15 percent of the national budget on the health sector or the 2007 Year of Science and Technology that calls for spending 1 percent of gross domestic product (GDP) on science and technology. Those and other commitments make it difficult to see how the leaders can make significant shifts in expenditures across different sectors to achieve the Maputo Declaration. It is therefore not surprising to find that only 13 countries have achieved or surpassed the 10 percent agriculture expenditure target in any year since 2003, when the Maputo Declaration was signed, with only seven of the countries doing so on a consistent basis (Benin and Yu 2013). For the continent as a whole, the share of agriculture expenditure in total expenditure actually declined in 2008–2014 (Table 1.1). Similarly, growth in various agricultural performance indicators (gross production, value-added, land and labor productivity, and cereal yield) in recent years declined or stagnated (Table 1.1). These trends raise a critical question that this paper tries to address: is the slowdown in public agriculture expenditure causing the slowdown in agricultural growth and other related outcomes?

Table 1.1 Agriculture expenditure and productivity in Africa, 1995–2014

Variable	1995–2003	2003–2008	2008–2014
Agriculture expenditure:			
Growth rate (%)	6.1	6.6	2.3
% of total expenditure	3.3	3.5	3.0
% of agricultural value-added	5.1	6.1	5.8
Agricultural growth rate (%):			
Agricultural value-added	2.8	3.8	2.6
Labor productivity	0.8	1.6	0.6
Land productivity	2.2	2.3	0.9
Cereal yield	1.4	1.6	1.6

Source: Author's calculation based on IFPRI (2015a, 2015b).

Whereas a large body of research examines overall growth and productivity effects of public expenditure in general, far fewer studies examine the agricultural growth and productivity effects of public agriculture expenditure, especially in Africa. The limited research on the productivity effects of public agriculture expenditure in Africa, as well as in many developing countries, is due largely to the lack of extended time-series expenditure data that are adequately disaggregated by type of spending. Some of the few studies in Africa have been country case studies on the relative effects of different types of spending in and outside agriculture—such as in Ghana (Benin et al. 2012), Ethiopia (Mogues 2011), Tanzania (Fan, Nyange, and Rao 2012), and Uganda (Fan and Zhang 2008)—where expenditure data were available for short periods of time, that is, not more than 10 years. These studies show that public expenditure has positive growth and productivity effects, but that different types of spending have different effects and that spatial differences in the effects exist even within a country. Thirtle, Piesse, and Lin (2003), Fan, Yu, and Saurkar (2008), and Alene and Coulibaly (2009) use cross-country analysis to also establish strong positive effects of spending on agricultural research and development (R&D). The study by Thirtle, Piesse, and Lin includes 22 African countries among a total of 48 developing countries over the period 1985–1995. Similarly, the study by Fan, Yu, and Saurkar includes 17 African countries among a total of 44 developing countries, but over varying periods of time of not more than 10 years, whereas Alene and Coulibaly's study includes 27 countries in Africa south of the Sahara (SSA) over the period 1980–2003. All three studies use a system of simultaneous equations to estimate the effect of agricultural research on income or poverty via agricultural output or productivity. The estimated elasticity of agricultural productivity (that is, agricultural value-added per hectare) with respect to agricultural research expenditure per hectare is 0.36 in the Thirtle, Piesse, and Lin study and 0.38 (0.17 for national agricultural research and 0.21 for international agricultural research) in the Alene and Coulibaly study. The estimated elasticity is lower in the Fan, Yu, and Saurkar study, 0.08 for total agriculture expenditure and 0.04 and -0.07 for disaggregated expenditures on research and nonresearch, respectively. Alene and Coulibaly and Thirtle, Piesse, and Lin estimate the aggregate rate of return (ROR) to expenditure on agricultural research to be 55 percent and 22 percent, respectively, with substantial cross-country differences.[1]

As Table 1.1 shows, recent trends in agricultural expenditure in Africa, especially following renewed commitments to the sector such as reflected by CAADP, are quite different from the trends associated with the periods analyzed in the above studies. Similarly, a recent study by Benin and Nin Pratt (2015) on trends in agricultural productivity in Africa from 1961 to 2012 show significant differences over different subperiods of time and across different subregions and countries. For example, from 1961 until the mid-1980s, they found a sort of U-shaped trend for growth in land and labor productivity, but a declining trend for total-factor productivity (TFP) growth. From the mid-1980s onward, they found an increasing trend for growth in labor productivity and TFP but a declining trend for land productivity growth. Whereas the widespread stagnation or decline in TFP observed prior to the mid-1980s was due to negative efficiency change, from the mid-1980s onward efficiency change and technical change contributed positively and equally to TFP growth. Therefore, evidence of the agricultural productivity effects of public spending that accounts for recent trends in expenditures and productivity is needed.

Public expenditure data constraints have been eased somewhat by the International Food Policy Research Institute (IFPRI) through its datasets associated with the Statistics on Public Expenditures for Economic Development (SPEED), the Regional Strategic and Knowledge Support System (ReSAKSS), and Agricultural Science and Technology Indicators (ASTI) initiatives. These provide country-level, time-series data from 1980 to the most recent year available on public expenditure in the agricultural and nonagricultural sectors globally (via SPEED), government agricultural expenditure in Africa (via ReSAKSS), and agricultural research investments globally (via ASTI).

Exploiting cross-country and temporal differences in public expenditures and agricultural productivity growth, this paper assesses the returns to public spending in the agricultural sector in SSA, considering spending on agriculture as a whole versus spending on agricultural research. We use data on 34 SSA countries from 1980 to 2012 to econometrically estimate an aggregate agricultural production function covering the relationship between agricultural productivity (output per hectare) and the different types of public expenditure, as well as the determinants of the expenditure.

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[1] See Mogues, Fan, and Benin (2015) for a recent review of the evidence on the effects of different types of agriculture expenditure in developing countries.

2. CONCEPTUAL FRAMEWORK

The fundamental notion underlying the productivity effects of public spending is that public capital and private capital are complements in the production process, so that an increase in public spending that leads to an increase in the public capital stock raises the productivity of private capital and other factors in production (Aschauer 1989; Barro 1990). The productivity effects can be categorized into four pathways of impact—technology advancing, human capital enhancing, transaction cost reducing, and crowding-in of private capital. Each of these is discussed below. Because there are several studies that analyze the productivity effects of public expenditure in general, the specific rationale for and pathways of the effects of public agriculture expenditure are often assumed and have not been as widely and explicitly discussed. As such, we focus on the literature with respect to public agriculture expenditure in developing countries, although we refer to some of the more general studies to support part of the arguments where necessary.

Pathways of Impact

Technology-advancing productivity effects derive typically from the yield-enhancing technologies[2] of public expenditure in agricultural R&D. These have been widely studied and found to have large RORs on investment (for example, Rosegrant, Kasryno, and Perez 1998; Fan, Hazell, and Thorat 2000; Fan, Zhang, and Zhang 2004; Fan, Yu, and Saurkar 2008; Thirtle, Piesse, and Lin 2003; Fan and Zhang 2008; and Alene and Coulibaly 2009). The studies by Rosegrant, Kasryno, and Perez (1998) and Fan, Hazell, and Thorat (2000), for example, analyze the effect of agricultural R&D expenditures on TFP, with estimated elasticities in the range of 0.05 to 0.25, whereas the studies by Thirtle, Piesse, and Lin (2003), Fan, Zhang, and Zhang (2004), Fan, Yu, and Saurkar (2008), and Alene and Coulibaly (2009) analyze the effect on land or labor productivity, with estimated elasticities in the range of 0.09 to 0.44. The productivity effects of agricultural R&D investments, however, tend to materialize with a long time lag and can persist long afterward. Thirtle, Piesse, and Lin, for example, consider a five-year lag of agricultural R&D investments whereas Alene and Coulibaly consider a 16-year lag. The choice of the length of the lag seems to be influenced by the length of the time-series data used in order to accommodate degrees-of-freedom issues, with longer lags being used in studies that have longer time-series data.

Human-capital-enhancing productivity effects derive typically from public expenditure in agricultural education, extension, and information that raises the knowledge and skills of farmers and those engaged in agricultural production. This is important for successful agricultural enterprises because agricultural production processes tend to be complex and are increasingly becoming knowledge intensive. A comprehensive review of 80 case studies on the impacts of agricultural extension by Alston et al. (2000) shows that there are large positive economic returns to public spending on agricultural extension, with an average ROR of 85 percent. In general, public spending on rural education, health, water, sanitation, and so forth, by making the rural labor force more literate and healthier, may increase human capital accumulation in agricultural production (Schultz 1982). The studies by Fan, Hazell, and Thorat (2000), Fan, Zhang, and Zhang (2004), and Fan, Yu, and Saurkar (2008), for example, show significant positive effects of public spending on education on agricultural TFP, land productivity, or labor productivity, with estimated elasticities in the range of 0.05 to 0.68. Similar to agricultural R&D investments, human capital productivity effects materialize with a lag and can persist long afterward. Fan, Yu, and Saurkar, for example, consider a seven-year lag of expenditure on agricultural extension in Uganda.

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[2] Technologies may be biological (for example, genetically modified organisms and hybrids), chemical (for example, fertilizers and pesticides), mechanical (for example, tractors and implements), or informational (for example, husbandry, value chains, and early-warning systems).

The transaction-cost-reducing productivity effects are expected to derive from public expenditure on infrastructure in the agricultural sector (for example, storage facilities, market information, and feeder roads) that contributes to improving access to input and output markets, thereby reducing the cost of agricultural inputs and technologies. Transaction costs are important, as they drive whether markets are integrated, are thin, or fail (Sadoulet and de Janvry 1995). By facilitating the movement of goods and services and reducing the costs of doing business, public investment in rural infrastructure in general (roads, bridges, transportation, energy, and so on) may raise the productivity of other forms of capital in agricultural production. This is implied in, for example, the studies by Fan, Hazell, and Thorat (2000), Fan, Zhang, and Zhang (2004), Fan, Yu, and Saurkar (2008), Teurel and Kuroda (2005), Fan and Zhang (2008), and Benin et al. (2012) that find significant positive effects of public spending on road infrastructure on agricultural TFP, land productivity, or labor productivity. In their Uganda study, for example, Fan and Zhang (2008) find that the returns to spending on feeder roads were three to four times higher than the returns to spending on laterite, gravel, or tarmac roads.

The crowding-in productivity effect of public agriculture expenditure is a commonly advanced rationale used to advocate for greater public spending on the sector. The notion is that by raising the productivity of all factors in production, as discussed in preceding sections, an increase in public expenditure is expected to cause an increase in private capital to the extent that public and private investments are complements. For example, public investment in dams and canals for irrigation is expected to increase private investment in irrigation systems on the farm, as found by Fan, Hazell, and Thorat (2000). Malla and Gray (2005) and Görg and Strobl (2006) also find significant crowding-in effects of public R&D on private R&D in the United States and Ireland, with estimated elasticities in the range of 0.10 to 0.28. Similar crowding-in arguments have been made for input subsidies (that is, subsidizing the price of the input sold in the market)—especially for chemical fertilizers and mechanical equipment. In many cases however, such expenditures have not increased overall use of the input, because poor targeting of the programs has crowded out use of commercial inputs as the bulk of the subsidized inputs has been provided to farmers who would have purchased them regardless (Jayne et al. 2013).

The literature also shows that not all public spending is productive, as the evidence found by Devarajan, Swaroop, and Zou (1996) and Benin et al. (2012) regarding spending on salaries and other recurrent items, for example, shows. With respect to agricultural subsidies, for example, there are indirect price effects that may restrict or encourage production and supply of particular agricultural inputs and commodities. Thus, public spending on such subsidies rarely creates any productive capital, and so the link with productivity is often weak.

To summarize the discussion so far, the literature shows that the productivity effects of public agriculture expenditure may materialize through various channels, that the effects are not the same for all types of expenditure, and that the effects often materialize with a lag rather than contemporaneously.

Marginal Effects and Elasticities

To analyze these differences, let the aggregate production function for the agricultural sector in year *t* be modeled as

$$Y_t = A_t * f(L_t, K_t, D_t, \boldsymbol{Z}_t), \tag{1}$$

where *Y* is the value-added of agricultural output, *L* is labor, *K* is the value of private capital and other intermediate inputs, *D* is agricultural land, ***Z*** is a vector of other factors affecting agricultural output, and *A* is a measure of TFP. Rewrite equation 1 in terms of per unit agricultural land area as[3]

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[3] We could have alternatively divided through by *L* or *K* to arrive at similar results, although with different interpretations—for example, labor productivity instead of land productivity.

$$y_t = A_t * f(l_t, k_t, \boldsymbol{Z}_t), \tag{2}$$

where $y = Y/D$, $l = L/D$, and $k = K/D$ to represent value-added, labor, and capital per unit agricultural area, respectively. To explicitly capture the different productivity-effect pathways of public agriculture expenditure, G, equation 2 can be modified as follows:

$$y_t = A_t(G_t \dots G_{t-N}) * f\big(l_t(G_t \dots G_{t-N}), k_t(G_t \dots G_{t-N}), \boldsymbol{Z}_t^y, G_t, G_{t-1}, \dots, G_{t-N}\big) + e_t^y \tag{3a}$$

$$G_t = h(y_t, \boldsymbol{Z}_t^G) + e_t^G, \tag{3b}$$

where $\boldsymbol{Z}^y$ and $\boldsymbol{Z}^G$ are used to differentiate the vector of other factors that affect y and G, respectively, N is a positive integer representing the maximum lag, and e^y and e^G are random error terms in equations 3a and 3b, respectively.[4] Ignoring equation 3b for now, the total elasticity of land productivity with respect to public agriculture expenditure at any time t, which is defined as the ratio of the percentage change in land productivity (dy/y) to the percentage change in public agriculture expenditure (dG/G), can be obtained from equation 3a according to

$$\frac{dy_t/y_t}{dG_t/G_t} = \frac{\partial y_t}{\partial A_t} \sum_{q=0}^{\mathrm{N}} \frac{dA_t}{dG_{t-q}} \frac{G_t}{A_t} + \left[\frac{\partial y_t}{\partial l_t} \sum_{q=0}^{\mathrm{N}} \frac{dl_t}{dG_{t-q}} + \frac{\partial y_t}{\partial k_t} \sum_{q=0}^{\mathrm{N}} \frac{dk_t}{dG_{t-q}} + \sum_{q=0}^{\mathrm{N}} \frac{\partial y_t}{\partial G_{t-q}}\right] * \frac{G_t}{f(\cdot)}, \tag{4}$$

where ∂ refers to the partial derivative, so that $\partial y_t/\partial G_{t-q}$, for example, measures the direct marginal effect of public agriculture expenditure on land productivity at time t and $\partial y_t/\partial k_t * \partial k_t/\partial G_{t-q}$ measures the indirect marginal effect via its effect on capital k. The elasticity is interpreted generally as the percentage change in land productivity (y) due to a 1 percent change in public agriculture expenditure (G). Together, the first terms on the right-hand side of equation 4 capture the technology-advancing productivity effect of public agriculture expenditure. The first parts of the first and second terms in the brackets capture the human-capital-enhancing and transaction-cost-reducing productivity effects, whereas the second parts of the first and second terms in the brackets capture the crowding-in productivity effects. The third term in the brackets measures the productivity effects through other channels.

Rate of Return

Using $(\hat{\vartheta}_t^{yG})$ to represent the estimated elasticity from equation 4, the ROR can be estimated using equation 5 as the discount rate (r) that equates the net present value of marginal productivities $(\hat{\vartheta}_{t-q}^{yG}\bar{y})$ over the relevant time periods of lag (that is, q = 0, 1, ..., N) to an initial or one-time public agriculture expenditure (G_0):

$$\sum_{q=0}^{N} \frac{\hat{\vartheta}_{t-q}^{yG}\bar{y}}{(1+r)^q} = G_0, \tag{5}$$

where $\bar{y}$ is the annual average land productivity and G_0 is equivalent to one percent of the annual average public agriculture expenditure (that is, $0.01 * \bar{G}$).

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[4] Note that G could have been written in a similar manner as Z^j to differentiate its effect via the different channels based on the notion that different types of spending may influence TFP and each factor of production differently. The general form presented here simplifies the model.

Endogeneity of Expenditures and Other Issues in Estimation

Because change in G (that is, dG) may derive from change in y, as implied in equation 3b, the elasticity represented in equation 4 may be overestimated if $\frac{dG}{dy} > 0$ and underestimated if $\frac{dG}{dy} < 0$. Furthermore, because change in y (that is, dy) may derive from change in e_t^y, it means that G may be influenced by the same unobservable factors that influence y—that is, G_t is correlated with e_t^y or $\mathrm{E}[e_t^y|G_t] \neq 0$. These issues reflect the potential endogeneity of G, which failing to address will render the estimates of the productivity effects or elasticities by ordinary least squares (OLS) biased and inconsistent. There are at least three sources of the endogeneity discussed in the literature—simultaneity of y and G, omitted explanatory variables in equation 3a, and measurement errors in G—and there are different ways of addressing each of them.

With respect to simultaneity of y and G, higher agricultural output and productivity may raise the tax base or revenues that G depends on, meaning that y and G are simultaneously determined. This also implies that change in unobservable factors e_t^y that cause change in y may potentially cause change in G, so that G_t becomes correlated with e_t^y or $\mathrm{E}[e_t^y|G_t] \neq 0$. The standard approach for addressing this problem is to use instrumental variables (IV), which must satisfy two requirements: the instrument(s) must be correlated with G_t and orthogonal to e_t^y. The vector of variables $\boldsymbol{Z}^G$ specified in equation 3b become critical here in terms of determining G_t, or identifying equation 3b. The estimation is done in a two-stage procedure, which also gives it another name, two-stage least squares (2SLS). In the first stage, G is regressed on $\boldsymbol{Z}^G$ and all the exogenous variables in equation 3a. Then, the results are used in a second-stage estimation of equation 3a. Variables on political processes and institutions have been shown to work well as instruments for expenditures (for example, Cox and McCubbins 1986; Lindbeck and Weibull 1993; Benin et al. 2012), and so we exploit these in this paper. Some studies have used lagged values of the endogenous explanatory variables as instruments (for example, Alene and Coulibaly 2009; Thirtle, Piesse, and Lin 2003). Whereas this approach seems sound conceptually, in the sense that the lagged values are predetermined, they usually do not perform well empirically (or tend to be weak instruments) because such lagged values also tend to be correlated with the dependent variable and violate the second requirement of orthogonality to the error term.

A way that has been used in addressing the simultaneity problem is to use the current and lagged values of G (that is, G_t, $G_{t\text{-}1}$, $G_{t\text{-}2}$, …, $G_{t\text{-N}}$) to first construct a stock variable that is a weighted aggregate of current and past expenditures, which is then used in the estimation of equation 3a (for example, Fan and Zhang 2008; Benin et al. 2012). The main issue to deal with here is the set of the aggregation weights, which often are chosen arbitrarily. Because the stock variable is a composite including current values of G, exogeneity of the stock variable still needs to be dealt with. Another way that some past studies have used to get around the simultaneity problem (which is not the same as addressing the problem) is to use the lagged values of G_t (that is, $G_{t\text{-}1}$, $G_{t\text{-}2}$, …, $G_{t\text{-N}}$) in the estimation of equation 3a (for example, Thirtle, Piesse, and Lin 2003). This approach seems conceptually sound because current values of y cannot affect past values of G, that is, y_t cannot affect, say, $G_{t\text{-}1}$. However, this estimation approach fundamentally assumes that there is no contemporaneous effect, that is, current values of y do not depend on current values of G, which is a specification that introduces the endogeneity problem due to omitted variables. By omitting G_t as an explanatory variable in equation 3a and using only the lagged values of G_t (that is, $G_{t\text{-}1}$, $G_{t\text{-}2}$, …, $G_{t\text{-N}}$) in the estimation, then G_t will be captured in the error term and, consequently, $G_{t\text{-j}}$ will become correlated with the error term to the extent that $G_{t\text{-j}}$ and G_t are correlated.

Regarding the omitted explanatory variables in general, suppose that agriculture expenditure is influenced by agroecological and climatic factors—say a greater amount is spent in high-agricultural-potential areas compared with low agricultural potential areas, or a lower amount is spent in relatively poor rainy years compared with other years. Suppose further that these factors, represented by C_t, which also affect y, are omitted as explanatory variables in equation 3a; then they will be captured in the new error component, say φ_t^y (where $\varphi_t^y = C_t + e_t^y$), so that G_t becomes correlated with φ_t^y. Instrumental variables or 2SLS are still the standard approaches used for addressing this source of endogeneity, where the instruments must be correlated with G_t and orthogonal to φ_t^y. Often, the omitted variables are also unobservable; otherwise they would not have been missing or omitted from the estimation in the first place. If the omitted but unobservable factors are fixed over time, represented by C without the time subscript, such as with certain agroecological and climatic factors, then the endogeneity of G due to omitted C could be addressed by using a first-difference (FD) estimator, for example, in the estimation of equation 3a. This is equivalent to estimating equation 3a in FD by OLS, which excludes the effect of all time-invariant factors including C. Differencing, however, may remove the long-term productivity effects of G whose benefits typically materialize with a lag (Hsiao 1986). More on this later.

Regarding measurement errors in G, there are general legitimate concerns about reliability of the formal-sector data governments self-report. Since the initiation of CAADP in 2003, for example, concern has emerged over differences in the definition of agriculture expenditures that governments have used to report progress in meeting the Maputo Declaration (Benin and Yu 2013), which is consistent with the measurement-error issues highlighted in Jerven (2013). Suppose that the observed value G_t^* is equal to the true unobserved value G_t plus the measurement error μ_t according to

$$G_t^* = G_t + \mu_t. \tag{6}$$

The consequence is that the measurement error will be captured in the new error component in equation 3a, say ω_t^y (where $\omega_t^y = \mu_t + e_t^y$), so that G_t becomes correlated with ω_t^y or $E[\omega_t^y|G_t] \neq 0$. Because the problem is that the measurement error μ_t is correlated with G_t^*, the standard solution here is to find an instrument for G_t^*, that is, a variable that is correlated with G_t^* but not with μ_t. As the literature suggests, finding such a variable is not as difficult as in the case where G_t is correlated with e_t^y in equation 3a (Griliches 1997; Greene 1993). Observed outputs of G_t may be used as instruments. For example, numbers of research scientists or agricultural technologies generated may be used as instruments, or proxies, for agricultural research expenditures. Similarly, the amount of fertilizer and improved seeds distributed to farmers may be used as an instrument, or proxy, for the amount spent on agricultural subsidies.

To reliably estimate equation 3a and the productivity effects or elasticities represented in equation 4, adequate time-series data on y, l, k, G, $\boldsymbol{Z}^y$, and $\boldsymbol{Z}^G$ are needed. Because the productivity effect of G is different for different types of spending, disaggregation of G by type is desirable. In the next section, we discuss the data and estimation methods used.

3. DATA SOURCES AND EMPIRICAL APPROACH

Data and Sources

The main data constraint faced in this paper lies with public expenditure, which has been compiled from SPEED (IFPRI 2015a) and ReSAKSS (IFPRI 2015b) for total government expenditure (*TE*) and total agriculture expenditure (*GT*) from 1980 to 2014 (Table 3.1). Expenditure on agricultural research (*GR*) and number of research scientists (*GS*) were obtained from ASTI (IFPRI 2015c) for 1980 to 2012. Agricultural production data were compiled from the World Development Indicators (World Bank 2015a) and FAOSTAT (FAO 2014) as shown in Table 3.1. These include data on agricultural value-added (*Y*); agricultural land area (*D*); agricultural labor (*L*); crop and livestock capital, chemical fertilizers, and feed (*K*); and irrigation (*I*). Data representing $\boldsymbol{Z}^{y}$ were obtained from other sources, including precipitation and agroecological zones from HarvestChoice (2015), population density from World Bank (2015a), and participation in CAADP from AU (2015). The level of technology (*A*) is measured using a time dummy variable representing the level available at specific time periods (1961–1969, 1970–1979, 1980–1989, 1990–1999, and 2000–2102) based on the TFP estimates in Benin and Nin Pratt (2015). We use the quartiles of the estimates as the cutoff points (Table 3.2) to categorize the relative level of technology, where 1 = low if the estimated TFP is less than quartile 1; 2 = medium-low if the estimated TFP is greater than quartile 1 but less than quartile 2; 3 = medium-high if the estimated TFP is greater than quartile 2 but less than quartile 3; and 4 = high if the estimated TFP is greater than quartile 3. Data representing $\boldsymbol{Z}^{G}$ were obtained from two sources: the Worldwide Governance Indicators project for six dimensions of governance (voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption) from 1996 to 2013 (World Bank 2015b); and the Polity IV project on political regime characteristics and transitions for combined (democracy and autocracy) polity score and durability of regime (SCP 2015).

Table 3.1 Description of variables, data, and sources used in estimating productivity effects of public agriculture expenditure

Variable	Description/Disaggregation	Years available	Data sources
Total expenditure (*TE*)	Total government expenditure in constant 2006 US$.	1980 to 2014	IFPRI (2015a&b)
Agricultural expenditure (*GT*)	Government expenditure on agriculture (crops, livestock, forestry, fishery, and research) in constant 2006 US$.	1980 to 2014	IFPRI (2015a&b)
Agricultural research expenditure (*GR*)	National agricultural research expenditure, including salary-related expenses, operating and program costs, and capital investments by government, nonprofit, and higher-education agencies. Original values in current local currency units (LCUs) were deflated using the ratio of gross domestic product (GDP) in constant 2006 US$ to GDP in current LCUs.	1981 to 2011	IFPRI (2015b); World Bank (2015a)
Agricultural research scientists (*GS*)	National agricultural researchers in full-time equivalents.	1981 to 2011	IFPRI (2015c); World Bank (2015a)
Agricultural value-added (*Y*)	Net output (gross output less intermediate inputs) in constant 2006 US$. Original values in current LCUs were deflated using the ratio of GDP in constant 2006 US$ to GDP in current LCUs.	1961 to 2014	World Bank (2015a)
Agricultural land area (*D*)	Hectares of land, including arable land, land under permanent crops, meadows, pastures, and forests.	1961 to 2014	FAO (2015)
Agricultural labor (*L*)	Total economically active population engaged in or seeking work in agriculture, hunting, fishing, or forestry.	1961 to 2012	Benin and Nin Pratt (2015) based on FAOSTAT

Table 3.1 Continued

Variable	Description/Disaggregation	Years available	Data sources
Capital ($K1$)	Sum of gross fixed capital stock in constant 2006 US$: • Crop capital: land development, plantation crops, and machinery and equipment • Livestock capital: animal stock, structures for livestock, and milking machines	1961 to 2012	Benin and Nin Pratt (2015) based on FAOSTAT
Fertilizer ($K2$)	Metric tons of nitrogen, phosphorus, and potassium nutrients consumed.	1961 to 2012	Benin and Nin Pratt (2015) based on FAOSTAT
Animal feed ($K3$)	Metric tons (maize equivalent) of edible commodities fed to livestock.	1961 to 2012	Benin and Nin Pratt (2015) based on FAOSTAT
Rainfall (R)	Total rainfall in millimeters.	1960 to 2013	HarvestChoice (2015)
Irrigation (I)	Share of agricultural area equipped with irrigation.	1960 to 2013	FAO (2015)
Population density (P)	Total population divided by the total land area in persons per square kilometer.	1961 to 2014	World Bank (2015a)
Agroecology (AEZ)	Dummy variable representing the dominant agroecological zone within the country: 1 = subtropic; 2 = tropic, cool, semiarid or arid; 3 = tropic, cool, semihumid or humid; 4 = tropic, warm, semiarid or arid; 5 = tropic, warm, semihumid or humid; 6 = other.	2015	HarvestChoice (2015)
CAADP	Number of years since country signed a CAADP compact, measured in 2012.	2012	AU (2015)
Technology (A)	Dummy variable representing the level of technology at specific time periods (1961–1969, 1970–1979, 1980–1989, 1990–1999, and 2000–2102): 1 = low, 2 = medium-low, 3 = medium-high, 4 = high.	1961 to 2012	Benin and Nin Pratt (2015)
Instruments (Z^G) • Voice • Stability • Effectiveness • Regulation • Law • Corruption	Governance indicators with range -2.5 to 2.5: • Voice and accountability • Political stability and absence of violence • Government effectiveness • Regulatory quality • Rule of law • Control of corruption	1996 to 2013	World Bank (2015b)
 • Polity • Durability	Political regime characteristics: • Combined polity score, -10 to 10 • Durability of regime, number of years	1961 to 2014	SCP (2015)

Source: Author’s description based on cited literature.

Table 3.2 Annual average level of technology in African agriculture, 1961–2012 (index, 1961 = 1.00)

TFP quartile cutoff	1961–1969	1970–1979	1980–1989	1990–1999	2000–2102
0 (minimum TFP)	1.00	1.00	1.00	1.00	1.01
Quartile 1 cutoff	1.03	1.06	1.09	1.13	1.19
Quartile 2 cutoff	1.05	1.10	1.18	1.19	1.28
Quartile 3 cutoff	1.08	1.18	1.24	1.39	1.47
4 (maximum TFP)	1.28	1.52	1.82	2.10	2.65

Source: Author’s calculation based on Benin and Nin Pratt (2015).

Although the data were compiled for all countries in Africa on the various indicators for all years available, the actual panel used in the estimation is dictated by the availability of data on all the relevant indicators for at least 10 consecutive years, with the data on expenditures and governance indicators being the most limiting. Therefore, the final dataset used is an unbalanced panel on 35 countries with respect to total agricultural expenditure and 24 countries with respect to expenditures on agricultural research, as shown in Table 3.3.

Table 3.3 Coverage of countries in the panel data

Expenditure type	Years	Countries
Total agriculture (*GT*)	1996–2012	Benin, Botswana, Burundi, Central African Republic, Chad, Congo–Republic of, Côte d'Ivoire, Ethiopia, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Liberia, Madagascar, Malawi, Mali, Mauritius, Mozambique, Namibia, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia
	1997–2012	Congo–Democratic Republic of
Agricultural research (*GR*)	1996–2011	Benin, Botswana, Burundi, Congo–Republic of, Côte d'Ivoire, Ethiopia, Gambia, Ghana, Guinea, Kenya, Madagascar, Malawi, Mali, Mauritius, Nigeria, Senegal, Sudan, South Africa, Togo, Uganda, Zambia
	2000–2011	Tanzania
	2001–2011	Sierra Leone, Namibia

Source: Author's representation based on IFPRI (2015a, b, c).

Estimation Methods

Because of the panel data, we use a fixed-effects (FE) regression framework, which is suitable for controlling for variables that are time-invariant but vary across countries (denoted by v_i), such as culture and size, or may be time-variant but do not vary across countries (denoted by S_t), such as CAADP and other international agreements. Essentially, the FE estimator is fitting OLS to a transformed version of the model and variables presented in equation 3a, according to

$$(y_{it} - \bar{y}_i + \bar{\bar{y}}) = \alpha + \left(G_{it} - \bar{G}_i + \bar{\bar{G}}\right)\gamma + (\boldsymbol{x}_{it} - \bar{\boldsymbol{x}}_i + \bar{\bar{\boldsymbol{x}}})\boldsymbol{\beta} + (e_{it} - \bar{e}_i + \bar{\bar{e}}) + \bar{v}, \tag{7}$$

where $\bar{y}_i = \sum_{t=1}^{T_i} y_{it}/T_i$ and $\bar{\bar{y}} = \sum_i \sum_t y_{it}/nT_i$ (which are similarly defined for the other variables in equation 8 and $\boldsymbol{x}$ represents all other variables used in the regression, that is, l, k, and $\boldsymbol{Z}^y$), i represents country, the set of parameters ($\alpha, \gamma,$ and $\boldsymbol{\beta}$) are to be estimated, and $\bar{v}$ is calculated as the mean of the individual country heterogeneity obtained from the fitted values using the estimated parameters ($\hat{\alpha}, \hat{\gamma},$ and $\widehat{\boldsymbol{\beta}}$) according to $\hat{v}_i = \bar{y}_i - \hat{\alpha} - \bar{G}_i\hat{\gamma} - \bar{\boldsymbol{x}}_i\widehat{\boldsymbol{\beta}}$.

A fundamental issue is whether to use the FE estimator or the random-effects (RE) estimator, which depends on a combination of the desired estimates and underlying assumptions of the model. With the FE estimator, the main assumption is that the individual country heterogeneity v_i is fixed and correlated with G_{it} or $\boldsymbol{x}_{it}$, which if not controlled for will bias the estimated parameters ($\hat{\alpha}, \hat{\gamma},$ and $\widehat{\boldsymbol{\beta}}$). Furthermore, the error term and individual heterogeneity (e_{it} and v_i) are uncorrelated across countries. The FE estimator, however, cannot be used to investigate the productivity effects of v_i or S_t, as they are absorbed by the constant term α. With the RE estimator, on the other hand, the main assumption is that v_i is random and uncorrelated with G_{it} or $\boldsymbol{x}_{it}$, and so its effect can be directly estimated. Therefore, v_i needs to be specified. This can be problematic if the variable is not available and may then lead to omitted variable bias in the estimated parameters. We use the FE estimator in this paper but test it against the RE estimator using the Hausman test (Greene 1993), which is basically a test of whether v_i is correlated with G_{it} and $\boldsymbol{x}_{it}$.

We assess the productivity effects of different types of agriculture expenditure (*G*), first considering the aggregate effect of total agriculture expenditure (*GT*), and then separately for agricultural research expenditure (*GR*) and agricultural nonresearch expenditure (*GNR*). More on this later. For now, we continue with the discussion of the estimation issues using the conceptual variable *G*. As discussed in the conceptual framework, a major issue with the estimation is addressing endogeneity of *G*. The FE estimator addresses some of it to the extent that the endogeneity is due to omitted, time-invariant variables. Potential endogeneity due to simultaneity of *y* and *G* is addressed using IV or 2SLS within the FE estimation. The IV or 2SLS method is very challenging to implement. It entails finding variables or instruments that are correlated with expenditures G_{it} but not correlated with the error term e_{it}. The instruments in addition to all the other exogenous variables in equation 7 are used in a first-stage estimation of G_{it}, and then the results are used in a second-stage estimation of equation 8. Because use of weak instruments causes IV estimators to be biased and low statistical significance of the estimated parameters (Greene 1993), we try each of the governance and democracy variables (Z^G), as well as combinations of them, and use several statistical tests to test exogeneity of G_{it} in equation 7 and validity of the instruments in the first-stage regression. The tests include the Shea partial *R*-squared test of exogeneity, the Kleibergen-Paap rank tests of weak identification, and the Anderson-Rubin and Stock-Wright joint tests of exogeneity and overidentification (Schaffer 2010).

With respect to potential endogeneity of *G* deriving from measurement errors, because of data constraints on suitable instruments or proxies, we assess the effect of this source of endogeneity with the estimation of the impact of spending on agricultural research (*GR*), where we use the number of researchers (*GS*) as a proxy for *GR*. The measurement errors could be quite significant in some countries. For example, expenditure on agricultural subsidies (call this *GD*) could be financed outside the conventional agricultural-sector budget, which may lead to underestimation of total agriculture expenditure (*GT*) and overestimation of nonagricultural expenditure, which is $NGT = TE - GT$, to the extent that the subsidies are financed within the total government expenditure (*TE*). This means that the estimated productivity effect of agricultural spending using *GT* may be underestimated if the effect of *GD*, conditioned on the other factors, is positive, and vice versa. Similarly, the true effect of nonagricultural expenditure may be overestimated. Estimating agricultural nonresearch expenditure (*GNR*) from total agriculture expenditure and agricultural research expenditure (that is, $GNR = GT - GR$) is tricky because *GT* and *GR* are from different sources. Whereas *GT* is based on total government expenditure on the agricultural sector including crops, livestock, forestry, fishery, and research on the aforementioned subsectors, *GR* includes agricultural research expenditure by government, nonprofit, and higher-education agencies (see Table 3.1 for details). Therefore, *GR* is not a strict subset of *GT*, as *GR* includes nongovernment expenditure. Therefore, the productivity effect of *GNR* is not directly estimated but inferred from the estimated effects of *GR*, controlling for *GT*.

Another issue to deal with is whether to use levels of expenditure (that is, *TE*, *GT*, *GR*, and *GS*) or their per unit area equivalents (that is, *te*, *gt*, *gr*, and *gs*, where $te = TE/D$, $gt = GT/D$, $gr = GR/D$, and $gs = GS/D$), as done with the other continuous explanatory variables $\boldsymbol{x}$. Because public goods and services deriving from public expenditure are generally nonrival for users, it is the level (that is, *G*) rather than the per unit amount (that is, *g*) that matters. Due to the cross-section component of the panel data, however, it is computationally desirable to use the per unit area values in order to control for cross-country variation in the levels that may derive from cross-country differences in observable factors, such as size of the country or the agricultural sector. Therefore, we use the per unit equivalents of *G* (that is, *te*, *gt*, *gr*, and *gs*) in the estimation, where the level of each variable is divided by the agricultural land area (*D*), except for *te*, which is *TE* divided by total population. Similarly, per capita nonagricultural expenditure (*ngt*) is obtained from *NGT* divided by total population.

To address the lagged effect of public spending, we include past values of *G* as explanatory variables, which, because they are predetermined compared to any time period *t*, do not suffer from endogeneity. We try up to a 10-year lag in line with the Holtz-Eakin, Newey, and Rosen (1988) recommendation of the lag length being less than a third of the total time span of the data, but use the Akaike information criterion (AIC) and adjusted *R*-squared to determine the appropriate lag length

(Greene 1993). The optimal lag length is determined by the minimum AIC and maximum adjusted *R*-squared, which we found to be around five years. Including all the lags at the same time in the model, as with having many explanatory variables in any regression model, could lead to multicollinearity problems that result in unstable and inefficient (that is, large standard errors) parameter estimates (Greene 1993). We do not find multicollinearity to be a problem with estimating the effect of total agriculture expenditure (*gt*), since the estimated parameters are of generally high statistical significance, and the value of the largest variance inflation factor associated with the explanatory variables in the various equations is less than 20, the value suggested by Kennedy (1985) to use as the cutoff point for indication of multicollinearity. With the estimation of the effect of agricultural research expenditure (*gr*), however, multicollinearity is a problem when the lags of *gr* are included in the regression model. To tackle this, we use the lagged values of *gr* (that is, gr_{t-1}, gr_{t-2}, …, gr_{t-N}) to first construct a capital stock variable (sgr_t), which is then used in addition to the current expenditure (gr_t) in the estimation of equation 7. Following Griliches (1980), Fan (2008), and others, capital stock in agricultural research (sgr_t) is created according to

$$sgr_t = (1-\rho)sgr_{t-1} + \hat{\tau}gr_{t-1} \tag{8a}$$

$$sgr_{1980} = \frac{gr_{1980}}{\rho+\sigma}, \tag{8b}$$

where ρ is the stock depreciation rate (which we set at 10 percent), $\hat{\tau}$ is the capital formation rate, σ is the investment growth rate prior to 1980 (which we assume to be the same as the annual average growth rate in *gr* from 1980 to 2012, about 3.5 percent for all the countries taken together), and gr_{1980} and sgr_{1980} are our starting values of expenditure and capital stock in the data, respectively. The capital formation rate ($\hat{\tau}$) is estimated from a regression of researchers per hectare (gs_t) on the lag of research expenditure per hectare (gr_{t-1}), which is 0.23—meaning that 23 percent of expenditure on agricultural research is transformed into capital.

Because we are using panel data (that is, cross-section and time-series data), other issues arise, particularly serial correlation and heteroskedasticity of the error term, which if present may render the estimates inconsistent, even after correcting for endogeneity of *G*. Serial correlation, which is relevant for time-series data analysis, means that the unobservable factors in one period are correlated with the unobservable factors in a subsequent period (that is, e_t and e_{t-1} are correlated or e_t and e_{t-j} are correlated for autocorrelation in general). Heteroskedasticity, on the other hand, typically applies to cross-sectional data analysis, where the variance of the error term is not constant across the values of the explanatory variables. These problems lead mostly to underestimation of the standard errors and overestimation of the student *t*-statistics, and we correct for them by clustering the standard errors (Wooldridge 2013) using three types of clusters—each country, different countries within the same agroecological zone, and different countries with the same number of years of participation in CAADP. Because clustering the standard errors tends to result in larger standard errors and lower statistical significance of the estimated parameters, which we find to be true with the estimates obtained here, we attach greater confidence to the parameter estimates that are statistically significant at the 10 percent level or lower. Nevertheless, we report the statistical significance of the estimated parameters with both nonclustered and clustered standard errors.

All continuous variables used in the estimation (that is, *y*, *l*, *k1, k2, k3*, *R*, *P*, *ngt*, *gt*, *gr*, and *gs*) were transformed by natural logarithm, so that their respective estimated coefficients within $\hat{\gamma}$ and $\hat{\boldsymbol{\beta}}$ are interpreted as elasticities, which is a unitless measure meaning percent change in *y* due to a 1 percent change in the explanatory variable. The estimated elasticities with respect to total agricultural expenditure and agricultural research expenditure (that is, $\hat{\beta}_{gt}$ and $\hat{\beta}_{gr}$) are then used to estimate their respective ROR as given in equation 5. The RORs are obtained for all the countries taken together, for countries grouped by agroecological zone, for countries grouped by number of years of participation in CAADP, and then for individual countries as done in Thirtle, Piesse, and Lin (2003) and Alene and Coulibaly (2009), for example. The regressions were done with STATA software version 14.0 (StataCorp 2015) using mostly the xtivreg2 estimation and postestimation commands (Schaffer 2010). The RORs were estimated using the IRR command function in Excel spreadsheet.

To summarize the empirical methods used to assess the impact of agricultural public spending, we estimate an aggregate agricultural production function of two general forms: one that includes current and lagged values of total agricultural expenditure per hectare (gt_t, gt_{t-1}, …, gt_{t-5}); and another that includes current agricultural research expenditure per hectare (gr_t) and capital stock (sgr_t, which is derived from lagged values of *gr*). The effect of nonagricultural expenditure per capita (*ngt*) and other factors $\boldsymbol{x}$ are controlled for. Panel data on 34 countries in SSA from 1980 to 2012 and an FE estimator are used to estimate the effects and to address potential endogeneity of agricultural expenditure that may derive from omitted, time-invariant variables. Potential endogeneity of agricultural expenditure that may derive from simultaneity is addressed with instrumental variables on governance and political processes, whereas potential endogeneity deriving from measurement error is addressed by using the number of researchers per hectare (*gs*) as a proxy for agricultural research expenditure per hectare (*gr*). Potential serial correlation and heteroskedasticity of the error term are addressed by clustering the standard errors using three types of clusters—each country, different countries within the same agroecological zone, and different countries with the same number of years of participation in CAADP. Various statistical tests are used to test the exogeneity of expenditures, validity of the instruments used to identify expenditures, and multicollinearity of the explanatory variables. The estimated elasticities with respect to expenditure are then used to estimate the ROR for different groups of countries and for individual countries.

4. RESULTS AND DISCUSSION

Summary Statistics

Table 4.1 shows descriptive statistics of the variables used in the estimation, presented separately for the panel used to estimate the impact of total agricultural spending (34 countries from 1996 to 2012) and then for the panel used to estimate the impact of agricultural research spending (23 countries from 1996 to 2011). The data on many of the variables show an increasing or improving trend over time, with a few of the variables showing stagnation or deterioration in the trend. Looking at statistics on all 34 countries, annual average agricultural value-added per hectare (that is, land productivity) was US$159 in 1996–2012, rising by 24 percent from US$141 in 1996–2003 (pre-CAADP period) to US$175 in 2004–2012 (during CAADP).5 Agriculture expenditure per hectare almost doubled from US$4.5 in 1996–2003 to US$8.3 in 2004–2012. This represents an increase in the share of agriculture expenditure in total expenditure from 2 percent to 2.8 percent, respectively, far lower than the 10 percent Maputo Declaration target. Agricultural research expenditure per hectare remained stagnant at US$1, which represents a decline in the share in total agricultural spending from 19 percent in 1996–2003 to 12 percent in 2004–2011. Looking at spending intensities, agricultural expenditure as a share of agricultural value-added increased from 3.2 percent in 1996–2003 to 4.7 percent in 2004–2012, whereas agricultural research expenditure as a share of agricultural value-added declined from 0.7 percent in 1996–2003 to 0.6 percent in 2004–2012. With the exception of rainfall and irrigation, whose averages remained stagnant over the two subperiods, the data on other variables (labor, capital, fertilizer, animal feed, and population density) show an increase between 14 and 45 percent. Regarding the level of technology, there is little change in the distribution of countries over time according to the four-level classification of technology, with slightly more of the countries being classified as having medium-low or medium-high technology compared with those with low or high technology. The distinction is more pronounced in the panel dataset used to estimate the impact of agricultural research spending.

Table 4.1 Summary statistics of variables, 1996–2012

	Panel for analyzing impact of total agricultural spending			Panel for analyzing impact of agricultural research spending		
Variable	**1996–2012**	**1996–2003**	**2004–2012**	**1996–2011**	**1996–2003**	**2004–2011**
Agricultural value-added, US$/ha (*y*)	158.72	140.74	174.69	154.05	140.02	167.02
Agricultural expenditure, US$/ha (*gt*)	6.48	4.47	8.25	6.98	4.94	8.86
Agricultural research expenditure, US$/ha (*gr*)	n.e.	n.e.	n.e.	1.00	0.96	1.03
Agricultural research capital, US$/ha (*sgr*)	n.e.	n.e.	n.e.	4.00	4.79	3.27
Nonagricultural expenditure, US$/capita (*ngt*)	257.21	224.18	286.56	289.48	254.90	321.42
Agricultural labor, number per hectare (*l*)	0.37	0.35	0.40	0.37	0.35	0.39
Agricultural capital, US$/ha (*k1*)	502.18	462.05	537.83	520.03	483.31	553.96
Fertilizer, kg/ha (*k2*)	2.79	2.59	2.97	3.52	3.48	3.55
Animal feed, kg/ha (*k3*)	59.64	48.09	69.90	67.19	57.72	75.94
Rainfall, mm (*R*)	1078.41	1074.38	1081.99	1013.82	996.68	1029.65
Irrigation, share (*I*)	0.01	0.01	0.01	0.01	0.01	0.01
Population density, number per sq. km (*P*)	67.73	59.24	75.26	72.45	65.63	78.75

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[5] All monetary values are 2006 constant prices to remove the effect of inflation.

Table 4.1 Continued

Variable	Panel for analyzing impact of total agricultural spending 1996–2012	 1996–2003	 2004–2012	Panel for analyzing impact of agricultural research spending 1996–2011	 1996–2003	 2004–2011
Technology, share (A)						
Low	0.24	0.25	0.24	0.20	0.19	0.22
Medium-low	0.27	0.27	0.27	0.28	0.31	0.26
Medium-high	0.26	0.27	0.26	0.32	0.34	0.30
High	0.23	0.22	0.24	0.19	0.16	0.22
Instruments (Z^G)						
Voice, -2.5 to 2.5	-0.67	-0.74	-0.61	-0.51	-0.57	-0.45
Law, -2.5 to 2.5	-0.81	-0.85	-0.76	-0.63	-0.64	-0.62
Regulation, -2.5 to 2.5	-0.66	-0.67	-0.64	-0.50	-0.49	-0.51
Stability, -2.5 to 2.5	-0.73	-0.82	-0.64	-0.59	-0.63	-0.55
Effectiveness, -2.5 to 2.5	-0.77	-0.76	-0.77	-0.63	-0.61	-0.65
Corruption, -2.5 to 2.5	-0.68	-0.68	-0.68	-0.57	-0.54	-0.59
Polity, -10 to 10	1.55	0.78	2.22	2.33	1.48	3.12
Durability, years	8.60	6.33	10.62	8.48	6.74	10.09
Number of observations	576	576	576	354	354	354
Number of countries	34	34	34	23	23	23

Source: Author's representation based on model results.
Note: See Table 3.1 for detailed description of variables. US$ are in 2006 constant prices. n.e. = not estimated as data are not available for some countries in panel.

Regarding the instruments, slight improvements are evident in voice and accountability, rule of law, regulatory quality, and political stability and absence of violence for the governance indicators. We see no change in either the level of government effectiveness or control of corruption. As for the political regime characteristics, democracy increased and the average number of years that a government stays in power increased from six in 1996–2003 to about 11 in 2004–2012.

Estimated Elasticity of Land Productivity with Respect to Agricultural Public Spending

The estimated elasticities with respect to agricultural public spending and other factors using the FE estimator are presented in Tables 4.3 and 4.4. First, let us look at the results related to addressing the potential endogeneity of the expenditures, which are presented in Table 4.2.

Instruments and Determinants of Agricultural Expenditure

All of the eight potential instruments were tried in the estimation, but only two worked very well in terms of meeting both requirements of being correlated with expenditure (*gt* or *gr*) and orthogonal to the error term. These two instruments are stability for the estimation of the impact of total agricultural expenditure (*gt*) and polity for the estimation of the impact of agricultural research expenditure (*gr*). The IV tests shown in Table 4.2 confirm this. The test of endogeneity of expenditure, however, is rejected, implying that total agricultural expenditure (*gt*) and agricultural research expenditure (*gr*) are in fact exogenous in the model specification. This means that the impact of agricultural spending can be consistently estimated with the regular FE model, and that estimation by IV may not bring any improvements—more on this later. With weak instruments, however, estimation by IV may introduce bias (Greene 1993).

Table 4.2 First-stage results of fixed-effects, instrumental variables regression of agricultural spending in SSA, 1996–2012

Explanatory variable	Agricultural expenditure, US$/ha (*gt*)		Agricultural research expenditure, US$/ha (*gr*)			
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Lags of agricultural expenditure						
gt_{t-1}	0.58 ***	0.57 ***		0.10 ***		0.08 **
gt_{t-2}	0.01	0.01				
gt_{t-3}	-0.06	-0.06				
gt_{t-4}	0.04	0.04				
gt_{t-5}	-0.07 *	-0.07 *				
Total elasticity‡	0.49 ***	0.49 ***				
Agricultural research capital (*sgr*)			0.52 ***	0.49 ***	0.54 ***	0.52 ***
Nonagricultural expenditure (*ngt*)	0.44 ***	0.44 ***	-0.02	-0.02	-0.02	-0.02
Lag of agricultural value-added (y_{t-1})		-0.06			-0.59 ***	-0.56 ***
Agricultural labor (*l*)	0.30	0.35	0.29	0.48	0.31	0.44
Agricultural capital (*k1*)	0.50 **	0.50 **	0.00	-0.09	0.19	0.11
Fertilizer (*k2*)	0.00	0.00	-0.03 *	-0.03 *	-0.02	-0.02
Animal feed (*k3*)	-0.10	-0.10	0.12	0.14	0.17 *	0.18 *
Rainfall (*R*)	-0.18	-0.17	-0.07	-0.06	-0.04	-0.03
Irrigation (*I*)	19.36	17.51	-57.06 ***	-49.01 **	-65.50 ***	-59.04 ***
Population density (*P*)	0.45 *	0.50 *	0.52 *	0.12	0.82 ***	0.51 *
Technology (*A*), cf. low						
Medium-low	0.11	0.12	0.17	0.13	0.22 **	0.19 *
Medium-high	0.05	0.05	0.05	0.04	0.01	0.00
High	-0.05	-0.06	-0.04	-0.04	-0.09	-0.08
Instruments (Z^G)						
Stability	0.15 ***	0.15 ***				
Polity			0.03 ***	0.03 ***	0.03 ***	0.03 ***
Overall model statistics						
R-squared	0.74	0.74	0.20	0.22	0.26	0.27
F-statistic	82.21 ***	77.57 ***	5.99 ***	6.28 ***	7.98 ***	7.84 ***
IV tests:						
Expenditure is exogenous (χ^2 statistic)	2.22	0.28	0.00	0.02	0.21	0.22
Underidentified (χ^2 statistic)	15.58 ***	15.58 ***	15.90 ***	16.94 ***	15.72 ***	16.51 ***
Instrument is weak (*F*-statistic)	15.53 ***	16.39 ***	16.05 ***	17.10 ***	15.80 ***	16.59 ***

Source: Author's representation based on model results.

Note: See Table 3.1 for detailed description of variables. All continuous variables are transformed by natural logarithm. US$ are in 2006 constant prices. ‡ Total elasticity is obtained by summing elasticities with respect to gt_{t-1}, …, and gt_{t-5}. For IV (instrumental variables) tests, the null hypothesis that expenditure is exogenous = that agricultural expenditure (*gt*) or agricultural research expenditure (*gr*) can be treated as exogenous using the Sargan-Hansen χ^2 statistic; = rank of matrix of first-stage reduced-form coefficients is underidentified, using the Anderson or Kleibergen-Paap Lagrange multiplier test with the χ^2 statistic; and weak = first-stage reduced-form equation is weakly identified using the Cragg-Donald or Kleibergen-Paap Wald test with the *F*-statistic.

As the results in Table 4.2 show, greater stability and absence of violence is significantly associated with higher total agricultural spending, whereas greater polity (or more democracy in the autocracy–democracy regime continuum) is significantly associated with higher agricultural research spending.[6] The results are consistent in different model specifications of the overall exogenous

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[6] Note that the other instruments tried also had positive associations with agricultural spending, some with greater statistical significance than others. In the case of total agricultural expenditure, for example, those with significant effects include rule of

explanatory variables, involving exclusion or inclusion of the lag of value-added per hectare (y_{t-1}) in the estimation of both the impact of total agricultural expenditure (*gt*) and agricultural research expenditure (*gr*), and exclusion or inclusion of the lag of total agricultural expenditure (gt_{t-1}) in the estimation of the impact of agricultural research expenditure (*gr*).

Past expenditure significantly determines current expenditure, which supports the notion of continuing to spend according to the existing trend. In the case of total agricultural expenditure, for example, the immediate past expenditure is the most important. Nonagricultural expenditure significantly influences total agricultural expenditure, but it had no direct effect on agricultural research expenditure. The effect of nonagricultural expenditure on agricultural research expenditure is indirect via the effect of the lag of total agricultural expenditure (gt_{t-1}).

The effect of the other nonexpenditure variables is mixed. For example, whereas population density has a significant positive association with both total agricultural expenditure and agricultural research expenditure, capital has a significant positive association with total agricultural expenditure only, and irrigation and lag of value-added per hectare (y_{t-1}) have strongly significant negative associations with agricultural research expenditure, which reflects substitution among different types of agricultural expenditure in general. Fertilizer and animal feed also have weakly significant but opposite associations with agricultural research expenditure.

Elasticity of Land Productivity with Respect to Total Agricultural Expenditure

Table 4.3 shows detailed results of the regression estimates—both regular FE estimation and FE-IV estimation—using different model specifications (that is, exclusion or inclusion of the lag of value-added per hectare, y_{t-1}), and clustering of the standard errors by different variables. The finding that endogeneity of total agricultural expenditure (*gt*) is rejected, implying that total agricultural expenditure can be treated as exogenous, is upheld when the standard errors are clustered by different variables (that is, for each country, for countries with the same years of participation in CAADP, and for countries in the same agroecological zone). Because the FE estimator addresses endogeneity due to omitted, time-invariant variables, additional endogeneity that may be due to simultaneity of *y* and *gt* seems to have been reduced or eliminated, rendering the need for FE-IV estimation unnecessary. Nevertheless, results from that estimation are presented for comparative analysis.

The model specification that includes the lag of value-added per hectare (y_{t-1}) gives much higher explanatory power, with *R*-squared values ranging from 0.77 to 0.92 and an *F*-statistic of 89.3, compared with specification without it, with *R*-squared values ranging from 0.57 to 0.71 and an *F*-statistic of 38.27. The total elasticity with respect to agricultural expenditure per hectare is estimated at 0.04, which is more consistently estimated with the specification that includes the lag of value-added per hectare and whether or not the standard errors are clustered. This means that a 1 percent increase in agricultural expenditure per hectare is associated with a 0.04 percent increase in agricultural value-added per hectare, or land productivity. Compared with findings from other cross-country studies, this is lower than the estimated elasticity of 0.08 in Fan, Yu, and Saurkar (2008), for example.

Including the lag of value-added per hectare in the model seems to help reduce potential omitted variable bias, as shown by the higher *R*-squared values. However, including the lag of value-added per hectare in the model absorbs the effects of several of the other explanatory variables, particularly labor, fertilizer, rainfall, irrigation, population density, and technology. For example, the magnitudes of the estimated coefficients on these variables were higher in the specification without the lag of value-added per hectare (FE model 1) than in the specification with it (FE model 2). Furthermore, the statistical significance of the estimated coefficients was lower or eliminated when the lag of value-added per hectare was included. Because we are more interested in the impact of agricultural expenditure, these differences are secondary in the paper, as long as other factors that affect land productivity are adequately accounted

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law, government effectiveness, regulatory quality, and control of corruption. Voice and accountability, polity, and durability of regime had no significant effect. In the case of agricultural research expenditure, voice and accountability and stability and absence of violence were the only ones that had significant effects.

for, as the results of FE model 2 show. With this specification then, only irrigation and population density have direct effects on land productivity. The estimated negative effect of the irrigation variable must be interpreted with caution. Because the irrigation variable used here is a measure of the share of agricultural area fitted with irrigation systems, rather than a measure of actual amount of irrigation water applied, the variable may be capturing the vulnerability of production systems that are intended to depend on irrigation but may not necessarily be operating as such due to water-availability problems. Note the positive effect of rainfall in FE model 1.

Briefly looking at the results from the FE-IV estimation, we see that the pattern of the magnitudes and the statistical significance of estimates discussed above with respect to exclusion or inclusion of the lag of value-added per hectare and with clustering of the standard errors still holds. The main difference is with the estimated elasticity with respect to agricultural expenditure, which is higher: 0.13 in the specification without the lag of value-added per hectare, but statistically significant when the standard errors are not clustered or clustered by country only (FE-IV model 1); and 0.6 in the specification with the lag of value-added per hectare, although not statistically significant whether or not the standard errors are clustered (FE-IV model 2).

Table 4.3 Fixed-effects estimates of impact of total agricultural spending on agricultural value-added per hectare in SSA, 1996–2012

Explanatory variables	**Fixed-effects only**						**Fixed effects, instrumental variables**					
	FE model 1			**FE model 2**			**FE-IV model 1**			**FE-IV model 2**		
Agricultural expenditure												
gt_t	-0.01			0.00			0.17			0.04		
gt_{t-1}	-0.01			0.01			-0.11			-0.02		
gt_{t-2}	0.03		r c a	0.02		a	0.03		c a	0.02		c a
gt_{t-3}	-0.03		r c a	-0.03	*	r c a	-0.02			-0.03		r c a
gt_{t-4}	0.00			0.01			-0.01			0.00		
gt_{t-5}	0.07	***	r c a	0.04	***	r c a	0.08	***	r c a	0.04	***	r c a
Total elasticity‡	0.04	**		0.04	**	r c a	0.13	**	r	0.06		
Nonagricultural expenditure (*ngt*)	-0.08	***	r c a	-0.01			-0.16	**	r	-0.03		
Lag of agricultural value-added (y_{t-1})				0.65	***	r c a				0.65	***	r c a
Agricultural labor (*l*)	0.83	***	r	0.21			0.75	***	r c a	0.19		c a
Agricultural capital (*k1*)	0.06			0.07			-0.02			0.05		
Fertilizer (*k2*)	0.02	**	a	0.01		a	0.02	*	r a	0.01		a
Animal feed (*k3*)	0.03			0.01			0.04			0.02		
Rainfall (*R*)	0.14	**		0.05			0.17	***	r c	0.06		
Irrigation (*I*)	-35.31	***	r c	-14.44	*	r c	-37.02	***	r c a	-14.83	*	r c
Population density (*P*)	0.77	***	r c a	0.26	***	r c a	0.70	***	r c a	0.24	**	r c a
Technology (*A*), cf. low												
Medium-low	0.11	**	r c a	0.00			0.08		r c a	-0.01		
Medium-high	0.04			-0.03		a	0.01			-0.04		c a
High	-0.14	*	r	-0.07		r a	-0.14	*	r a	-0.07		r c a
Intercept	2.36	***		0.36								
Overall model statistics												
R-squared (within)	0.57			0.77			0.51			0.77		
R-squared (between)	0.71			0.93								
R-squared (overall)	0.70			0.92								
F-statistic	38.27	***	r	89.29	***	r	33.71	***	r c	87.83	***	r c a
IV tests:												
gt is exogenous (χ^2 statistic)							2.22			0.28		
Underidentified (χ^2 statistic)							15.58	***	r c a	15.87	***	r c a
Instrument is weak (*F*-statistic)							15.53	***	r c a	15.80	***	r c a

Source: Author's representation based on model results.

Note: See Table 3.1 for detailed description of variables. All continuous variables are transformed by natural logarithm. US$ are in 2006 constant prices. ‡ Total elasticity is obtained by summing elasticities with respect to gtt, gtt-1, …, and gtt-5. For instrumental variables (IV), instrument used is stability. For IV tests: the null hypothesis that gt is exogenous = that agricultural expenditure (gt) can actually be treated as exogenous using the Sargan-Hansen $\chi 2$ statistic; underidentified = rank of matrix of first-stage reduced-form coefficients is underidentified, using the Anderson or Kleibergen-Paap Lagrange multiplier test with the $\chi 2$ statistic; and weak = first-stage reduced-form equation is weakly identified using the Cragg-Donald or Kleibergen-Paap Wald test with the F-statistic. *, **, and *** represent statistical significance at the 0.1, 0.5, and 0.01 probability level, respectively, for nonclustered standard errors. r, c, and a represent statistical significance at the 0.1 or higher probability level for clustered standard errors by country (r), countries with the same years of participation in CAADP (c), and countries within the same agroecological zone (a).

Elasticity of Land Productivity with Respect to Agricultural Research Expenditure

Table 4.4 shows detailed results of the regression estimates, which also are presented for estimation by regular FE and FE-IV, again for different specifications (that is, exclusion or inclusion of the lag of value-added per hectare, y_{t-1}), and clustering of the standard errors by different variables. Because we are interested in estimating the impact of agricultural research expenditure (*gr*), it is important to control for agricultural nonresearch expenditure, which we do not have as discussed in the data section. Therefore, we consider exclusion or inclusion of the lag of total agricultural expenditure (gt_{t-1}) as another variable in the specification of the regression model.

The implications of rejection of endogeneity of agricultural research expenditure (*gr*) and the pattern of the magnitudes and statistical significance of estimates with respect to exclusion or inclusion of the lag of value-added per hectare (y_{t-1}) and with the clustering of the standard errors are similar to the previous findings. Basically: the model specification that includes the lag of value-added per hectare gives much higher explanatory power; including the lag of value-added per hectare, however, absorbs the effects of several of the other explanatory variables, particularly capital, fertilizer, rainfall, irrigation, population density, and technology; and the statistical significance of the estimated elasticity with respect to agricultural research expenditure is not affected whether or not the standard errors are clustered. In addition, exclusion or inclusion of the lag of total agricultural expenditure (gt_{t-1}) has no effect on the estimates.

The total elasticity of land productivity with respect to agricultural research expenditure per hectare is estimated at 0.09, which means that a 1 percent increase in agricultural research expenditure per hectare is associated with a 0.09 percent increase in agricultural value-added per hectare, or land productivity. Compared with other cross-country studies, for example, this is lower than the estimated elasticity of 0.17 in Alene and Coulibaly (2009) and 0.36 in Thirtle, Piesse, and Lin (2003) but higher than 0.04 in Fan, Yu, and Saurkar (2008). Those studies used simultaneous equation systems in their estimations, as they were interested in the impact of expenditure on other development outcomes such as income and poverty. In addition, potential endogeneity of explanatory variables was mostly addressed using their lagged values as instruments, invoking weak exogeneity.

Comparative analysis of the results from the FE and FE-IV estimations is generally similar to that of the case of the estimation of impact of total agricultural expenditure. The main difference here is that the estimated elasticity with respect to agricultural research expenditure from the FE-IV estimation (0.07–0.08) is quite close to that from the FE estimation (0.09), although the results are not statistically significant except for when the standard errors are clustered by countries within the same agroecological zone. This is again consistent with the notion that estimation by FE-IV does not bring any improvements following valid rejection of endogeneity of agricultural research expenditure.

Table 4.4 Fixed-effects estimates of impact of agricultural research spending on agricultural value-added per hectare in SSA, 1996–2011

Explanatory variable	FE model 1			FE model 2			FE model 3			FE model 4		
Agricultural research expenditure (gr)	-0.06	***		-0.06	**		0.02			0.02		
Agricultural research capital (sgr)	0.14	***	r c a	0.15	***	r c a	0.08	**	r c a	0.08	**	r c a
Total elasticity‡	0.08	**		0.09	**		0.09	***	r c a	0.09	***	r c a
Lag of agricultural expenditure (gt_{t-1})				-0.03						0.00		
Nonagricultural expenditure (ngt)	0.01			0.01			0.01			0.01		
Lag of agricultural value-added (y_{t-1})							0.63	***	r c a	0.63	***	r c a
Agricultural labor (l)	0.05			0.00			0.01			0.00		
Agricultural capital ($k1$)	0.41	***	r c a	0.44	***	r c a	0.20	***	r c a	0.20	***	r c a
Fertilizer ($k2$)	0.02	**	a	0.02	**	a	0.01		a	0.01		a
Animal feed ($k3$)	0.07			0.06			0.01			0.01		
Rainfall (R)	0.10	*	c	0.09		c	0.06			0.06		
Irrigation (I)	-19.77	**	r c a	-21.58	**	r c a	-7.11		c	-7.35		c
Population density (P)	0.60	***	r c a	0.69	***	r c a	0.24	**	r c a	0.25	**	r c a
Technology (A), cf. low												
Medium-low	0.05			0.06			-0.02			-0.02		
Medium-high	-0.10	**		-0.10	*		-0.05		r c a	-0.05		r c a
High	-0.12	*	c	-0.12	*	c	-0.06		r c	-0.06		r
Intercept	-0.90			-1.40		a	-0.85			-0.91		
Overall model statistics												
R-squared (within)	0.54			0.54			0.73			0.73		
R-squared (between)	0.83			0.84			0.97			0.97		
R-squared (overall)	0.83			0.83			0.96			0.96		
F-statistic	27.89	***	r	26.18	***	r	60.54	***	r	56.34	***	r

Source: Author's representation based on model results.

Note: See Table 3.1 for detailed description of variables. All continuous variables are transformed by natural logarithm. US$ are in 2006 constant prices. ‡ Total elasticity is obtained by summing elasticities with respect to *gr* and *sgr*. *, **, and *** represent statistical significance at the 0.1, 0.5, and 0.01 probability level, respectively, for nonclustered standard errors. [r], [c], and [a] represent statistical significance at the 0.1 or higher probability level for clustered standard errors by country (r), countries with the same years of participation in CAADP (c), and countries within the same agroecological zone (a).

Table 4.4 Continued

Explanatory variable	FE-IV model 1					FE-IV model 2					FE-IV model 3					FE-IV model 4				
Agricultural research expenditure (*gr*)	-0.07					-0.07					-0.02					-0.02				
Agricultural research capital (*sgr*)	0.15	**	r	c		0.15	**	r	c		0.09	*	r	c	a	0.09	*	r	c	a
Total elasticity[‡]	0.08			c		0.08			c		0.07			c		0.07			c	
Lag of agricultural expenditure (gt_{t-1})						-0.02										0.00				
Nonagricultural expenditure (*ngt*)	0.01					0.01					0.01				a	0.01				a
Lag of agricultural value-added (y_{t-1})											0.61	***	r	c	a	0.61	***	r	c	a
Agricultural labor (*l*)	0.06					0.01					0.02					0.02				
Agricultural capital (*k1*)	0.41	***	r	c	a	0.43	***	r	c	a	0.21	***	r	c	a	0.21	***	r	c	a
Fertilizer (*k2*)	0.02	**	r		a	0.02	**	r	c	a	0.01				a	0.01				a
Animal feed (*k3*)	0.07					0.06					0.01				a	0.01				a
Rainfall (*R*)	0.10	*	r	c		0.09	*	r	c		0.06			c		0.06			c	
Irrigation (*I*)	-19.92	**	r	c	a	-22.11	**	r	c	a	-8.55			c		-8.49			c	a
Population density (*P*)	0.60	***	r	c	a	0.69	***	r	c	a	0.26	**	r	c	a	0.26	**	r	c	a
Technology (*A*), cf. low																				
Medium-low	0.05					0.06				a	-0.01					-0.01				
Medium-high	-0.10	**	r	c		-0.09	*	r	c	a	-0.06		r	c	a	-0.06		r	c	a
High	-0.12	*	r	c	a	-0.12	*	r	c	a	-0.06			c	a	-0.06			c	a
Overall model statistics																				
R-squared (within)	0.53					0.54					0.73					0.73				
F-statistic	27.18	***	r	c	a	25.61	***	r	c	a	59.52	***	r	c		55.38	***	r	c	a
IV tests:																				
gr is exogenous (χ^2 statistic)	0.00					0.02					0.21					0.22				
Underidentified (χ^2 statistic)	15.90	***	r	c	a	16.94	***	r	c	a	15.72	***	r	c	a	16.51	***	r	c	a
Instrument is weak (*F*-statistic)	16.05	***	r			17.10	***	r			15.80	***	r			16.59	***	r		

Source: Author’s representation based on model results.

Note: See Table 3.1 for detailed description of variables. All continuous variables are transformed by natural logarithm. US$ are in 2006 constant prices. [‡] Total elasticity is obtained by summing elasticities with respect to *gr* and *sgr*. For instrumental variables (IV), the instrument used is polity. For IV tests, the null hypothesis that *gr* is exogenous = that agricultural research expenditure (*gr*) can actually be treated as exogenous using the Sargan-Hansen χ^2 statistic; underidentified = rank of matrix of first-stage reduced-form coefficients is underidentified, using the Anderson or Kleibergen-Paap Lagrange multiplier test with the χ^2 statistic; and weak = first-stage reduced-form equation is weakly identified using the Cragg-Donald or Kleibergen-Paap Wald test with the *F*-statistic. *, **, and *** represent statistical significance at the 0.1, 0.5, and 0.01 probability level, respectively, for nonclustered standard errors. [r], [c], and [a] represent statistical significance at the 0.1 or higher probability level for clustered standard errors by country (r), countries with the same years of participation in CAADP (c), and countries within the same agroecological zone (a).

Rates of Return to Agricultural Public Spending

Based on the estimated elasticities of 0.04 and 0.09 for total agricultural expenditure and agricultural research expenditure, respectively, we calculated the RORs for all the countries together, for countries with the same number of years of participation in CAADP, for countries within the same agroecological zone, and then separately for individual countries. The estimates, including the annual average expenditures and value-added that are the main influential factors in determining ROR, are presented in Tables 4.5 and 4.6.

Returns to Total Agricultural Expenditure

The results in Table 4.5 show that total agricultural expenditure in SSA has an aggregate ROR of 11 percent, which generally increases with the number of years that countries have been participating in CAADP. The exception is with the group of countries that signed on to the CAADP agenda in 2010 (that is, five years ago), which has a very low ROR of 2 percent. This group constitutes several countries with zero or negative RORs, including Guinea (0 percent), Malawi (-6 percent), Senegal (-7 percent), and Swaziland (-9 percent). The other countries in the group include Côte d'Ivoire (23 percent), Kenya (14 percent), Tanzania (17 percent), and Uganda (24 percent).

Looking at the returns by agroecological grouping, the results show that countries in the cool or in the warm, semiarid/arid areas have negative returns (up to -11 percent) compared with those in the warm, semihumid/humid areas (22 percent) or in other areas including the cities (22 percent) and perhaps involved with high-value agricultural production that is typical of peri-urban agriculture.

In general, groups of countries or individual countries with very low or negative RORs are those with high expenditure-to-value-added ratios, particularly those with ratios in excess of 10 percent, including the group of countries that have yet to sign on to CAADP (ratio of 21 percent), group of countries in the cool areas (16 percent), Botswana (58 percent), Malawi (16 percent), Namibia (19 percent), Senegal (12 percent), South Africa (16 percent), Swaziland (13 percent), and Zambia (11 percent). Similarly, groups of countries or individual countries with high RORs are those with low expenditure-to-value-added ratios, particularly those with ratios of not more than 2 percent, including several countries that are emerging from civil war such as Liberia, Sierra Leone, and Rwanda.

Table 4.5 Rates of return to total agricultural public spending in SSA, 1996–2012

	Agricultural expenditure (US$/ha)	Agricultural value-added (US$/ha)	ROR (%)
Africa south of the Sahara (SSA)	6.48	158.72	11
Participation in CAADP * (number of years since signed compact)			
0	6.92	33.17	-14
1 or 2	1.74	43.79	12
4	2.61	99.05	23
5	10.15	155.21	2
6 or more	8.08	257.60	18
Agroecological zone			
Tropic, cool	11.38	73.00	-11
Tropic, warm, semiarid/arid	7.77	99.46	-1
Tropic, warm, semihumid/humid	7.80	264.41	19
Other	5.05	189.09	22
Country			
Angola	3.14	45.03	1
Benin	17.44	430.19	11
Botswana	5.83	10.04	-25
Burundi	3.95	211.97	34
Cameroon	10.82	364.37	19
Central African Republic	1.40	136.37	65

Table 4.5 Continued

	Agricultural expenditure (US$/ha)	Agricultural value-added (US$/ha)	ROR (%)
Chad	0.27	51.68	128
Congo, Democratic Republic of	2.73	138.67	32
Congo, Republic of	1.89	31.17	3
Côte d'Ivoire	5.47	210.79	23
Ethiopia	8.11	143.33	5
Gambia	12.83	265.05	8
Ghana	4.59	230.11	32
Guinea	3.18	43.46	0
Guinea Bissau	0.66	177.18	179
Kenya	6.39	176.93	14
Liberia	0.19	148.19	507
Madagascar	1.71	32.04	6
Malawi	18.65	176.57	-6
Mali	3.18	46.74	1
Mozambique	1.57	33.94	9
Namibia	3.20	16.45	-14
Niger	2.59	32.57	-1
Nigeria	8.52	413.59	31
Rwanda	12.77	525.39	25
Senegal	16.00	137.60	-7
Sierra Leone	5.39	254.55	30
South Africa	11.75	73.00	-11
Sudan	2.01	61.42	17
Swaziland	22.25	167.23	-9
Tanzania	4.62	142.81	17
Togo	6.42	226.00	20
Uganda	4.67	186.26	24
Zambia	5.47	48.73	-7

Source: Author's calculation based on model results.
Note: ROR = rate of return. ^ number of years since signed compact.

Returns to Agricultural Research Expenditure

The results in Table 4.6 show that the returns to agricultural research expenditure are much higher than the returns to total agricultural expenditure. The aggregate ROR to agricultural research expenditure is estimated at 93 percent, which is higher than the estimated ROR of 22 percent in Thirtle, Piesse, and Lin (2003) and 55 percent in Alene and Coulibaly (2009). In calculating the ROR, Alene and Coulibaly, for example, assume a period of five years between initiation of research and the beginning of flow of benefits and, thus, impose the constraint that the first five elasticity coefficients are jointly zero, contrary to what was actually estimated. Given that the estimated coefficients on all of the research expenditure variables (one current and one-year through 16-year lags) were statistically significant, the ROR would have been about 600 percent if the constraint was not imposed. Thirtle, Piesse, and Lin considered only the benefits in the fifth year following the research expenditure in their calculation of the ROR. Should a cumulative benefit method have been used, the estimated ROR would have been much higher than the 22 percent reported.

The returns are also estimated for different groups of countries by number of years of participation in CAADP and by agroecological zone, and the results presented in Table 4.6 show marked differences across the different groups. Looking at the returns by agroecological grouping for example, countries located in the cool or in the warm, semiarid/arid areas had lower returns (24–66 percent) compared with those in the warm, semihumid/humid areas (87 percent) or in other areas including the cities (126 percent).

Table 4.6 Rates of return to public spending on agricultural research in SSA, 1996–2011

Variable	Agricultural research expenditure (US$/ha)	Agricultural value-added (US$/ha)	ROR (%)
Africa south of the Sahara (SSA)	1.00	154.05	93
Participation in CAADP^			
0	0.90	35.39	21
1 or 2	0.14	41.43	178
4	0.29	48.06	98
5	1.21	151.96	76
6 or more	1.24	243.48	119
Agroecological zone			
Tropic, cool	1.68	73.14	24
Tropic, warm, semiarid/arid	0.89	97.85	66
Tropic, warm, semihumid/humid	1.19	172.67	87
Other	0.95	197.85	126
Country			
Benin	2.09	423.45	123
Botswana	0.40	9.79	9
Burundi	1.09	209.42	116
Congo, Republic of	0.21	31.16	91
Côte d'Ivoire	1.08	210.13	118
Ethiopia	0.44	136.36	186
Gambia	2.48	264.36	64
Ghana	1.38	228.66	100
Guinea	0.14	43.35	183
Kenya	2.05	172.24	50
Madagascar	0.09	31.70	225
Malawi	1.50	174.96	70
Mali	0.34	45.60	81
Namibia	0.52	17.73	17
Nigeria	1.41	408.21	175
Senegal	1.34	135.86	61
Sierra Leone	0.58	258.94	270
South Africa	1.68	73.14	24
Sudan	0.13	61.42	287
Tanzania	0.54	145.38	162
Togo	1.12	221.16	119
Uganda	1.61	180.17	67
Zambia	0.29	48.06	98

Source: Author's calculation based on model results.
Note: ROR = rate of return. ^ Number of years since signed compact.

As with the returns to total agricultural expenditure, groups of countries or individual countries with low RORs are those with high research-expenditure-to-value-added ratios, particularly those with ratios in excess of 2 percent, including the group of countries that have yet to sign on to CAADP, the group of countries in the cool areas, Botswana, Namibia, and South Africa. Similarly, groups of countries or individual countries with high RORs are those with low expenditure-to-value-added ratios, particularly those with ratios of not more than 0.5 percent, including Ethiopia, Guinea, Madagascar, Nigeria, Sierra Leone, Sudan, and Tanzania.

Overall, the higher returns to agricultural research expenditure (aggregate ROR of 93 percent) versus returns to total agricultural expenditure (aggregate ROR of 11 percent) reflect the low and declining research spending intensities in the continent. For the 23 countries taken together, agricultural research expenditure as a share of agricultural value-added declined from 0.7 percent in 1996–2003 to 0.6 percent in 2004–2012, which is far from the 1 percent targeted by the African Union's New Partnership for Africa's Development (NEPAD). Furthermore, agricultural research expenditure in the continent, compared with that of other developing regions, has been very volatile, due to low levels of government funding and high dependence on short-term and ad hoc donor and other external funding (Stads and Beintema 2015).

5. CONCLUSIONS AND IMPLICATIONS

Evidence of the impacts of agricultural spending in Africa south of the Sahara is scant. Many of the studies commonly cited in reference to this, such as Thirtle, Piesse, and Lin (2003), Fan, Yu, and Saurkar (2008), and Alene and Coulibaly (2009), were conducted with data prior to 2003. Recent trends in agricultural expenditure in the continent, especially following the commitment by African leaders in 2003 to increase their annual spending on agriculture to 10 percent of total national expenditure, are quite different from the trends associated with the periods analyzed in the above studies. Therefore, evidence of the agricultural productivity effects of public spending that accounts for recent trends in expenditure and productivity is needed.

Using data on 34 countries in SSA from 1980 to 2012, this paper assesses the returns to public spending in the agricultural sector in SSA, considering expenditure on agriculture as a whole versus expenditure on agricultural research. First, an aggregate agricultural land productivity (that is, value-added per hectare) function is estimated using an FE estimator that addresses potential endogeneity of agricultural expenditures to obtain elasticities of land productivity with respect to total agricultural expenditure and agricultural research expenditure. Various statistical tests are used to test endogeneity of expenditures and to validate the instruments used to identify expenditures. Different model specifications are used to test the sensitivity of the results to different assumptions, and we address serial correlation and heteroskedasticity of the error term, typical with panel data as used in the paper, by clustering the standard errors using different types of clusters. The estimated elasticities are then used to estimate the RORs to expenditure in different countries and groups of countries categorized by number of years of participation in CAADP and by agroecological zone.

Elasticity with respect to total agricultural expenditure per hectare is estimated at 0.04, which means that a 1 percent increase in total agricultural expenditure per hectare is associated with a 0.04 percent increase in agricultural value-added per hectare. Elasticity with respect to agricultural research expenditure per hectare is estimated to be higher at 0.09, which is lower than the estimated elasticities of 0.17 in Alene and Coulibaly (2009) and 0.36 in Thirtle, Piesse, and Lin (2003) but higher than the 0.04 in Fan, Yu, and Saurkar (2008).

The aggregate return to total agricultural expenditure in SSA is estimated at 11 percent. The aggregate return to agricultural research expenditure is estimated at 93 percent, which is higher than the estimated 22 percent in Thirtle, Piesse, and Lin (2003) and 55 percent in Alene and Coulibaly (2009). The estimated returns vary substantially across countries and groups of countries. In general, the return to total agricultural expenditure increased with the number of years that countries participated in CAADP. Furthermore, countries located in the cool or in the warm, semiarid/arid areas had the lowest returns, versus those in the warm, semihumid/humid areas that had moderate returns. Those located in other specific areas, such as in the cities, had the highest returns, perhaps because they are involved with high-value agricultural production that is typical of peri-urban agriculture.

Overall, the higher returns to agricultural research expenditure (93 percent) compared with the returns to total agricultural expenditure (11 percent) reflect the low and declining research spending intensities in the continent. For example, agricultural research expenditure as a share of agricultural value-added declined from 0.7 percent in 1996–2003 to 0.6 percent in 2004–2012, which is far from NEPAD's targeted 1 percent. However, because returns to agricultural research expenditure take time—typically a decade—to develop, having stable and sustained agricultural research funding will be critical for maintaining the high returns and, consequently, for accelerating agriculture-led development in the continent. Because agricultural spending encompasses expenditures on different functions (for example, research, extension, irrigation, marketing, subsidies) that are expected to have different productivity effects, the estimated low return to total agricultural expenditure (which was in fact negative in several countries and in some groups of countries) suggests that more disaggregated analysis is needed to better inform prioritization of agricultural spending.

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2033 K Street, NW
Washington, DC 20006-1002 USA
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