Long-term structural change and determinants of agricultural output in small-scale farming in Rwanda

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Abstract

This paper takes a long-term view of drivers of agricultural output in a densely populated area of rural Rwanda. Farm households that had been surveyed in 1986 were resurveyed in 2012, and their split-off children's farm households were included, which results in a unique two-wave panel dataset spanning 26 years. Far-reaching structural change in the small farm sector is identified, with a further decline in farm size, significantly increased labour use and much increased capital use. Average farm size decreased from 0.76 to 0.43 hectares. Output per farm was about constant compared to the initial survey round, while off-farm income had increased. OLS and fixed effect panel data estimates of production functions suggest that, over the long-run study period, agricultural output was characterised by more or less unchanged elasticity of land and somewhat decreased elasticity of capital, whereas the elasticity of labour had grown substantially, from 0.2 to 0.4. Overall economies of scale tend to be increasing.

Key words: development economics; long-term growth; agricultural productivity; smallholder farmers; Rwanda; Africa

1. Introduction

Agricultural growth has long been recognised as an engine for economic growth and poverty reduction in developing countries (Byerlee *et al*. 2005; Headey *et al*. 2005). Agriculture is also the backbone of the economy in Rwanda, being the second biggest contributor to the gross domestic product (31% in 2010/2011), after the service sector. Moreover, agriculture remains the main employer, especially of the poor smallholding farmers and less educated segments of the population. More than 87% of the population in Rwanda derive their livelihoods from agricultural production, usually in small, fragmented plots on erosion-prone hills (MINAGRI 2009). The growth in agriculture averaged 4.9% between 2006 and 2010 (Hansl *et al*. 2011).

This study assessed the drivers of agricultural change in the long run among a community of smallholder farmers in rural Rwanda. A unique dataset was generated for the purpose. It spans a periods of 26 years, originating from two detailed household surveys conducted in 1986 and 2012 respectively. Besides the original farms, the second survey also included the farms established by the offspring (children) of the original farm families.

Production functions are estimated to identify changes in the relative contributions of land, labour and capital to output. Despite the data challenge involved, one of the contributions of the paper is the notion that agricultural change can be meaningfully compared between generations of farm households.

2. Relevant literature

Sources and determinants of agricultural growth in Rwanda have been studied extensively, for instance by Diao *et al*. (2010), Donovan *et al*. (2002), McKay and Loveridge (2005), Clay *et al*. (1996) and Von Braun *et al*. (1991). Since the seminal work of Cobb and Douglas (1928) the concept of "production function" has undergone a long debate by economists (Chambers 1988). A production function represents the output that is achieved using an input vector $x = (x_1, \ldots, x_n)$ (Hackman 2008). It is also defined as the amount of output that can be produced with a given amount of inputs through the use of a given production technology (Rasmussen 2011). The use of capital and other intermediate inputs in traditional agriculture is thought to be limited, and the volume of agricultural output is mostly determined by land and labour (Cornia 1985). Over time, agriculture has become more input intensive, but the evolution of input shares depends on the degree of technical substitution between land, labour and capital. Labour and capital are substitutable in the long run, but mechanisation is limited in Rwanda's agriculture. High output elasticities of land were obtained from production function estimation in Asian countries in the 1970s (Lau & Yotopoulos 1971; Okhawa 1972), with the former's tendency to decrease over time in favour of labour and capital elasticities. In the study on factor demand and agricultural development in rural areas of Uganda, Deininger and Okidi (1999) estimated a production function and found that farm size and the use of seeds and fertilisers are important factors of agricultural output growth. Besides, household demographics, education level and farmer's experience were found to be relevant to agricultural productivity. Tripathi and Prasad (2009) found in India that land, labour and capital significantly explain the changes in agricultural output over time. Mundlak *et al*. (2012) used country panel data to estimate agricultural production functions with heterogeneous technology and found agricultural inputs to be relevant to agricultural output across countries. The inclusion of state variables, such as technology, institutions, prices and environmental variables, in the production function improve its explanatory power. Using a Cobb-Douglas specification, agriculture productivity relationships have been empirically tested in Rwanda by Von Braun *et al*. (1991), Clay *et al*. (1996) and Ali and Deininger (2014), who found that farm size and labour exhibit a major contribution to agricultural output variations. The existing literature on agricultural research in Rwanda by Diao *et al*. (2010), Donovan *et al*. (2002), McKay and Loveridge (2005), Clay *et al*. (1996) and Von Braun *et al*. (1991) does not capture the farm productivity drivers in the long term because they used single-year cross-sectional data in their analyses. This gap in the research is being addressed by this paper.

3. Data

The study was conducted in five selected sectors (local areas) that belong to the former *commune* of Giciye,[1] which was selected during a study on the commercialisation of agriculture under population pressure (Von Braun *et al*. 1991). The five sectors under study are Jomba, Muringa, Rambura, Rurembo and Shyira. They are currently collated in Nyabihu district. Agriculture is still a major source of livelihoods, and almost half of agricultural land (49%) is located in these five sectors. The local setting is shown in Figure 1.

[1] After 1994, the local administrative units in Rwanda were modified and given new names, as districts (formerly communes) and sectors (district sub-units). In this study, current names are being used and the old are recalled where necessary.

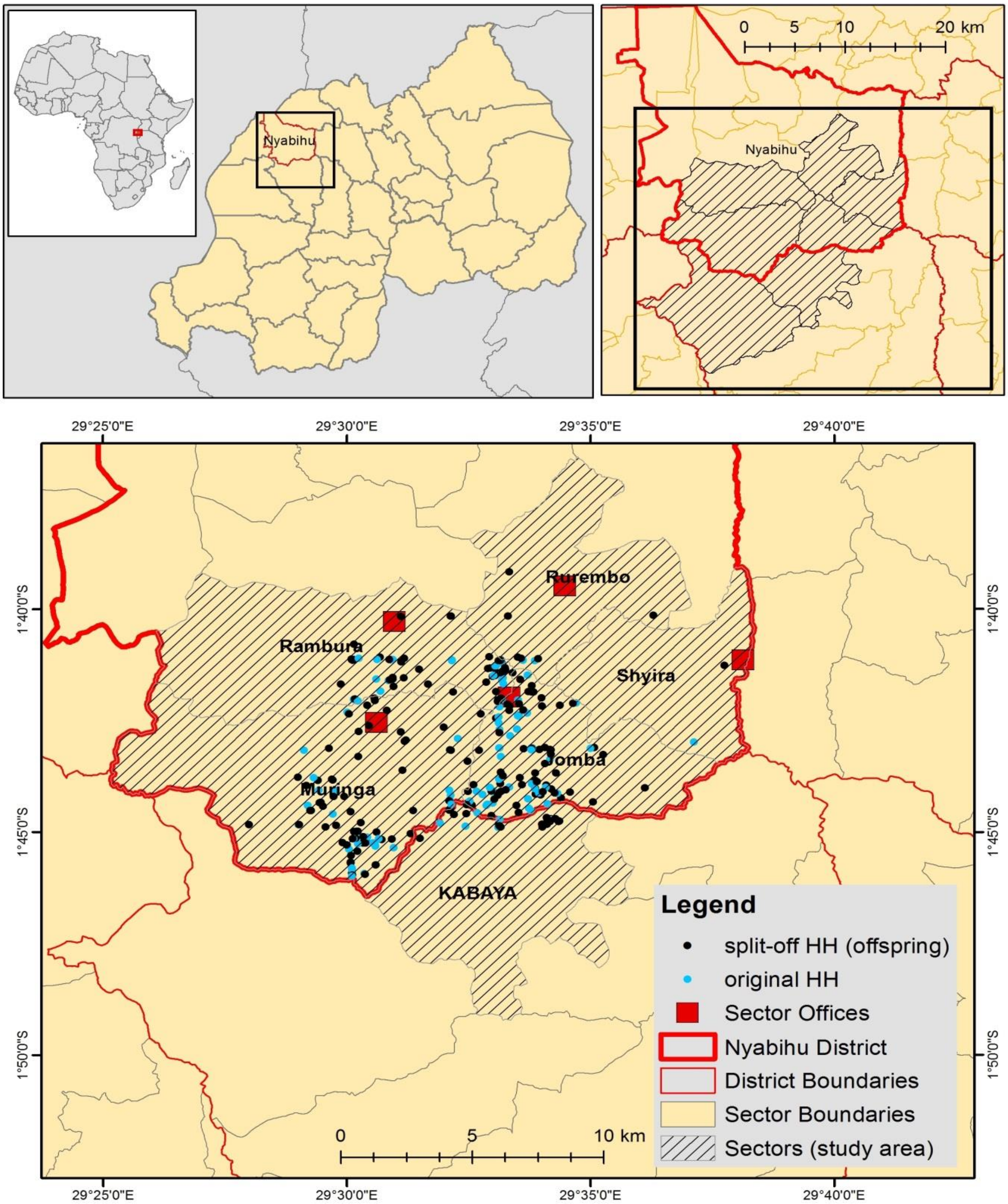

Figure 1: Map of the study area identifying the surveyed households
Source: Authors' conception

The dataset used in this study comes from a two-wave panel that spans a 26-year period. The first household survey, done by a team of IFPRI and the University of Göttingen in 1986, included 190 households randomly selected across five sectors from a list of farmers in the area, which is in the neighbourhood of the Gishwati Natural Forest. A structured questionnaire was used to collect relevant information on household demographics, household expenditure, health and nutrition, agricultural production, crop use information, and others. That survey is described in Von Braun *et al*. (1991). The second wave of data comes from a revisit to the same original sample in the area in 2011/2012 and was supervised by the authors. The activities consisted of retracing and resurveying the same households as surveyed in 1986, along with their split-off households of children, i.e. the next generation. With a group of trained research assistants and key informants from the area, 164 of the 190 original households (that is 86%) were traced and resurveyed, together with their 200 split-off households, comprising the children of the originally surveyed households (offspring) who had established farms and still reside in the district and its neighbourhood. Only 14% of original households could not be traced.

The annual attrition rate of 0.6%[2] is far below the attrition rates among developing countries' household surveys reviewed by Alderman *et al*. (2001), and proved not to be a problem in relation to obtaining consistent estimates. To check the possible impact of panel attrition on our results, we conducted the Becketti-Gould-Lillard-Welch (BGLW) test of Becketti *et al*. (1988). The test has been used by researchers to assess the impact of panel attrition in the different household surveys in the USA and developing countries (Duncan & Hill 1989; Fitzgerald *et al*. 1998; Alderman *et al*. 2001). The rationale of the BGLW test is to compare the total sample and the "stayers" sample in order to assess how different the parameter estimates would be from those in the total sample if only the "stayers" sample was used in the analysis (Fitzgerald *et al*. 1998). We found a non-significant difference among the output regression coefficients from the original sample and the non-attriting sample. This is a good indicator that, if only the non-attriting sample is used for the panel data analysis, there is no evidence that unbiased and inconsistent estimates will be obtained (Becketti *et al*. 1988; Duncan & Hill 1989; Fitzgerald *et al*. 1998; Alderman *et al*. 2001), especially when the interest is to estimate the production functions presented below.

The unique feature of this study dataset is that it followed both the original and split-off households during the second wave. This allowed constructing an extended family dataset and using it for the current wave as units of analysis in panel regressions.

Table 1: Number of original and split-off households

	1986	**2012**
Original household interviewed	190	164
Split-off household interviewed	-	200
Total households interviewed	**190**	**364**

Source: Household surveys, 1986 and 2012

Extended families play a key role in risk sharing by pooling their income and other resources to support their relatives, especially in agriculture-dependent societies, where production and income variations are very frequent (Cox & Fafchamps 2007). Witoelar (2013) suggests that researchers should consider extended families as a unit of analysis when analysing consumption growth and decisions. Even though the extended family does not fully act as a unitary household, some important allocations may be made at the extended family level, such as land allocation, capital, and labour use. Consequently, while analysing long-run changes in households' production, income and consumption over time, using a panel of extended families is preferable to using a panel of original households only. In this view, our study links the split-off households (offspring) to their original parent households and takes advantage of this featured dataset to assess the determinants of long-term growth in agricultural production in this setting of rural Rwanda. An *extended family* is defined here as a set of households that originate from the same 1986 nuclear household. An *extended family dataset* (or *balanced panel*) was therefore constructed, consisting of 164 original households (stayers) from the first wave, and 164 extended families (that is 164 stayers merged with their respective 200 offspring households) in the second wave. On the other hand, a *full sample* (or *unbalanced panel*) is referred to as a panel dataset made up of 164 original households for the 1986 wave, and 364 households for the 2012 wave (164 stayers and 200 split-offs considered individually).

[2] Annual attrition rate = $1 - (1-q)^{1/T}$, where q is the overall attrition rate and T is the number of years covered by the panel (Alderman *et.al*. 2001).

4. Agricultural system in the study area

Agriculture is still the backbone of subsistence in the area under study. Land is the major factor of agricultural production, and the major source of access to land is through inheritance (64%), followed by purchasing land (33%). The remaining 3% are obtained through gifts via family linkages, accessible free land, for instance on hillsides, or rented-out lands. This major asset (land) shrank by half, from 0.76 hectares per household in 1986 to 0.43 hectares in 2012. Land scarcity is mainly attributed to population pressure, and to the loss of land that was used previously in the adjacent Gishwati forest area, but that is inaccessible today due to conservation measures. In addition, the area has been exposed to severe soil erosion, which has removed a large amount of fertile soil.

Agriculture is mainly subsistence oriented and the application of modern inputs such as chemical fertilisers by households has increased only recently. In the past, the use of modern inputs was found only in big agricultural development projects and tea plantations. Table 2 summarises, for each survey round and by farm size quartiles, the land ownership among the sample households.

Table 2: Household size, landholdings and age of the household head, 1986 and 2012

Farm size group	Average total land ha[a]		Average household size		Average age of the household head	
	1986	2012	1986	2012	1986	2012
Bottom quartile	0.24	0.06	4.5	4.8	35	41
Second quartile	0.49	0.16	5.7	5.2	40	41
Third quartile	0.77	0.37	6.2	5.3	46	49
Top quartile	1.54	1.12	6.5	5.8	48	47
Average	0.76	0.43	5.7	5.3	42	44

[a] The total land owned includes available land used in Gishwati forest.

Table 3 represents the transition matrix of land ownership between 1986 and 2012. Among 100 households that were in the second quartile of land in 1986, for example, 12.5% had lost a large part of their land over the past 26 years and found themselves among the first quartile of the almost landless, or with less than 0.1 hectare of land. Of 100 households in the third quartile of landholding before, about 34% lost portions of their land and now belonged to the first (17%) and second (17%) quartiles. More than 40% of the top landowners in the first survey in 1986 are now also found among the smallholders in the first and second quartiles, and only 27% are still in the top quartile of land in 2012.

Table 3: Transition matrix of landholdings (percentage of households)

Quartiles of land in respective year		Percent, 2012				Total 1986
		Bottom	Second	Third	Top	
Percent, 1986	Bottom	33.3	16.7	38.1	11.9	100
	Second	12.5	22.5	37.5	27.5	100
	Third	17.1	17.1	26.8	39.0	100
	Top	14.6	29.3	29.3	26.8	100

Source: Authors' calculation based on survey data.

The existing farming system in the study area is still based on smallholder agriculture, with family labour as a major source of total labour input. Through the intercrop system, which is the most common in the area, the major crops grown include maize, sorghum, sweet potatoes, Irish potatoes, climbing and bush beans, wheat, peas, and a variety of vegetables. Many households grow perennials, such as fuel wood, banana trees and/or plantains. Coffee and tea are nowadays not grown as much on the household plots due to increased land scarcity and for environmental, and subsistence reasons.

Alongside mineral fertilisers introduced by the government through the extension services, land fertilisation is facilitated by livestock keeping. Most households rear cows, goats, sheep and pigs. Over the past 26 years there has been a decrease in the average number of goats and sheep per household. The average number of goats was 1.8 in 1986 (owned by 62% of households), but it has fallen to 1.7 goats per extended family in 2012 (raised by only 45% of the sample of extended families). The number of sheep averaged at one in the first survey (animals kept by 45% of the households), and rose to 1.5 sheep by household, kept by 42% of the families. However, the decline in goat- and sheep-keeping observed in the area has been compensated for by a considerable increase in the number of cattle, which rose from 0.7 cows per household (cows kept by only 19% of households in 1986) to an average of three cows per family, kept by 76% of the extended families in 2012. This is partly a result of the government initiative called the "*Girinka* programme", which aims to give one cow to every poor family in order to eradicate food insecurity and poverty in rural Rwanda by the year 2025.

5. Empirical strategy

In what follows we analyse how these long-run structural changes have affected production. Different functional forms are used in various applications to describe production (Rasmussen 2011). The most famous functional form of production function used in many applications is the Cobb-Douglas function, which satisfies a large number of properties. It i is also used in this study. Basically, the production relationships have been evaluated using the equation of the form:

$$\ln Output = \ln A_i + \beta_1 \ln Land_i + \beta_2 \ln Labor_i + \beta_3 \ln Capital_i + \varepsilon_i \quad (1)$$

However, deriving conclusions from the above standard specification is problematic. Von Braun *et al*. (1991) point out that some unobserved variables may affect both input and output levels. These may be household or location specific and need to be borne in mind while cautiously interpreting estimates from equation 1. Even though we controlled for education level of the head (as a proxy of farmer's ability) and the quality of the land, a number of latent variables might not have been measured, and their effect is not possible to capture using cross-section estimation.

To tackle this issue, the panel model was used for this study. The fixed-effect model is specified as follows:

$$\ln Y_{it} = \ln A_{it} + \beta_1 \ln L_{it} + \beta_2 \ln M_{it} + \beta_3 \ln K_{it} + \beta_4\, LQ_{it} + \alpha_i + \varepsilon_{it}\ ; \quad i = 1,2,\dots n\ ; t = 1,\dots T \quad (2)$$

where A_{it} is an index that measures the household's total factor productivity, Y_{it} is the household's gross agricultural output value, L_{it} is the household's land endowment, M_{it} is the total labour use, K_{it} is agricultural capital endowment, LQ_{it} is the land quality, α_i is the household-specific fixed effect, and ε_{it} is the idiosyncratic error term. The β_i's are technology parameters to be estimated (elasticities of production) and are assumed to be constant across households. It is assumed that the total factor productivity index A_i of farm household is affected by education, farmer's experience, wealth, and other household and community characteristics (Deininger & Okidi 1999) that need to be controlled for. Table 4 shows the mean statistics per year. The statistics show that the levels of agricultural output are about the same (5% lower) in 2012 as in 1986, and farm size, as already mentioned above, was significantly lower in 2012 compared to 1986. Output per hectare increased by 67%, and the value of agricultural capital also increased about fivefold (from 1 264 Rwf in 1986 to 6 671 Rwf – constant prices – in 2012). It is obvious that agriculture is becoming more capital and labour intensive in the study area, while landholding decreased by half over the past three decades.

Table 4: Summary statistics of regression variables per year

Variable name	Variable definition	1986		2012	
		Mean	Std. dev.	Mean	Std. dev.
Output	The gross output value for all crops in Rwandan francs	19 199	16 991	18 242	32 381
Land	Total farm size per household in hectare	0.76	0.67	0.43	0.61
Labour	Total labour units (person-days/hectare) used per household per year	493	218	1 792	2 926
Capital	Total value in Rwandan francs of agricultural tools and equipment	1 264	1 530	6 671	15 571
Land quality	Subjective judgment of land quality: 1 = very good; 2 = medium; 3 = bad (here: percentage of households with at least good land quality)	96%	-	60%	-

Source: Authors' calculation based on survey data. Std. dev.: Standard deviation.

The dependent variable (gross output value) is calculated as total market value of all crops produced within a household/family, evaluated at constant prices (1986). Agricultural capital is hereby referred to as the market value of all agricultural tools and equipment. Farm size (land) is evaluated in hectares, while labour is captured by the number of person-days per hectare of land used in agriculture in a year. The land quality variable comes from a subjective judgement by the farmers of their own land quality. Land quality takes values of 1, 2 and 3 for good, medium and poor land quality respectively. A positive relationship is expected between the three factors and agricultural output. Lower quality of land is expected to lower production.

Note on deflator

For a study of long-run economic change, deflated economic values are needed, and thus a credible deflator is to be established. Nominal values in 2012 were converted into real terms using our own calculated Food Price Index, taking 1986 as the base year. The Fixed Basket Approach (or Laspeyres Approach) was used, where the same food basket for median sample household was priced in each period. The following modified Laspeyres formula was used (FEWSNET, 2009; Turvey, 2004):

$$LFPI = 100 * (\sum W_n \, \mathrm{Pr}) / \sum W_n \tag{3}$$

where:
LFPI = Laspeyres Food Price Index
Wn = is the budget share of different commodities that form the food basket
Pr = are the relative prices (a relative price is a ratio of a good or service in one period to the price of that same good or service in the reference period).

This was motivated by the fact that household spending on food commodities in the study area accounts for more than 80% of total expenditure. Farmers will be affected more by price variations in food than in non-food items, making the FPI the best deflator for output, expenditure and income values in rural areas. Besides, the existing dataset lacks some information on non-food item prices necessary that would be needed to calculate a complete Consumer Price Index (CPI) for the sample population. The resulting FPI in 2012, taking 1986 as base year, was 914.51%, which does not differ much from the national CPI of 950.80%.

6. Empirical results and discussions

The estimations carried out in this section are mainly an expression of the technical relationship between inputs and outputs in farming systems. According to Von Braun *et al*. (1991), it is not easy to capture the interactions of factors in agricultural systems, especially the complementarity between capital, labour and land as the major factors of production, and how they relate to aggregate output using crop-specific analysis. An attempt was made to compare the cross-sectional results from a Cobb-Douglass production function and, thereafter, a remedy to the abovementioned constraint was attempted through panel data analysis.

Table 5 reports the OLS regression results for the independent cross-sectional data of 1986 and 2012. Between 1986 and 2012 there was an increase in the elasticity of labour (from ca. 0.2 to 0.4), some increase in the elasticity of land (from ca. 0.5 to 0.6), and a decrease in the elasticity of capital (from ca. 0.2 to 0.1). The quality of land also matters for crop output growth in the study area.

Table 5: OLS results on determinants of agricultural output 1986 & 2012

Independent variables	**(1) OLS 1986**	**(2) OLS 2012 Extended family**	**(3) OLS 2012 Full sample**
Constant	7.261***	6.022***	5.679***
	(0.743)	(1.466)	(0.482)
Land (log)	0.507***	0.635***	0.609***
	(0.062)	(0.087)	(0.065)
Labour (log)	0.225**	*0.438****	0.457***
	(0.100)	(0.060)	(0.068)
Capital (log)	0.199***	0.101	0.137***
	(0.050)	(0.117)	(0.041)
Land quality (base: good)			
2. Medium	-0.24	-0.129	0.045
	(0.103)	(0.350)	(0.208)
3. Bad	-0.525**	-0.343	-0.193
	(0.214)	(0.350)	(0.217)
Observations	188	161	330
R squared	0.52	0.60	0.43
F-statistic	52.00***	44.64***	37.92***

*, ** and *** denote significance at the 10%, 5% and 1% level respectively. The reported are regression coefficients and the robust standard errors are between brackets. The dependent variable is the logarithm of gross output value for both specifications.

Nevertheless, as noted earlier, the interpretation of the above cross-section model should be done with caution due to unobserved household heterogeneity. To control for the hidden bias that may arise, panel data models were estimated that allow interpreting the changes in agricultural output over time (Table 6). Columns (1) and (2) in Table 6 report pooled OLS or difference in difference, while columns (3) and (4) report fixed-effects results. The results confirm the predominant role of labour, capital and land quality in output growth in the study area.

The difference-in-difference coefficients obtained on labour, land and capital do not differ very much from the independent cross-sectional elasticities for 1986, as presented in the table above. However, the elasticities obtained from the extended families dataset[3] (column 1) are slightly smaller than those from the full sample dataset[4] (column 2), even though both still show an increased contribution to agricultural output over time. The sum of output elasticities is 1.12 in column 1 and 1.13 in column 2, indicating increasing returns to scale economies.

[3] An *extended family* is hereby defined as a set of households that originate from the same 1986 nuclear household. An *extended family dataset* (or *balanced panel*) therefore was constructed, consisting of 164 original households (stayers) for the first wave, and 164 extended families (that is 164 stayers merged with their respective 200 offspring households) in the second wave.

[4] A *full sample* (or *unbalanced panel*) is referred to as a panel dataset made up of 164 original households for the 1986 wave, and 364 households for the 2012 wave (164 stayers and 200 split-offs considered individually).

Table 6: Panel model results for production function: Pooled OLS and fixed effects

Independent variables	(1) Pooled OLS Extended family	(2) Pooled OLS Full sample	(3) FE Extended family/balanced	(4) FE Full sample/ unbalanced
Constant	6.527***	6.403***	6.651***	6.074***
	(0.476)	(0.350)	(0.577)	(0.620)
Land (log)	0.560***	0.563***	0.415**	0.474***
	(0.050)	(0.047)	(0.069)	(0.078)
Labour (log)	0.390***	0.416***	0.385***	0.468***
	(0.048)	(0.054)	(0.056)	(0.076)
Capital (log)	0.165***	0.152***	0.145***	0.146**
	(0.058)	(0.035)	(0.077)	(0.071)
Land quality (Base: Good)				
2. Medium	-0.153	-0.082	-0.203	-0.090
	(0.105)	(0.102)	(0.148)	(0.181)
3. Bad	-0.357**	-0.312**	-0.423**	-0.229
	(0.138)	(0.130)	(0.174)	(0.216)
Year dummy 2012	-1.006***	-0.530***	-0.834***	-0.649***
	(0.371)	(0.121)	(0.472)	(0.219)
Observations	323	492	323	492
R squared	0.60	0.459	0.59	0.44
F-statistic	76.52***	54.10***	32.12***	16.07***

*, ** and *** indicate statistical significance at the 10%, 5% and 1% levels respectively. Robust standard errors are reported in brackets. The dependent variable is the logarithm of the agricultural output value. All continuous explanatory variables are expressed in logarithmic terms.

Similarly, the fixed effects results in columns 3 and 4 suggest that output elasticity of labour and land are still higher than the elasticity of capital. Over the period of the study, holding the capital and labour inputs constant, a 10% increase in land ownership led, on average, to an increase of about 4.2% to 5.6% in agricultural output. Similarly, holding land and capital constant, a 10% increase in labour input led, on average, to a 3.9% to 4.7% increase in output. The stagnation of land productivity over time may be attributed to the reduction of fallow periods, accompanied by losses in soil fertility over the past decades. The continuing population growth has resulted in very high pressure on land and high agricultural intensity for subsistence purposes.

Furthermore, the productivity of capital was estimated at between 0.15 and 0.17, indicating that, holding labour and land inputs constant, a 10% increase in agricultural capital increases output by almost 1.5% on average. The results also show that the poor quality of land significantly decreases agricultural output. Adding the three output elasticities, we obtain 0.95 in column 3 and 1.09 in column 4. Similar to the independent cross-section and pooled OLS results, it seems that agriculture in the sample area has increasing returns to scale economies. The total factor productivity (indicated by the constant term in the production function) is statistically significant. This indicates the positive role of technological progress and other farm-specific variables in increasing agricultural output. The significant coefficient obtained on the year dummy suggests that, compared to 1986, the agricultural output was lower in 2012. Without the government green revolution actions and conductive climatic conditions, this might have been even lower (Bizimana *et al*. 2012). From a statistical point of view, the R squared obtained for various specifications above indicate a good fit, meaning that more than 50% of the variation in the log of output is explained by the log of land, labour, capital and land quality.

The above results confirm those obtained in productivity analyses in Rwanda (Clay *et al*. 1996; Ali & Deininger 2014) with respect to output elasticities and economies of scale. Table 7 summarises the major findings on output elasticities in micro-econometric studies in Rwanda over the past two and a half decades. Most studies show decreasing returns to scale, and suggest the application and substitution of farm inputs with caution. As these results rely on different approaches, study purposes, datasets and study areas, and different units of analysis, they show different patterns of Rwandan smallholding agriculture. The production elasticities of land and labour from pooled OLS estimation in this study differ slightly from those obtained by Ali and Deininger (2014) and Clay *et al*. (1996). They are quite different from the OLS estimates obtained by Von Braun *et al*. (1991), based on the original sample in the same study area in 1986, compared with the OLS estimates from the new survey in 2012 (Table 7). Since OLS estimation cannot fully ascertain the production relationships at the household level, the alternative results – by panel fixed effects that correct for unobserved heterogeneity – are assumed to provide more appropriate output elasticities in this setting of Rwandan agriculture. Still, the fixed effects results do not differ much from the OLS estimates of the output elasticities (Table 6 and Table 7). We may thus cautiously conclude that the pattern of output elasticities actually changed in a somewhat surprising direction, with an increased output elasticity of labour in this increasingly land-constrained context, while the capital inputs strongly increased over the 26 years (as observed in Table 4).

Table 7: Output elasticities from selected micro-econometric studies in Rwanda

Author and year	Method used	Land	Labour	Capital	Other conditioners	Economies of scale
Von Braun *et al*. (1991)*	**OLS**	**0.526**	**0.22**	**0.192**	**-**	**Decreasing**
Clay *et al*. (1996)	OLS	0.38	0.54	-		Decreasing
Ali & Deininger (2014)	OLS	0.308	0.410	-	0.313	Constant
Our findings (2012)	**OLS**	**0.560**	**0.390**	**0.165**	**-**	**Increasing**
	Fixed effects	**0.415**	**0.385**	**0.145**		**Constant or increasing****

* OLS estimates based on the first round of the panel dataset from 1986 used in our analysis
** according to estimation results in Table 6, columns 3 and 4
Source: Von Braun *et al*. (1991), Clay *et al*. (1996) and Ali and Deininger (2014).

7. Concluding remarks

This paper has analysed the long-term drivers of agricultural output in a densely populated area of Rwanda. The analysis is based on a unique panel dataset that spans a 26-year period. That it was feasible to resurvey farm households, including their split-off households comprising the children's families, may encourage more such research to be done in the long run to discover intergenerational agricultural change in Africa based on earlier surveys that are revisited.

The findings suggest that labour, capital, land and land quality are key drivers of output growth in the study area, but the pattern of weights of these production factors have changed and shifted toward more labour and more capital intensity. Farm size declined by almost half over the past two and a half decades, largely due to population growth. Agriculture in these communities has shown a more or less constant output elasticity of land, despite increased land constraints, and a decreasing capital elasticity, as the use of capital increased a lot. In parallel, rural development and education facilitated more off-farm employment in the area.

Our findings show a substantial contribution of farm size to agricultural growth, and stresses the relative importance of labour in the study area. Farmer education and training would be important for sustained growth in labour productivity. Investment in both land quality and agricultural capital are also important to boost agricultural growth. Pathways to agricultural innovations and off-farm employment are required in the study area, accompanied by a population policy for a transition to lower population growth.

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