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Education and Agricultural Productivity: Evidence from Uganda

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ABSTRACT: Existing evidence on the impact of education on agricultural productivity in Africa is mixed, with estimates usually insignificant although sometimes large. Analysis of the first nationally representative household survey of Uganda gives an estimate of the impact of household primary schooling on crop production comparable to the developing country average. In addition, the primary schooling of neighbouring farm workers appears to raise crop production and these external returns exceed the internal returns. Education complements capital and substitutes for labour. Further productivity increases arise through education increasing physical capital and purchased inputs, but effects via crop choice appear negligible.

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1. Introduction

Like most of the poorest countries in Africa, Uganda receives more of its income from agriculture than from any other sector. In 1993, agriculture accounted for 53% of Uganda's GDP (World Bank, 1995a). The sector is even more important in generating foreign exchange, with food and live animals constituting 75% of exports in 1992 (Republic of Uganda, 1994). Dependence on agriculture is also pronounced amongst the poor. In 1992/3, the poorest half of the population received over four-fifths of their incomes from agriculture (World Bank, 1995b). Consequently, assessments of the returns to schooling in Uganda and other poor African countries should cover returns in the agricultural sector. Typically, however, attention centres around rate of returns to schooling estimated from urban wage employment (see Psacharopoulos, 1995; Bennell, 1996).

When returns to schooling in African agriculture are considered, they are often assumed to exist. Pinckney (1995) discusses the example of a World Bank policy study of the region, which stated that "raising educational levels enhances agricultural productivity" (World Bank 1989, p.64). However, as Pinckney notes, this assertion was not supported by references to African evidence. Instead, it drew upon the widely cited literature review of the developing country literature by Lockheed, Jamison and Lau (1980). Only two of the 18 studies included in this review were from Africa[1]. Differences in farming systems and technology imply that results from Asia and elsewhere cannot be assumed to carry over to Africa. Indeed, both the African studies in Lockheed, Jamison and Lau found zero or negative effects of education. Moreover, there is wide variation in the estimates of the other, non-African, studies. Nearly half the studies reviewed by Lockheed, Jamison and Lau did not find significant effects of education. The authors argue that these cases are typically ones where agriculture is "traditional" rather than "modernising". They conclude that the returns to four years of primary schooling average 10% in "modernising" environments but only 1% in "traditional" ones. To the extent that much of Africa is characterised by traditional rather than modernising agriculture, the favourable conclusions often drawn from Asia may not be relevant. A closer look at the evidence for Africa is required.

The aim of this paper is twofold. The first, lesser, objective is to survey commonly overlooked existing evidence on education and agricultural productivity in Africa. In Section 2 we show that the results are mixed: the effects are usually insignificant but often large in size[2]. We interpret this as implying that returns to education in agriculture in Africa may be substantial but often vary, both within and across localities. This increases the value of further empirical research: one cannot assume returns exist in a particular setting. The major objective of the paper is to present original estimates of returns in Uganda, using the country's first nationally representative household survey. Section 3 discusses data and empirical specification. Section 4 gives the core results with estimates of agricultural production functions for Uganda. Section 5 discusses variants and extensions to these results.

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[1]Phillips (1994) provides an up-date of Lockheed, Jamison and Lau (1980). He lists only one more African example, which in fact is a re-working of a study included in Lockheed, Jamison and Lau.

[2] In this paper, statistical significance is assessed at the 5% level unless stated otherwise.

2. Background

2.1 Why Should Education Matter?

Education may affect agricultural productivity in a number of different ways (see Schultz, 1988). A useful distinction is between cognitive and non-cognitive effects of schooling. Within the former, one can distinguish the formation of general skills, such as literacy and numeracy, and the transmission of specific knowledge. Although several African countries have attempted to reform the curriculum so as to teach specific agricultural knowledge, more weight is placed on the formation of general skills[3]. Literacy enables one to follow written instructions for chemical inputs and other aspects of modern farm technology (Harma, 1979). Numeracy permits one to calculate correct dosages and may assist in making other planning decisions. These cognitive effects of education may increase the output produced by a given combinations of inputs. They correspond to what Welch (1970) terms "worker effects". However, one may distinguish between the increases in productivity due to the education of the workers and those due to the education of those making the decisions about the farm (the "farm-managers"). In practice, the distinction between farm workers and farm managers is likely to be blurred in small-holder agriculture because decisions may be made collectively by the household members who work on the farm.

Functional literacy may also change allocative efficiency by altering the selected combination of outputs and inputs. This may be particularly important in disequilibria, when prices or technology are changing (Schultz, 1975). Indeed, there is a substantial literature documenting the greater propensity of educated farmers to adopt agricultural innovations, for example, modern inputs or new crops (see Feder, Just and Zilberman, 1985). If education alters input and output mixes, this may be because education alters farmers' ability to use particular mixes or changes their preferences. However, there may also be financing effects. If education gives access to more remunerative activities, such as formal non-agricultural employment, it may increase the funds available to the household to purchase marketed inputs and seeds. Such effects are stressed by Collier and Lal (1986), who find a large effect of non-farm income on agricultural productivity in Kenya.

Education may also have non-cognitive effects, changing people's attitudes and practices. These have typically been discussed more in the context of industry than agriculture, with sociologists noting the similarity between the requirements of the classroom and the factory-floor, for example: discipline and acceptance of hierarchy; punctuality and working to timetable; teamwork. We are not aware of research on the non-cognitive effects of education on agriculture but can conceive of a number of possibilities. In a developing country, education may increase people's achievement-orientation, with greater awareness of the possibility of improvements in one's standard of living. There may also be a greater openness to new ideas and modern practices. Against this, it is often argued that education leads to a disdain for agriculture, as students aspire to formal sector employment.

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[3] Jamison and Moock (1984) argue that this is entirely appropriate, with specific agricultural knowledge being better transmitted by extension agents.

2.2 *African Evidence*

Although there are several mechanisms through which education may affect agricultural productivity, whether the net effects are large and significant is an empirical matter. Table 1 summarises the microeconometric estimates of the effect of education on agricultural productivity in Africa known to the authors[4]. These estimates may have been overlooked in policy discussions and existing literature surveys for two reasons. First, they are often not published in mainstream journals. Second, they typically come from studies which are not focused specifically on the impact of education.

The results of the various studies are hard to compare directly because of differences in the specification of dependent variables, education measures and other regressors. The dependent variable is commonly either the output of a single crop or total agricultural output[5]. Education variables are usually defined only by reference to the education of the household head, although the education of other farm-workers may be equally, if not more, important (see Ram and Singh, 1988). Even a single individual's education can be parameterised in various forms. Some, such as the five level categorical variable used by Aguilar and Bigsten (1994) and by Collier, Radwan and Wangwe (1986), are difficult to interpret and may be too restrictive[6]. The estimated effects of education are likely to be sensitive to which other explanatory variables are controlled for. Researchers commonly estimate production functions, with land, labour and capital as additional determinants of output. However, since education often increases the use of purchased inputs, controlling for these may under-estimate the full effect of education on farm productivity[7,8]. Conversely, education often reduces labour input into farming, so omitting to control for this may lead to a negative relation between education and farm production which tells us nothing about any productivity effects of education (as in Gurgand, 1993)[9].

Taken at face value, however, the studies summarised in Table 1 make one cautious about the effect of education on agricultural productivity in Africa. In only a minority of studies is education estimated to have a significant positive effect on agricultural productivity for

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[4] There is a literature based on aggregate data. For example, analysis of cross-country aggregate data for sub-Saharan Africa 1971-86 suggests that primary education raises farm efficiency whilst secondary education boosts technical change (Thirtle, Hadley and Townsend, 1995).

[5] Phillips (1994) suggests *a priori* reasons why education may have more effect on the latter, but finds no empirical evidence for this.

[6] Four dummy variables would be more flexible and easier to interpret.

[7] For example, Bingswanger, Khandker and Rosenzweig (1993) find that primary education raised agricultural output in India largely through an increase in fertiliser demand.

[8] Similarly, Aguilar and Bigsten (1994) may have under-stated the effect of education by controlling for a number of other variables through which education may work: for example, off-farm income, migration and possession of a bank account.

[9] Nonetheless, one must be sceptical of whether education does raise agricultural productivity in the Côte d'Ivoire given that analysis of the determinants of household economic welfare using the same data-set found an insignificant relationship with education in rural areas (Glewwe, 1991).

the whole sample. Nonetheless, the estimated effects are positive in most studies and often fairly large. For example, in Bigsten (1984), none of the education variables are significant determinants of agricultural production but together they imply that some secondary schooling of the household head raises output by 39% *ceteris paribus*[10]. In such cases, one's "best guess" is that education substantially raises agricultural productivity. However, one cannot be confident of this or even that education has any effect at all[11]. A number of reasons can be suggested for the lack of significance of education. In a few cases, the samples may be too small. More generally, agricultural production is likely to be measured with considerable error[12]. Alternatively, it may be that there is genuine variability in the effect of education: for example, if samples include both "traditional" and "modernising" environments. Whatever the reason, these mixed results from the existing literature imply that it is hard to generalise and research on the location of interest is required.

A fundamental problem with empirical studies of the effects of education is inferring causality: do the coefficients on educational variables in production functions reflect the impact of education or the effects of omitted variables correlated with it? This issue is hard to settle without experimental data, although some progress has been made by Pinckney and colleagues. They use measures of cognitive skills (literacy and numeracy) and of reasoning ability (assumed independent of schooling) to see which (if either) drive the coefficients on education. They find large and significant positive effects from having a threshold level of cognitive skills in both Tanzania and Kenya[13]. This is consistent with a human capital interpretation of education, although it is still possible that the coefficient on cognitive skills - like that on schooling - does not reflect causality.

Like most researchers, we can merely note this problem of interpretation in the original estimates that follow. Conventional estimates of the impact of education are still of interest, despite possible biases. If education appears to have no effect on agricultural productivity, then one should be cautious about asserting high returns; if there appear to be large effects, then this is suggestive.

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[10] F-tests were not used to test for the joint significance of education.

[11] Whether the size and significance of the results are stressed can be important. For example, Bigsten's (1984) description of his results makes one downbeat: education has no significant effects. By contrast, Collier and Lal (1986) present results from the same data and give an upbeat conclusion: education appears to have a large impact on agricultural production. On a first reading, these two accounts appear contradictory and indeed initially we assumed there must be some interesting difference in model specification. In fact, both refer to exactly the same results (jointly produced by Bigsten and Collier in 1983) but merely interpret them differently.

[12] There is likely to be a trade-off between sample size and accuracy of measurement. Some of the smaller sample results reported are based on very intensive observation not feasible with large, nationally representative samples.

[13] In the Kenyan study, schooling alone is not significant. However, the findings about cognitive skills mirror those for manufacturing earnings in the same two countries (Boissiere, Knight and Sabot 1985). Similar exercises using agricultural data have been carried outside of Africa: see Jamison and Moock (1984) on Nepal; Chou and Lau (1987) on Thailand; and de la Cruz (1991) on Pakistan.

We know of no microeconometric estimates of the returns to education in Uganda as a whole. However, Bigsten and Kayizzi-Mugerwa (1995) have recently reported results in this journal for Masaka, a district which includes 5% of the country's population. They find education to have an insignificant effect on agricultural production but do not report the size of the relevant coefficients. The actual coefficients referred to are presented in Bigsten and Kayizzi-Mugerwa (1996) and reproduced here in the first column of Table 3. They raise the same issue of interpretation discussed in the context of Bigsten's (1984) results for Kenya. Although none of the education coefficients are significant, they are non-negligible in size. For example, they imply that some post-secondary education of the household head raises output by 94% *ceteris paribus* (for primary and secondary schooling the figures are 12% and 26% respectively)[14]. Further suggestive evidence is provided by Appleton (1995) using the same data-set as this paper. Education appears to raise household consumption *ceteris paribus*, amongst the poor and the non-poor, in both urban and rural areas. Given the high dependence of the poor on agriculture for their incomes noted in the introduction, this suggests that education may raise agricultural productivity[15].

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[14] To calculate the effect of a dummy variable with coefficient β_j on a logarithmic dependent variable, the transformation $\exp(\beta_j)$-1 is used (see Halvorsen and Palmquist, 1981). We also use this transformation when assessing the effect of crop shares in Section 4.6.

[15] This may not generalise to some other African countries: similar exercises for Côte d'Ivoire and for Mauritania reached negative conclusions (see Glewwe, 1991; Coulombe and Mackay, 1995).

Table 1

Existing Studies on Education and Agricultural Productivity in Africa

a) Kenya

Area and Study	Data	Dependent variable	Estimated effect of farmer education variable(s)	Other comments
1. Kenya (Hopcraft, 1974)	674 small farms surveyed in 1969-70	Maize production	Negative and sometimes significant	
		Combined crop and livestock production	Essentially zero	
2. Kenya, Vihiga (Moock, 1981)	101 male-headed farms in Vihiga district surveyed in 1971-2	Maize production per acre	1-3 years of schooling significantly negative, 4 or more years, positive insignificant	
3. Kenya (Bigsten, 1984)	Integrated Rural Survey 1: 1613 farms surveyed in 1974/5	Crop production	1-4 years of schooling significantly positive, further schooling insignificant and positive	Sizable effect even though seldom significant; eg those with some secondary schooling are predicted to have 39% higher combined output *ceteris paribus*
		Livestock production	Mixed and insignificant results	
		Combined crop and livestock production	Positive but insignificant	
4. Kenya (Bevan, Collier and Gunning, 1989)	Integrated Rural Survey 5 (IRS 5): 783 households surveyed in 1982. Sub-samples used in analysis.	Coffee production	Positive but insignificant	Fairly large magnitudes: some primary education raises coffee output by 21%; maize by 28%
		Hybrid maize production	Positive but insignificant	
5. Kenya (Aguilar and Bigsten, 1994)	IRS 5: sub-sample of 693 households	Crop production	Positive and insignificant in Central and in coffee-growing areas; negative significant in Nyanza and negative insignificant in non-coffee-growing areas	Definition of education as a 5 level categorical variable unclear and may not be best specification empirically
6. Kenya (Husbands, Konyango and Pinckney, 1994)	103 households in a village in Muranga district in 1991/92	Combined Crop and Livestock Production	Without controls for cognitive skills and reasoning ability, schooling is insignificant (unreported results given in private correspondence)	Some primary schooling has a significant negative effect if control for cognitive skills and reasoning ability

b) Other countries

Area and Study	Data	Dependent variable	Estimated effect of farmer education variable(s)	Other comments
7. Tanzania (Collier, Radwan and Wangwe, 1986)	540 households surveyed in 20 villages in 1980	Crop production	Positive and significant	Effect of categorical education on crop production hard to interpret; authors cite 27% effect of complete primary schooling.
		Livestock production	Positive and insignificant	
8. Tanzania (Pinckney and Kimuyu, 1995)	95 households surveyed in one village of the Kilimangaro region in 1991/92	Combined crop and livestock production	Without controls for cognitive skills and reasoning ability, four or more years of primary schooling have a positive and significant effect (unreported results given in private correspondence).	Schooling insignificant if control for cognitive skills and reasoning ability.
9. Burkina Faso (Ram and Singh, 1988)	51 households in seven villages the "Mossi" plateau	Crop production minus cost of purchased inputs	School years of all farm workers positive and significant with a 7% rate of return	Schooling of the household head not significant as educational variable
10. Côte d'Ivoire (Gurgand, 1993)	686 households surveyed in the 1985 Living Standards Survey	Combined crop and livestock production	Education variables either insignificant or negative	No controls for labour inputs
11. Ethiopia (Aredo, Croppenstedt and Demeke, 1995)	277 households in Arssi and Sina-Debre-Sina provinces surveyed in 1989/91	Combined crop and livestock production	Numeracy had a positive but insignificant effect on farm efficiency	Education variables not entered
12. Ethiopia (Croppenstedt and Demeke, 1995)	149 farms in Arssi province surveyed in 1989/91	Wheat and barley production	Numeracy had a positive significant effect on farm efficiency	Education variables not entered
13. Uganda (Bigsten and Kayizzi-Mugerwa, 1995)	198 farms in rural Masaka district surveyed in 1990	Agricultural production	Variables for some primary, secondary and post-secondary education of the household head all insignificant.	Coefficients on education not reported but in Bigsten and Kayizzi-Mugerwa (1996). Are of non-negligible size

3. Returns in Uganda: Data and Estimation Issues

The Integrated Household Survey of 1992/93 provides a good source of data to estimate the returns to education in Uganda. It is the country's first nationally representative household survey and drew a large sample of 10,000 households[16]. It gathered a comprehensive set of data, including questionnaires about household farm enterprises and community characteristics. In this paper, our dependent variable is annual household crop production. Output of individual crops were aggregated using the national median prices for the crops. Variations in household crop production thus reflect differences in physical production rather than spatial or temporal differences in prices. Livestock accounts for only 5% of agricultural revenue in Uganda and was not combined with crop production because of data problems (different recall periods were used for the two types of production). Similarly, crop production rather than crop value-added was used because information on purchased inputs was only available for the last 30 days.

We consider four factors of production: labour; land; capital; and purchased inputs (such as seeds and fertiliser). Labour was measured in terms of the number of adults working on the farm. Two types of workers were included: adult household members aged 15-60 whose main activity in the year prior to the survey was working on household crop farms, and men permanently hired to work on the farm[17]. Land was measured as available cultivable land[18]. Capital was measured as the value of capital goods: for most enterprises, capital was largely in the form of hoes and other tools. The number using tractors was negligible. Some areas use oxen for ploughing, but there is no household level data on this. The best that can be done is to capture average community-level effects by including a dummy variable for whether the community questionnaire reports sufficient oxen available for ploughing in the area[19]. Purchased inputs are measured by expenditures (in Uganda shillings) on seeds, fertilisers and related items in the 30 days prior to the survey[20]. To allow for flexibility in the effects of the four factors of production, X_j ($j=1,4$), on the output, Q, of farm i, we use the translog production function (see Berndt and Christensen, 1973):

[16] Sampling was not proportionate and population multipliers need to be applied to obtain a nationally representative picture from the sample. Since our focus is on regression analysis (where it is not appropriate to weight the data), we do not apply population multipliers in this paper.

[17] Preliminary estimates implied that other types of labour did not raise production. No significant sex differences were found in the productivity of family labour.

[18] Given that the translog includes squared terms, it is desirable to avoid negative logarithms. Consequently, land is measured in tenths of an acre.

[19] Preliminary estimates revealed no significant difference between areas where oxen were not used for ploughing and those where there were insufficient oxen.

[20] Due to the lags involved, inputs used in the 30 days prior to the survey are unlikely to have had a large impact on output in the year prior to the survey. However, they are the only available proxy for purchased inputs used in the entire period of interest. Since the measure used is only a proxy, the estimated impact of purchased inputs on production may be biased downwards.

(1) $$lnQ_i = \alpha_0 + \sum_{j=1}^{4} \alpha_j \, lnX_{ji} + \sum_{j=1}^{4}\sum_{k=1}^{4} \gamma_{jk} \, lnX_{ji} \, lnX_{ki} + \sum_{s=1}^{n} \beta_s \, Z_{si} + v_i \quad ,$$

where v_i is a random error term.

Individual coefficients are difficult to interpret in a translog because of the second-order terms. We overcome this problem by substituting $(lnX_{ji} - lnX_j^*)$ for lnX_{ji}, where X_j^* is the sample mean of input X_{ji} (see Jacoby, 1992). This transformation implies that the coefficients on the scaled factors of production $(lnX_{ji} - lnX_j^*)$ are elasticities of production evaluated at the sample means.

The other explanatory variables, Z_{si}, in equation (1) include measures of farmer education - discussed in detail in Section 5.1. In addition, farmer age is likely to affect productivity, possibly with an inverse U-shape reflecting the benefits of experience later being offset by physical deterioration. To try to control for such effects, we included a quadratic for the average age of the farmers. The farm manager, defined as the household member reported to be responsible for the farm, may be particularly important, so a quadratic for their age was also included[21]. To explore gender differences in productivity, variables were included for the proportion of farmers who were women and for whether the farm manager was a woman.

Agricultural productivity may vary across regions and over time. In Section 5.4, we estimate production functions separately by farming system. In our core results for the full national sample, we used two alternative techniques. One was to estimate the production function controlling for unobservable community-level "fixed effects"[22]. Equivalent to differencing within communities, such controls purge the data of the mean community-level unobservables. This method reduces biases due to correlations with community unobservables. However, it increases the problems of measurement error and for this reason may bias estimates towards zero. The alternative approach is to simply add regional and spatial variables. We divide the country into eight parts - rural and urban areas of the four administrative regions (Central, Northern, Eastern and Western)[23]. After experimenting with seasonal dummy variables, only that for the first three months of the survey (January-March 1992) was retained as significant. Other community-level variables included the availability of improved storage facilities and the availability of extension advice.

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[21] In four-fifths of cases, this was the household head. It is not obvious *a priori* whether it is the farm manager or the household head whose characteristics affect production. However, when both sets of characteristics were entered in preliminary estimates, the household head's age and sex could be rejected as insignificant but not the farm manager's.

[22] Communities in this case are enumeration areas of around 1000 households, from which about ten households were sampled at the same time (the survey was conducted for a period of over a year).

[23] A referee questions why urban households are included in a study of agricultural productivity, but this is necessary in order to obtain a truly national picture. Locations defined as urban often cover substantial areas of agricultural land and urban households may farm these, or other, areas. For a discussion of urban farming in Uganda, see Maxwell (1995).

Although 6870 households answered the crop enterprise questionnaire, the sub-sample used in the analysis is 4877 households[24]. This was obtained after rejecting outliers and those with zero values of inputs. The latter was due to the difficulty of dealing with zero values in a logarithmic function. The main exclusion was households who did not report any cultivable land as an asset (presumably tenant farmers). It might seem restrictive to exclude those with zero capital or purchased inputs. In practice there were only a handful of such cases: nearly all crop farmers reported using hoes (capital) and seeds ('purchased' inputs, values for which may have been imputed by the interviewer).

One econometric problem when estimating production functions is the possible endogeneity of the inputs (Durbin, 1954). We attempted to control for this by using two stage least squares. This appeared unproblematic in the case of labour but not capital nor inputs. In particular, when all three factors were treated as endogenous, the results were extremely sensitive to relatively minor changes in model specification. For example, the elasticity of production with respect to capital varied from -0.37 in a Cobb-Douglas production function to 0.45 under the translog (when inputs were assumed exogenous, the figures were 0.1 and 0.11 respectively). Given this non-robustness and the implausible magnitude of many estimated parameters, it was decided not to model capital and inputs as endogenous[25]. Although a Hausman (1978) test implied that labour was endogenous, using predicted labour input did not lead to any large changes in the estimated coefficients. The model with endogenous labour was reasonably robust to changes in specification; for example, the capital elasticity differed only 0.01 as between the translog and Cobb-Douglas functions.

4. Agricultural Production in Uganda: Core Results

Table 2 reports household crop production functions. Two sets of estimates are presented, one with and one without controlling for unobserved community fixed effects. A Hausman test of the fixed effects model against one without (and with no community-level variables) rejects the assumption of no community fixed effects. The controls almost double the explanatory power of the model, indicating considerable spatial variability in agricultural productivity. The signs of the estimated coefficients are robust to the fixed effects, but do sometimes change their size and significance. For example, the elasticity of production with

[24] This total falls to 4810 in community fixed effects models because 67 farms were the only ones sampled from their enumeration areas.

[25] The non-robustness may stem from a problem of identification. This is common with cross-section production functions (see Griliches and Mairesse, 1995). In this case, although a large range of instruments - including the wages, the price of hoes, the availability of inputs and infrastructure variables - were used to predict capital and inputs, they were nearly all insignificant. Moreover, the explanatory power of the first stage regressions was low (an R-squared of 0.21 for capital and 0.19 for inputs), with nearly all the explained variation attributable to exogenous variables included in the second stage. By contrast, labour input was fairly well explained by the first stage regression, with an R-squared of 0.55. Labour input to the farm was identified by total household labour (ie. non-agricultural workers plus agricultural workers).

respect to labour halves when such controls are made and becomes insignificant[26]. Aside from this, the most noticeable effect of controlling for community-level unobservables is to make significant the farm manager's age and the sex of the workers. Such controls also lower the estimates of the effect of education[27]. As noted above, it is unclear whether this reflects a reduction in omitted variables bias or the introduction of bias due to increased measurement error. However, since the fixed effects estimates provide something of a lower bound, we refer to them in what follows unless otherwise stated.

As explained in Section 3, because the factors of production are scaled, their coefficients are the output elasticities evaluating at the mean. These elasticities suggest the importance of land and, to a lesser extent, purchased inputs. Even without controls for community-fixed effects, the labour elasticity is low: doubling labour input would increase output by around 5-10%. By contrast, doubling land holdings would raise output by around a third. This suggests that agriculture is mainly land-constrained rather than labour-constrained. This national generalisation may not be true of some particular areas of the country but does seem to hold on aggregate. The sum of the elasticities give the returns to scale of the production function: since they are less than one, this implies decreasing returns. Land in particular exhibits diminishing returns[28]. This has implications for the ongoing debate on land reform in the country, which often assumes that land fragmentation reduces agricultural productivity (Republic of Uganda, 1993)[29].

Our main interest in Table 2 concerns the educational variables. Our preferred specification totals the years of schooling of household farm workers[30]. Total years of primary schooling have a significantly higher return than years of secondary schooling, so separate variables were used for the two types of schooling. Preliminary estimates indicated that the effects of total years of primary and of secondary schooling were non-linear, so squared terms

[26] By contrast, the elasticities with respect to other factors are fairly robust. This may be connected to the fact that labour is treated as endogenous whilst the other factors are assumed exogenous. When labour is treated as exogenous, its elasticity is robust to controlling for community fixed effects. After purging for community fixed effects, there may be relatively little information left in the predicted labour variable.

[27] This is most easily seen when the educational variables are entered without squared terms. Under this specification, controlling for community fixed effects reduces the coefficient on total years of primary schooling of the farm workers from 0.018 to 0.11; however it remains significant at 1%. The coefficient on total years of secondary schooling (without a squared term) is negative and insignificant with and without fixed effects.

[28] The restriction of the translog to a Cobb-Douglas specification is rejected due to the significance of some of the second order terms.

[29] Similarly, analysis of household consumption per adult equivalent suggest that economic welfare falls with land concentration, not fragmentation (Appleton, 1995).

[30] In this paper, we use the term "household farm workers" to refer to household members working on the farm and not to include workers hired in from outside the household. We have no data on the education (and age) of the latter.

were also included[31]. The quadratic for primary schooling implies that if the farm workers have four years of primary school, crop output will be 7% higher, *ceteris paribus*, than if they had no schooling. This increase is the same as the average effect of four years of schooling of the household head found by Lockheed, Jamison and Lau (1980) after surveying the developing country literature[32]. If the household farm workers have seven years of primary school (equivalent to one primary graduate), output is predicted to be 13% higher than if they had no schooling. If they had fourteen years of primary schooling (equivalent to two primary graduates), output would be 19% higher than if they had no schooling. These calculations illustrate the diminishing returns to primary schooling in household crop production. For secondary schooling, the results are more complicated. Overall, there is no evidence of returns: if total years of secondary schooling is entered as a regressor without a squared term, it is wholly insignificant with a negative coefficient close to zero (results not reported in Table 2). However, when entered as a quadratic (as in Table 2), the results imply that having five or more years of secondary schooling increases productivity, but those who have less than five years of secondary schooling are less productive than those with none[33]. These results suggest that lower secondary schooling (which lasts four years) does not raise agricultural productivity whereas upper secondary schooling may. We return to this issue in Section 5.1, but now discuss the other results in Table 2.

[31] When discussing variables which are entered as both linear and squared terms (eg primary schooling and schooling squared), we refer to both terms as a quadratic and evaluate its turning point as given by minus the coefficient on the linear term divided by twice the coefficient on squared term.

[32] Our estimates are not directly comparable with Lockheed, Jamison and Lau's. The latter are concerned with the education of the household head rather than all household farm workers and typically the models they survey have fewer explanatory variables. A more direct comparison of the Uganda results can be made by running a simple production function with land, labour, purchased inputs and a dummy variable for the household head having four or more years of schooling. This produces a coefficient of 0.1, close to weighted estimate of 9% referred to by Jamison and Lau (1982) in their revision of the literature review by Lockheed, Jamison and Lau.

[33] The quadratic reaches a turning point just after two years of secondary schooling and becomes positive just before five years.

Table 2

Core Results: Agricultural Production Functions for Uganda

Variables	Without Community Fixed Effects		With Community Fixed Effects	
	Coefficient	T-ratio	Coefficient	T-ratio
Constant	11.832	(117.43)***		
Log (predicted) labour	0.104	(2.16)**	0.048	(1.00)
Log land	0.304	(14.86)***	0.335	(15.02) ***
Log capital	0.083	(6.20)***	0.083	(5.59) ***
Log purchased inputs	0.241	(18.00)***	0.260	(19.21)***
Log labour squared	0.046	(0.88)	0.069	(1.31)
Log land squared	-0.029	(-1.78)*	-0.029	(-1.79)*
Log capital squared	-0.012	(-2.00)**	-0.017	(-2.41)**
Log inputs squared	0.034	(5.22)***	0.038	(6.46)***
Log labour x log land	-0.064	(-1.25)	-0.054	(-1.14)
Log labour x log capital	-0.053	(-1.61)	-0.054	(-1.70)*
Log labour x log inputs	-0.015	(-0.49)	-0.018	(-0.67)
Log land x log capital	0.046	(2.62)***	0.047	(2.58)***
Log land x log inputs	-0.034	(-2.17)**	-0.041	(-2.89)***
Log capital x log inputs	-.131E-02	(-0.11)	0.628E-02	(0.58)
Average age of farm workers	0.028	(4.76)***	0.022	(3.96)***
Av. age of farm workers squared	-.292E-03	(-4.39)***	-.231E-03	(-3.82)***
Proportion women farm workers	0.058	(1.17)	0.102	(2.15)**
Farm workers' primary schooling	0.028	(5.62)***	0.020	(4.30)***
Farm workers' prim. sch. squared	-.561E-03	(-2.34)**	-.445E-03	(-2.07)**
Farm workers' secondary schooling	-0.036	(-1.62)	-0.043	(-1.81)*
Farm workers' sec. sch. squared	0.760E-02	(2.15)**	0.893E-02	(1.98)**
Woman farm manager	0.040	(0.47)	0.071	(0.89)
Farm manager's age	0.288E-02	(0.51)	0.010	(2.02)**
Farm manager's age squared	-.310E-04	(-0.53)	-.108E-03	(-1.99)**
Proportion women farm workers x woman farm manager	-0.158	(-1.50)	-0.202	(-2.04)**
Surveyed Jan-Mar1992	0.207	(4.53)***		
Eastern rural	-0.329	(-9.24)***		
Western rural	-0.051	(-1.40)		
Northern rural	-0.638	(-17.82)***		
Central urban	-0.259	(-3.14)***		
Eastern urban	-0.571	(-6.42)***		
Northern urban	-0.591	(-9.25)***		
Western urban	0.064	(0.88)		
Sufficient oxen in cluster	0.113	(1.90)*		
Extension advice provided in area	0.161	(6.36)*		
% area using storage facility	0.236E-02	(2.70)***		
Adjusted R-squared	0.357		0.619	
Number of observations	4877		4810	

T-ratios for model without fixed effects calculated using White's heteroscedasticity consistent standard errors.

Here and in Tables 6 and 9, the logs of factors of production (land, labour, capital and purchased inputs) are scaled by subtracting the log of their sample mean.

In this and subsequent tables "*" denotes significant at 10%; "**" significant at 5% ; "***" significant at 1%.

Output varies with both the average age of the farm workers and the age of the farm manager[34]. Both age quadratics imply an inverse U-shape: productivity appears to peak just after the mid-forties. Most farm workers and around a third of farm managers are women. Splitting the sample according to the sex of the farm manager and estimating production functions separately on the two sub-samples revealed almost no significant differences in coefficients (results not reported). However, there was one significant difference: it appears that women workers are more productive than men in farms managed by men, and vice versa in farms managed by women[35]. This is unexpected given Ongaro's (1988) findings for Kenya, that women weed more efficiently in women-headed households. Our finding may partly reflect a gender division of labour, with limited substitutability between male and female labour. When a squared term for the proportion of workers who were women was entered into the model, neither it nor the interaction term were significant. The sex of farm manager *per se* has no significant effect on farm production.

The model without community fixed effects allows one to estimate the apparent effect of observable community-level variables[36]. In areas where oxen ploughs are readily available, production is 12% higher. In communities where extension agents provide advice, output is around 17% higher. The availability of improved storage facilities in the community also appears beneficial. Output is predicted to be 24% higher in a community where all households use improved storage facilities than in one where none use such facilities. Regional dummy variables also had large effects. *Ceteris paribus*, rural areas in the North are 47% less productive than those in the default area, Central rural. The pattern of these differences is expected, given the variations in climate and soil quality. However, the magnitude of the differences helps to explain the strong spatial variation in poverty within the country.

Our finding of significant effects of education stands in contrast to the findings of Bigsten and Kayizzi-Mugerwa (henceforth BKM), published in this journal. They used different data - a survey of rural areas in Masaka district - and a different specification for the production function. Since our data also cover rural Masaka, it is possible to estimate their specification on the sub-sample of observations from that area and see whether the results can be reconciled. Table 3 reports BKM's full results, including education variables. In addition, we present estimates of the same specification as BKM but using IHS data. The second pair of columns uses just the IHS data for rural Masaka, the same location analysed by BKM. Overall, the correspondence between these estimates and those of BKM is reasonably good. In particular, both imply that land has by far the largest output elasticity (at around 0.5), whilst labour is insignificantly different from zero. Purchased inputs are important in both. This correspondence is reassuring for the reliability of sets of results. Like BKM, the IHS

[34] Where the farm manager's main activity last year was working on the farm, she will also be included as one of the farm workers.

[35] This is shown in Table 2. The coefficient on the proportion of women farm workers gives the effect in farms managed by men. In farms managed by women, this coefficient must be added to that on the interaction term between the proportion and the dummy variable for a woman farm manager.

[36] There may be endogeneity problems with infrastructural variables: for example, extension agents may be allocated to areas with higher agricultural potential (see Rosenzweig and Wolpin, 1986).

estimates imply that education is generally not significant in raising agricultural output. This suggests that the difference in BKM's results and those in Table 2 does not represent a genuine difference between the two data-sets. Further insight is provided by running the BKM model on the full IHS sample for all Uganda. All the education variables become positive and significant in the estimates for all Uganda. This suggests that the apparent contradiction between Table 2 and BKM can be explained by the difference in geographic coverage, rather than by the model specification. Education is not significant in rural Masaka but this district represents only 5% of the country's population; in the country as a whole, education is significant. The much larger sample size for all Uganda increases the likelihood of obtaining significant results. However, this is not what explains the difference in the results for Masaka and all Uganda. It does not explain why the dummy variables for some secondary and post-secondary education have different signs for Masaka and for all Uganda. Moreover, experimentation with samples of only 100 households randomly drawn from the IHS also obtained significant effects of education. The comparison with BKM throws light on why much of the existing literature finds insignificant effects of education on agricultural productivity in Africa. There appears to be considerable variation in the returns to education. This may be partly geographic - as suggested by the comparison between the IHS estimates for Masaka and for all Uganda. However, there may also be variation between households in the same area, as suggested by the difference in the BKM and the IHS estimates for Masaka. Both types of variation may mean that, even if on average there appear to be substantial returns to education, the estimated coefficients may be low relative to their standard errors.

Table 3

A Comparison with Bigsten and Kayizzi-Mugerwa's (BKM) Results

	BKM's Estimates		IHS Estimates			
			Rural Masaka		All Uganda	
Constant	7.337	(12.88)***	7.669	(12.64)***	7.315	(47.56)***
Log labour[37]	0.088	(0.99)	0.039	(0.39)	0.262	(10.56)***
Log land	0.481	(6.32)***	0.565	(7.01)***	0.337	(19.38)***
Log purchased inputs	0.096	(3.44)***	0.240	(5.02)***	0.203	(19.47)***
Head some primary education	0.111	(0.33)	0.191	(1.85)*	0.118	(4.52)***
Head some secondary education	0.229	(0.62)	-0.281	(-1.26)	0.141	(3.22)***
Head some post-secondary educ.	0.663	(1.49)	-0.118	(-0.17)	0.230	(2.08)**
Head 31-50 years of age	0.623	(2.46)**	-0.086	(-0.66)	0.130	(4.12)***
Head 51 years of age or more	0.970	(3.65)***	0.010	(0.08)	0.144	(5.18)***
Adjusted R-squared	0.35		0.38		0.24	
Number of observations	198		215		4910	

T-ratios in brackets

[37] BKM measure labour in hours work; for the IHS estimates, the measure is number of workers.

5. Further Results: Variants and Extensions

5.1 Specification of the Farm-Level Education Variables

Like most household surveys, the basic information on education in the Ugandan IHS is the highest level of education attained by each household member[38]. However, even this simple and rather limited information can generate a wide variety of different measures of education which could be hypothesised to affect household crop production. This variety arises because of the different ways of aggregating over individuals and because of the possible heterogeneity of years of schooling. These issues are essentially empirical and one of the advantages of having such a large data-set as the IHS is that one can identify which particular measure of education is the best proxy. To simplify matters, we first abstracted from differences between years of schooling and between the gender of individuals. To choose between pairs of alternative proxies, we entered both simultaneously into a community fixed effects production function and used their t-ratios as tests of whether either could be rejected (for a defence of this procedure, see Leamer, 1983). Total years of schooling of household farm workers was tested against the following alternative specifications: average years of schooling of household farm workers; average years of schooling of all household workers; total years of schooling of all household workers[39]; years of schooling of the household head; years of schooling of the farm manager; years of schooling of the most educated household farm worker; years of schooling of the most educated household worker. In each pairwise test, total years of schooling was significant but the alternative educational measures were not.

Given that it was the total education of the household farm workers (alone) which appeared the best measure of education, we then explored whether there were gender differences. Without controlling for community fixed effects, it appeared that returns to education were higher for women farm workers. However, the difference was wholly insignificant once such controls were made. This suggests that female education may sometimes capture unobservable community effects (or possibly that it is either more prone to measurement error or generates greater externalities).

Some insight into the heterogeneity of different years of education is provided by totalling the number of farm workers whose highest schooling was the first year of primary school (P1), the number who attained P2 and so on. The first three columns of Table 4 give the relevant results when these variables are included with the other explanatory variables in Table 2 (excluding the quadratics for total years of schooling). The second three columns refer to parallel estimates using dummy variables for the highest school attainment of the farm manager. Table 4 reports the mean values of these variables for the sample: for example, 2% of farm managers have one year of primary schooling as their highest

[38] In Uganda, the school system has seven levels of primary schooling (called P1-P7), four of lower secondary schooling and two of upper secondary schooling (termed S1-S6). Individuals may take more than one year to graduate from one level to the next. However, in the absence of information on such repeating, we refer to the sum of levels of primary and secondary schooling attained as years of schooling.

[39] The education of household workers not employed on the farm may be important if they fund unobserved agricultural investments.

education attained (P1) and farms have on average 0.052 workers with such education. There is a reasonable correspondence between the effects of particular levels of education, whether they refer to the farm workers or the farm manager. It is only when at least four or five years of schooling have been attained that productivity is significantly higher than would be the case with no schooling. This is in accordance with the common view that at least four years of primary schooling are required for basic literacy and numeracy. In particular, with the farm manager's education, four years of primary schooling appears a distinct threshold: below that threshold, the schooling coefficients are close to zero. Lower secondary schooling (S1 to S4) is insignificant except for farm managers with complete lower secondary schooling. In some cases, having incomplete secondary schooling appears less beneficial for agricultural productivity than merely having complete primary schooling. Apparently negative effects of incomplete schooling on outcomes of interest are quite commonly found (see Moock, 1981, and the discussion by Lipton, 1985). They may not be causal, but may instead reflect the factors which lead individuals to drop-out of school (eg, unexpected adverse changes to family circumstances, low ability or motivation). It is possible that there is a causal link, with secondary school drop-outs being discouraged and having frustrated aspirations for non-agricultural employment. Upper secondary schooling and post-school training certificates have large coefficients, although few farm workers and managers have attained such education.

Table 4

Coefficients on Education by Grade:
Estimates from Community Fixed Effects Production Functions

	Number of farm workers with education of type			Farm manager's highest education		
	Coefficient	T-ratio	Mean	Coefficient	T-ratio	Mean
One year of primary (P1)	-0.0108	-0.233	0.042	0.028	0.409	0.020
Two years of primary (P2)	0.0106	0.380	0.127	0.018	0.437	0.064
P3	0.0207	0.801	0.157	0.013	0.348	0.082
P4	0.0372	1.513	0.178	0.070	1.901*	0.094
P5	0.0470	1.828*	0.162	0.064	1.670*	0.086
P6	0.0711	3.022***	0.182	0.081	2.230**	0.104
P7	0.0784	3.178***	0.171	0.103	2.745***	0.105
One year of secondary (S1)	0.572E-02	0.096	0.027	0.102	1.332	0.017
Two years of secondary (S2)	0.0706	1.320	0.033	0.027	0.403	0.024
S3	-0.853E-03	-0.013	0.021	-0.045	-0.566	0.016
S4	0.0588	0.957	0.026	0.139	1.925*	0.021
S5	0.2698	0.415	0.208E-03	0.368	0.563	0.208E-03
S6	0.5287	2.126**	0.146E-02	0.355	1.694*	0.208E-02
Post-primary training certificate	0.2552	2.103**	0.665E-02	0.152	1.657*	0.012
Post-secondary training certificate	0.3125	1.472	0.249E-02	-0.188E-02	-0.013	0.540E-02
University	NA	NA	0.	0.101	0.117	0.208E-03

NA = not applicable
Coefficients on other explanatory variables not reported (see Table 2 for a list of other variables included in the production function).

5.2 External Effects of Education

Lucas (1988) assumes that education has external benefits. He discusses this in a time series context where technology may change. However, such spillovers may also apply within a cross section through differences in adoption of technology. Foster and Rosenzweig (1995) show that farm profits rise with the experience of neighbouring farms with high yield crops. Burger, Collier and Gunning (1993) find that farms in Kenya copy their neighbours in deciding to adopt new crops. This evidence of learning from others suggests that if educated farmers are more likely to adopt modern techniques, uneducated neighbours may imitate them. This would imply that, along with own farm education, the education of neighbouring farms should enter positively into the household agricultural production function.

We test for external effects of education by augmenting the non-fixed effects production function in Table 2 with two variables for the average levels of primary and secondary schooling of other farmers sampled from the same enumeration area[40]. In order to easily compare internal and external effects of education, we use average, not total, measures of own farm workers' schooling. However, the results for external effects of education are robust to the specification of internal effects. Table 5 reports the results of the coefficients on the educational variables; for brevity, the coefficients on other determinants are not shown. The earlier conclusions about the internal effects of schooling are confirmed in the table. In particular, the strong effect of own farm workers's primary education is robust to the inclusion of measures for external effects; their secondary education appears to have no overall effect. The main interest of Table 5 is in the estimated external effects of education. The average primary schooling of other farm workers in the area significantly raises own production: an extra year of schooling on average corresponds to a 4% increase in output, *ceteris paribus*. This increase is larger than the corresponding internal effect of 2.8%[41]. This evidence for external benefits of education in agricultural production is only suggestive. The functions do not control for omitted community effects (to do this requires panel data covering a reasonably long time period). Nonetheless, what is striking about Table 5 is how large the external effects of primary schooling appear to be - exceeding the internal effects. If these did represent genuine external returns to schooling, they would provide one justification for substantial state funding of education.

5.3 Education Interactions

The models in Table 2 introduce education variables as augmenting the translog production functions in a simple additive manner. This may be restrictive: education may substitute for particular factors and strongly complement others. A more flexible form can be obtained by adding terms which interact education measures with other explanatory

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[40] Averaging the education of such observations is a less than ideal proxy for the education of neighbouring farms, both because of the small numbers sampled from each enumeration area (EA) and because those sampled may actually live some distance away. Average education is used rather than total education, since the number of households sampled from each EA can vary - in some cases, being as few as two.

[41] The external effects of farm worker secondary schooling, like the internal ones, are insignificant.

variables. Table 6 reports the results using interactions with total years of primary schooling of the farm workers (the most significant of the variables in Table 2).

Worker education appears to substitute for labour and to complement capital. The interaction term between labour and education is negative, although this is significant at only 10% with controls for community fixed effects. The interaction term between capital and education is positive and significant with controls for community fixed effects. There are also significant (and offsetting) interactions with the age of the farm workers and of the farm manager. The positive interaction between worker education and age may be a cohort effect. The expansion of primary schooling over time may have lowered returns either because it came at the expense of school quality, because it reduced the scarcity of human capital or because it reduced the value of primary schooling as a signal. Why there is a negative interaction between farm worker education and farm manager age is less easy to understand. One conjecture is that older manager's farm in a more traditional manner and hence are less willing to take advantage of their worker's education.

Table 5
The External and Internal Effects of Education on Crop Production

Farm workers' average years of schooling:	Coefficient	T-ratio
Internal returns:		
Primary	0.0275	5.02***
Secondary	0.0021	0.02
External returns:		
Primary	0.0433	3.72***
Secondary	-0.0142	-0.30

Coefficients on other variables in the production function not reported.

Table 6
Education Interactions in Agricultural Production

Variables	Without Community Fixed Effects		With Community Fixed Effects	
	Coefficient	T-ratio	Coefficient	T-ratio
Constant	11.782	(98.56)***		
Log (predicted) labour	0.202	(3.40)***	0.086	(1.49)
Log land	0.282	(9.29)***	0.325	(10.41)***
Log capital	0.097	(4.42)***	0.047	(2.15)**
Log purchased inputs	0.245	(11.88)***	0.268	(13.65)***
Average age of farm workers	0.029	(4.27)***	0.015	(2.40)**
Av. age of farm workers squared	-.305E-03	(-4.28)***	-.193E-03	(-2.93)***
Proportion farm workers women	0.064	(0.95)	0.077	(1.28)
Farm workers' primary schooling	0.030	(2.92)***	0.012	(1.39)
Farm workers' secondary schooling	-0.043	(-1.83)*	-0.055	(-2.29)
Farm workers' sec. sch. squared	0.716E-02	(1.76)*	0.010	(2.25)**
Farm manager's a woman	0.069	(0.70)	0.132	(1.45)
Farm manager's age	0.352E-02	(0.58)	0.015	(2.65)***
Farm manager's age squared	-.300E-04	(-0.50)	-.126E-03	(-2.28)**
Second order terms				
Log labour squared	0.143	(2.32)**	0.132	(2.14)**
Log land squared	-0.029	(-1.77)*	-0.030	(-1.85)*
Log capital squared	-0.012	(-2.03)**	-0.018	(-2.66)***
Log inputs squared	0.034	(5.22)***	0.038	(6.39)***
Log labour x log land	-0.090	(-1.59)	-0.062	(-1.19)
Log labour x log capital	-0.042	(-1.19)	-0.083	(-2.38)**
Log labour x log inputs	-0.016	(-0.50)	-0.013	(-0.45)
Log capital x log land	0.047	(2.66)***	0.045	(2.44)**
Log capital x log inputs	-.558E-03	(-0.05)	0.535E-02	(0.50)
Log land x log inputs	-0.033	(-2.08)**	-0.040	(-2.81)***
Proportion farm workers women x farm manager woman	-0.168	(-1.55)	-0.222	(-2.20)**
Interactions with farm workers' primary schooling:				
Log labour x education	-0.018	(-3.03)***	-.921E-02	(-1.67)*
Log land x education	0.406E-02	(1.16)	0.733E-03	(0.23)
Log capital x education	-.220E-02	(-0.86)	0.514E-02	(2.16)**
Log inputs x education	-.930E-03	(-0.43)	-.145E-02	(-0.74)
Worker av. age x education	-.810E-04	(-0.23)	0.706E-03	(2.28)**
Prpn. female workers x educ.	-.245E-02	(-0.27)	0.309E-02	(0.38)
Farm manager's age x educ.	-.116E-03	(-0.45)	-.451E-03	(-2.01)**
Farm manager's sex x educ	.-.444E-02	(-0.80)	-.688E-02	(-1.37)
Community variables:				
Surveyed Jan-Mar 1992	0.301	(4.50)***		
Eastern rural	-0.376	(-7.42)***		
Western rural	-0.038	(-0.71)		
Northern rural	-0.640	(-12.25)***		
Central urban	-0.365	(-2.73)***		
Eastern urban	-0.638	(-4.39)***		
Northern urban	-0.648	(-6.77)***		
Western urban	0.034	(0.31)		
Sufficient oxen in cluster	0.067	(0.77)		
Extension advice provided in area	0.192	(5.11)***		
% area using storage facility	0.239E-02	(1.89)*		
Interactions with farm workers' primary schooling:				
Jan-March 1992 x education	-0.015	(-1.92)*		
Northern rural x education	0.605E-03	(0.09)		
Eastern rural x education	0.980E-02	(1.61)		
Western rural x education	-.294E-02	(-0.42)		
Central urban x education	0.015	(1.09)		
Northern urban x education	0.856E-02	(0.81)		
Eastern urban x education	0.012	(0.62)		
Western urban x education	0.752E-02	(0.52)		
Oxen available x education	0.521E-02	(0.58)		
Extension available x education	-.522E-02	(-1.09)		
Storage available x education	-.150E-04	(-0.10)		

5.4 Education and Farming Systems

There are a number of very different agro-ecological zones within Uganda and the scope for "modernising" responses in each of these may vary. Consequently, education may be important in some zones and not others[42]. Table 7 gives some summary information on the characteristics of the farms surveyed in the IHS in each of the five farming systems identified by Parsons (1970). The largest, the Banana and Coffee System, covers most of the Central area bounded between Lakes Victoria, Albert and Kyoga. Although coffee is included in the zone's name, the crop accounts for a smaller share of agricultural revenue than cassava, sweet potatoes, beans and maize. The second system, Teso, covers the three districts of Kumi, Soroti and Pallisa. The principal crops grown are sweet potatoes, millet, sorghum and groundnuts. The system was unique in Uganda for the use of ox draught for cultivation, although many cattle were lost in the civil unrest in the mid-1980s. Third are the Northern systems, characterised by relatively low rainfall. A variety of staples are cultivated and sim-sim (sesame) accounts for a substantial proportion of agricultural revenue. In some areas, the Northern systems rely on communal labour for cultivation. Fourth are the montane systems in the East and West. These grow similar crops to the banana and coffee system, but have a higher altitude and greater population density. Lastly, there is the pastoral system in the Karamoja, covering two districts in the North East. These areas rely on sorghum and maize. They are less developed by most standard indicators, with notably less educated farm workers (averaging only one year of primary schooling per farm compared to five years elsewhere).

To see how the impact of education differs across farming systems, we estimated separate production functions for each system (Table 7). For simplicity, we used the Cobb-Douglas rather than translog functional form and included total years of primary schooling of the farm workers as the only measure of education[43]. The only other variables included were the four factors of production (labour, land, purchased inputs and capital). The production functions do differ by farming system, although not always in predictable ways. Labour appears most productive in both the high population density montane areas and in low population density semi-arid Karamoja. It is insignificant in the North, perhaps reflecting the prevalence of communal labour. Education appears to have similar effects in both the banana-coffee system and the Northern system. It has a larger effect in Teso and a smaller, insignificant effect in the Montane areas. Although the coefficients in the production functions differ by farming system, many of these differences are not statistically significant. Comparing the banana-coffee zone with each of the other four systems, the only cases where there were significant differences were: purchased inputs and schooling in Teso; and labour, capital and inputs in the Northern systems[44]. These results imply that, although farmer education appears less productive in the Montane areas and in Karamoja than in the banana-coffee zone, one cannot be confident about this claim. One must be sceptical of the findings for Karamoja in particular, given the relatively small number of people from that area in the sample and their low total years of education.

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[42] This is not ruled out by the insignificance of the interactions between education and region in the previous section. The administrative regions do not coincide with the agro-ecological zones.

[43] The models are estimated by ordinary least squares and used actual, rather than predicted, labour input.

[44] To see whether the differences in the coefficients on the production functions by farming system were significant, we estimated a pooled model with interactions between all the explanatory variables and dummy variables for the farming zones.

Table 7
Farming Systems in Uganda

Mean Characteristics

Variables	Banana-Coffee	Teso	Northern	Montane	Karamoja
Log agricultural output	12.25	11.81	11.97	12.35	10.81
Log labour	5.11	5.16	5.16	5.19	4.94
Log land	3.18	3.22	3.39	2.97	3.06
Log purchased inputs	10.85	11.21	11.17	10.91	10.92
Log capital	8.91	8.84	9.02	8.84	8.49
Total years of primary schooling of farm workers	5.62	5.47	5.74	5.44	1.03
Percentage of revenue from:					
Maize	8	3	5	7	24
Sorghum	1	11	8	3	43
Millet	5	14	9	4	10
Rice	0	4	0	0	0
Other grains	0	0	0	0	3
Matooke	20	2	1	36	0
Cassava	21	6	18	8	0
Sweet potatoes	12	33	13	11	3
Other tubers	1	0	0	4	0
Beans	11	1	7	13	2
Peas	0	1	3	0	3
Groundnuts	3	9	9	0	2
Sim-sim	0	1	12	0	0
Other pulses and nuts	0	1	1	0	1
Fruits	3	1	1	2	0
Vegetables	1	1	2	1	1
Cotton	1	3	2	0	0
Coffee	6	0	0	3	0
Other cash crops	0	0	1	0	3

Cobb-Douglas Production Functions:

Estimated coefficients (T-ratios in brackets)

Variables	Banana-Coffee	Teso	Northern	Montane	Karamoja
Intercept	6.86 (30.0)***	7.43 (11.3)***	7.34 (19.6)***	7.16 (17.3)***	5.86 (5.0)***
Log labour	0.17 (4.7)***	0.14 (1.3)	-0.04 (0.8)	0.25 (4.1)***	0.25 (1.3)
Log land	0.36 (15.8)***	0.36 (4.9)***	0.33 (9.4)***	0.39 (9.9)***	0.45 (2.6)**
Log capital	0.08 (5.1)***	0.12 (2.3)**	0.19 (7.2)***	0.08 (3.0)***	0.14 (1.4)
Log purchased inputs	0.23 (16.6)***	0.12 (3.1)***	0.17 (8.4)***	0.18 (7.7)***	0.10 (1.3)
Total years of primary schooling of farm workers	0.011 (3.4)***	0.03 (3.2)***	0.012 (2.5)**	0.006 (1.2)	-0.009 (-0.2)
Adjusted R-squared	0.33	0.30	0.28	0.27	0.26
Number of observations	2355	382	1091	972	77

5.5 *Effects of Education through Factors of Production*

In common with most of the literature, we have examined the effects of education on agricultural production holding all other inputs constant. However, education may raise agricultural productivity by increasing the use of other inputs, particularly capital and purchased inputs. In this section, we show that education is associated with greater use of such inputs and that holding these constant understates the apparent effects of education on agricultural production. Our analysis is limited since we focus on agricultural production, not value-added. Since the inputs are costly, one should ultimately be concerned with the latter; unfortunately, it was not possible to construct this from the data.

To show the impact of education on the use of capital and purchased inputs, Table 8 reports regressions for the logs of these factors on the other explanatory variables included in the production function in Table 2. The estimated determinants of capital and purchased inputs are remarkably similar, although we shall not discuss them in detail here. Our main focus is on the coefficients of the education variables. Total primary schooling of the farm workers enters as a quadratic with a positive but diminishing effect on both capital and inputs. If the farm workers collectively have four years of primary schooling, their farm is predicted to use 9% more capital and 9% more purchased inputs than if they had no primary schooling. If they had seven years of schooling, the figures are 14% and 15% respectively; if they had fourteen years, they are 22% and 25%. Secondary schooling has an even larger effect on the use of capital and purchased inputs. Each extra year of farm worker secondary schooling raises the amount of capital used by 4%, and the amount of purchased inputs by 5%.

These strong effects of schooling imply that controlling for capital and purchased inputs may under-state the effect of schooling on agricultural production. Omitting these factors from the production function leaves us with the quasi-reduced form regression for output shown in the last two columns of Table 8. Comparing the results with those in Table 2, we can see that the coefficients on education are indeed larger in Table 8. Having four years of worker primary schooling is predicted to raise production by 10% (compared with the 7% implied by Table 2). Fourteen years of primary schooling raises production by 26% (compared with 19%).

5.6 *Effects of Education through Crop Choice*

Education may affect household revenue from crop production by altering the composition of outputs, as well as the level and composition of inputs. These effects will be included in the returns to education estimated in the production functions in Table 2, which do not control for differences in the composition of output. A simple way of exploring whether this mechanism is important is to augment the production function with variables for the shares of different crops in total revenue (Table 9 refers). This method is not entirely satisfactory for three reasons. First, including the crop shares directly in the production function is rather *ad hoc*[45]. Second, output mix is likely to be endogenous: for example,

[45] However, rigorously deriving aggregate production functions from crop-specific ones is problematic. For example, the sum of two Cobb-Douglas production functions is not Cobb-Douglas. Furthermore, the data lack crop-specific information on inputs, making discussion of aggregation problems rather academic.

farms which have higher agricultural potential may choose higher return, higher risk crops. Such biases can be limited by controlling for unobservable community-level effects but may still persist within communities. Third, different crops may have different costs, so the focus on crop revenue may be misleading.

Table 9 takes sorghum as the default crop type, since this appears to generate the least revenue. Clearly, differences in crop choice are associated with large differences in crop revenue for given inputs. For example, the results suggest that a farm growing only cash crops other than coffee and cotton would have 466% higher revenue than a comparable one growing only sorghum. This comparison may be of limited relevance, since few farms do grow such "other" cash crops. However, there are almost equally large differentials with more common crops. For example, switching from sorghum only to matooke only would raise total revenue by 382%. Our main interest is in how much of the apparent return to education works through crop choice. In fact, the effect via crop mix appears relatively small. The coefficients in Table 9 imply that four years of primary schooling is associated with an increase in production of 7%, the same figure as implied by Table 2. Fourteen years of primary schooling is associated with a rise in production of 17%, only slightly less than the 19% predicted from Table 2. Similarly, for secondary schooling, the size and sign of the coefficients are roughly comparable in the two tables. Consequently, crop choice seems an important determinant of farm revenue, it does not appear to explain much of the apparent effect of education.

Table 8

Effects of Education through Capital and Purchased Inputs
Estimated Controlling for Community Fixed Effects

	Regression for Capital		Regression for Purchased Inputs		Reduced Form Regression for Output	
Variables	Coefficient	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio
Log of land	0.368	(16.81)***	0.423	(15.48)***	0.454	(24.14)***
Log of land squared	0.035	(2.04)**	0.033	(1.53)	-.701E-02	(-0.47)
Log of (predicted) labour	0.420	(7.93)***	0.211	(3.18)***	0.193	(4.22)***
Log of labour squared	-0.083	(-1.28)	-0.136	(-1.69)*	-.214E-02	(-0.04)
Log of labour x log of land	-0.054	(-0.99)	-0.076	(-1.13)	-0.092	(-1.98)**
Average age of farm workers	0.014	(2.04)**	0.022	(2.65)***	0.027	(4.59)***
Av. age of farm workers squared	-.139E-03	(-1.86)*	-.266E-03	(-2.84)***	-.290E-03	(-4.49)***
Proportion women farm workers	0.153	(2.60)***	0.246	(3.35)***	0.173	(3.41)***
Proportion women farm workers x woman farm manager	-0.208	(-1.69)*	0.062	(0.41)	-0.220	(-2.07)**
Woman farm manager	0.026	(0.26)	-0.221	(-1.79)*	0.028	(0.33)
Farm manager's age	0.011	(1.69)*	-.230E-02	(-0.28)	0.012	(2.14)**
Farm manager's age squared	-.135E-03	(-1.99)**	-.350E-04	(-0.42)	-.139E-03	(-2.39)**
Farm workers' primary schooling	0.024	(4.29)***	0.025	(3.54)***	0.026	(5.37)***
Farm workers' prim. sch. squared	-.590E-03	(-2.25)**	-.530E-03	(-1.62)	-.535E-03	(-2.38)**
Farm workers' secondary schooling	0.044	(3.14)***	0.053	(3.04)***	0.018	(1.48)
Adjusted R-squared	0.392		0.328		0.483	
Number of observations	4810		4810		4810	

The logs of factors of land and labour are scaled by subtracting the log of their sample means.

Table 9

Production Function Augmented with Crop Shares
Estimated Controlling for Community Fixed Effects

Variables	Coefficient	T-ratio
Log (predicted) labour	0.033	(0.73)
Log land	0.319	(15.16)***
Log capital	0.081	(5.78)***
Log purchased inputs	0.273	(21.16)***
Log labour squared	0.065	(1.32)
Log land squared	-0.026	(-1.72)*
Log capital squared	-0.016	(-2.51)**
Log inputs squared	0.033	(6.01)***
Log labour x log land	-0.065	(-1.45)
Log labour x log capital	-0.041	(-1.36)
Log labour x log inputs	-0.032	(-1.25)
Log land x log capital	0.046	(2.69)***
Log land x log inputs	-0.035	(-2.65)**
Log capital x log inputs	-.918E-02	(0.91)
Average age of farm workers	0.021	(4.20)***
Av. age of farm workers squared	-.247E-03	(-4.35)***
Proportion farm workers women	0.108	(2.44)**
Farm workers' primary schooling	0.0201	(4.68)***
Farm workers' prim. sch. squared	-.561E-03	(-2.34)**
Farm workers' secondaryschooling	-0.040	(-1.81)*
Farm workers' sec. sch. squared	0.817E-02	(1.93)*
Farm manager's a woman	0.066	(0.89)
Farm manager's age	0.801E-02	(1.64)
Farm manager's age squared	-.806E-04	(-1.57)
Proportion women farm workers x woman farm manager	-0.200	(-2.16)
Share of agricultural revenue from:		
Maize	0.479	(3.57)***
Millet	0.514	(3.89)***
Rice	1.467	(7.93)***
Other grains	1.175	(1.94)*
Matooke	1.572	(12.91)***
Cassava	1.243	(10.44)***
Sweet potatoes	0.980	(8.26)***
Other roots & tubers	0.872	(4.63)***
Beans	0.070	(0.52)
Peas	0.623	(2.58)**
Groundnuts	0.787	(5.49)***
Sim-sim	0.827	(5.02)***
Other pulses and nuts	0.175	(0.57)
Fruit	1.288	(8.41)***
Vegetables	0.726	(4.09)***
Cotton	0.800	(4.47)***
Coffee	1.039	(7.11)***
Other cash crops	1.734	(8.69)***
Adjusted R-squared	0.619	
Number of observations	4810	

6. Conclusions

There is a widespread assumption that education raises agricultural productivity in developing countries. This is typically justified by reference to the literature review by Lockheed, Jamison and Lau (1980), which found that four years of primary schooling raised output by 7%. However, this literature review included only two African countries, neither of which showed significant positive returns to education. We have surveyed a variety of other estimates from Africa which tend to be neglected in much of the debate. These studies give a mixed picture, with education effects often appearing insignificant, although sometimes large. Using its first nationally representative household survey, we have presented original results for Uganda. Here the estimated effect of education is significant and exactly in line with the developing country mean calculated by Lockheed, Jamison and Lau: four years of primary schooling appears to raise production by 7%. These results suggest that education may well benefit those in the agricultural sector, who include the poorest people in the country. This helps explains the earlier finding using the same data-set that education benefits the rural poor.

Although education appears to have returns in agriculture, these are probably lower than those in urban non-agricultural wage employment. Using the same data-set, Appleton, Hoddinott and Knight (1996) report wage returns to men of 28% for complete primary schooling (61% for complete secondary schooling). By comparison, the estimates given here imply that having one worker with complete primary schooling would raise crop production by 13% (18% for complete secondary schooling). The two sets of returns are not strictly comparable, since one is for wages; the other for crop production. However, the comparison probably understates the difference in returns, since the baseline wages for the uneducated are likely to be higher than baseline returns in agriculture. It is interesting to note that it is primary schooling which appears to have returns in agriculture; secondary schooling appears to have little or no overall effect. By contrast, in wage employment, secondary schooling appears to bring much greater returns. There may some problems of interpretation - for example, only the more able secondary school graduates may obtain employment. Nonetheless, the results suggest that the issue of allocating public resources to education across the primary, secondary and tertiary levels will involve difficult trade-offs.

Perhaps the most important finding of the paper is the large estimated effect of the education of other farmers in the area. This indicates that there may be positive externalities from schooling in the form of higher agricultural productivity. Although the evidence only suggestive, such spillovers are plausible - if education changes a farmer's techniques and practices, these may be easily observed and copied by neighbouring farmers. Such spillovers are particularly important in the case for public funding of education. If education merely raised a farmer's own output, this would not necessarily justify subsidising education. Further arguments would be needed, for example, concerning poverty or capital market failure. However, external benefits from primary education do provide a simple *prima facie* case for public subsidy. What is particularly striking here is the size of the apparent external benefits of primary education - exceeding the internal ones.

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Appendix Table
Descriptive Statistics

Variable	Mean	Standard Deviation
Dependent variable:		
Log of Crop Revenue		
(in survey average prices)	12.150	0.909
Factors of Production (in logs):		
Labour (number of workers)	5.186	0.471
Land (10ths of acre)	3.186	0.703
Capital (U.Sh.)	8.909	0.975
Purchased inputs (U.Sh. pa)	10.963	1.15 1
Dummy variables:		
Surveyed in Jan-March 1992	0.066	0.248
Resident in Eastern rural	0.024	0.427
Resident in Western rural	0.025	0.432
Resident in Northern rural	0.021	0.407
Resident in Central urban	0.022	0.14
Resident in Eastern urban	0.022	0.149
Resident in Northern urban	0.029	0.167
Resident in Western rural	0.027	0.161
Total schooling of household farm workers:		
Primary	5.527	5.239
Secondary	0.283	0.984
Community variables:		
Sufficient oxen for ploughing	0.043	0.202
Extension advice provided	0.570	0.495
Percentage use improved storage	2.149	12.386
Farm manager's characteristics:		
Female sex	0.319	0.466
Age (years)	41.332	15.285
Share of different crops in total revenue:		
Sorghum	0.047	0.118
Maize	0.075	0.147
Millet	0.068	0.128
Rice	0.011	0.068
Other grains	0.001	0.017
Matooke	0.175	0.270
Cassava	0.167	0.222
Sweet potatoes	0.143	0.194
Other tubers	0.017	0.075
Beans	0.098	0.139
Peas	0.011	0.047
Ground nuts	0.049	0.114
Sim-sim	0.031	0.095
Other pulses	0.006	0.038
Fruits	0.025	0.088
Vegetables	0.015	0.074
Cotton	0.014	0.069
Coffee	0.037	0.122
Other cash crops	0.007	0.055
Sample size	4877	