www.jard.edu.pl http://dx.doi.org/10.17306/J.JARD.2021.01427

Journal of Agribusiness and Rural Development

pISSN 1899-5241
eISSN 1899-5772

4(62) 2021, 383–399
Accepted for print: 30.09.2021

EFFECTS OF SOIL AND WATER CONSERVATION INVESTMENT ON HOUSEHOLD INCOME IN THE VOLCANOES NATIONAL PARK OF RWANDA: AN INSTRUMENTAL VARIABLE QUANTILE APPROACH

Ildephonse Musafili[1]✉, Oscar Ingasia Ayuya[1], Eliud Abucheli Birachi[2]

[1]Egerton University, Kenya
[2]International Center for Tropical Agriculture (CIAT), Rwanda

Abstract. Soil and water conservation (SWC) technologies contribute to sustainable agriculture and rural poverty reduction. Yet, the relationship between farm household income and SWC investment is not well-understood in Rwanda. This study aims to assess the effects of investing in SWC on household income and improve the knowledge of how various classes of smallholders can benefit from such an investment at a farm level. The study used survey data from 422 farming households in northern Rwanda's Burera, Gakenke and Musanze districts. Descriptive analysis was employed to determine levels of use of SWC and SF measures. Quantile estimation classified three classes of farming households: the poor, middle-income earners and the rich. Instrumental variable quantile regression was adopted to assess heterogeneous effects of financing SWC investment. The results revealed that the extent of using SWC and SF measures is generally low. Agriculture income and off-farm (casual) wages had the largest income shares among the poor and middle-income earners. Financing investment in SWC increases income significantly for middle-income earners, i.e. five times more than the poor, but it was ineffective for the wealthy. Socio-economic factors and commercial crops had a significant effect on income across the classes. Institutional factors demonstrated no significant impact on the poor and middle-income earners. The findings suggest that incorporating pro-poor interventions in SWC investment would increase the productivity and commercialisation of cash and staple crops. These results inform a need to promote linkages between SWC investment and income diversification strategies to increase asset-building for the poor and close income gaps among the three farming classes. This finding suggests the need to introduce saving and lending innovations in SWC that link farm activities to non-farm opportunities.

Keywords: soil and water conservation investment, income effects, instrumental variable quantile, farming household, Volcanoes National Park

INTRODUCTION

Soil and water conservation (SWC) technologies contribute to sustainable agriculture and rural poverty reduction for smallholder households. Empirical studies point out that productivity gains from SWC can be associated with an increase in household income and changes in food prices (Huang et al., 2019). In addition, on-farm adoption of SWC (Nyanga et al., 2016) links farm investment with employment generation and improvements in household welfare. However, barriers to technology adoption, initial asset endowments and market access inhibit the ability of the poor to invest in SWC. Also, land and environment degradation effects are observed mostly among socio-economically poor farmers (Thiry et al., 2018; Thorn et al., 2016).

✉Ildephonse Musafili, Department of Agricultural Economics and Agribusiness Management, Egerton University, Kenya, e-mail: musafili@gmail.com, https://orcid.org/0000-0002-7280-5831

There is a lack of empirical evidence backing the relationship between farm household income and SWC investment among smallholders in Rwanda. However, the benefits and impacts of SWC were linked to development in human capital and agricultural commercialisation. Thus, the commercialisation of agriculture could be geared towards financing investment in SWC (Chaudry and Wimer, 2016). SWC investment can, in turn, support commercialisation and sustainable agricultural development (Ochieng et al., 2017). From a rural development standpoint, it is critical to understand how various categories of smallholders can benefit from financing investment at a farm level.

Rwanda has increased public investments in the gross domestic product (GDP) from 5% to 15%, of which agriculture occupies 56% (World Bank, 2019). Farm-level investment is one of the principal sources of income of about 80% of households in the Volcanoes National Park (VNP). However, smallholders have small lands, ranging between 0.1 and 0.5 ha (Bigler et al., 2017). In addition, soil degradation due to heavy water erosion and persistent poverty hinders the development of the farm-level investment. Furthermore, low adoption of SWC measures has accelerated the rate of erosion and water quality deterioration, leading to heavy investment costs incurred by local farmers (Musafili et al., 2019). To reduce the effects of erosion and promote investment in soil and water conservation (SWC) and soil fertility (SF), the country introduced a nationwide crop intensification programme (CIP). Under it, the land husbandry, water harvesting and hillside irrigation (LWH) projects aim for hillside intensification and sustainable production systems by increasing access to input at 50% subsidy and household income while improving food and nutrition security (Mugonola et al., 2013).

Economic effects of SWC were determined using both market and non-market approaches focusing on farm practices and increased crop yield (Adgo et al., 2013). Previous studies on income and poverty effects of commercialisation (Ogutu and Qaim, 2019) and fiscal policies (Giorgia et al., 2013) concluded that differences in household incomes increase these effects. Therefore, the impact of SWC investments was expected to be highly correlated with income and potentially endogenous. SWC investment entails allocation of finances, time and labour on a farm for activities related to conservation of soil and water resources and improving soil fertility for future use. SWC measures (terraces, AEC ditches, agroforestry, hedgerows and waterways) contribute to stabilising slope profile, controlling soil erosion and surface runoff and rehabilitating degraded land (Baba et al., 2017). SF measures (NPK, DAP, urea, organic manure and pesticides) help to improve soil organic matter and nitrogen content degraded by erosion (Mosissa et al., 2019).

This study introduced an instrumental variable quantile regression (IVQR) approach to account for heterogeneous effects and the identification of causal effects. IVQR is motivated by the continuous nature of household income variable as different from the control functional (CF) approach adopted to dummy income-dependent variable (Chernozhukov and Hansen, 2008). Also, the inferential procedure of IVQR arises from an estimation algorithm. With its essential feature of being robust to weak and partial identification, IVQR remains valid in cases where identification fails completely (Lee, 2007).

This paper contributes to the literature that links farm household income with SWC investment in Rwanda. It provides evidence on the impact of policy-relevant variables essential in designing pro-poor interventions to close income gaps among smallholder farmers. The commercialisation variable includes information that links complementary investment in farm and non-farm activities, market participation and household asset ownership. Access to agricultural extension and communication services (AAECS) involves farmers' participation and social learning to enhance mindset change for technology uptake in SWC. The study contributes to the methodology of impact heterogeneity using IVQR and cross-sectional data, which is opposed to previous studies with standard quantile regression.

The remainder of this paper is structured as follows. Section 2 provides details on materials and methods, including the study area, study design, sampling and data and description and measurement of variables. Section 3 describes the econometric model of IVQR. Section 4 focuses on descriptive analysis and empirical findings. Finally, section 5 concludes the paper and provides policy implications.

MATERIALS AND METHODS

Description of the study area

This empirical research builds on cross-sectional data from farm household investment surveys in northern Rwanda (Fig. 1). Rwanda is a landlocked country

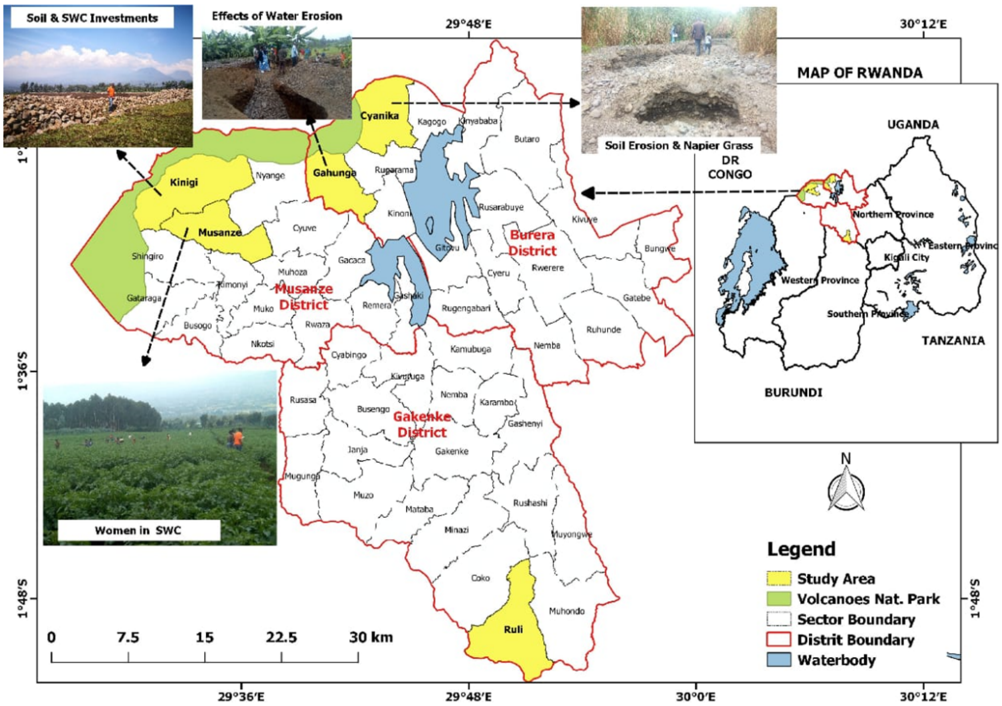

Fig. 1. Administrative map of the study area in the Northern Province
Source: adapted from ICPAC Geoportal and Humanitarian Data Exchange, 2015.

located in Eastern Africa. The population under the study included beneficiaries of the Feminisation, Agricultural Transformation and Rural Development (FATE) project in the volcano region. The study area covers Burera (located at 1°25' S and 29°44' E), Musanze (1°29' S and 29°38' E) and Gakenke (1°69' S and 29°26' E) districts in the Northern Province.

It is a high altitude area rich in volcanic soils; it is used predominantly for the intense cultivation of potatoes, beans, maize, sorghum and pyrethrum. Its production system is based on small and fragmented land. Maize supply accounts for 45% of national maize production. Beans are the second most cultivated crop with annual yields topping 330,000 MT and productivity of 1.8 MT per ha. The adoption of climbing beans is close to 100% compared to 65% in other parts of the country. The area has potential potatoes production (12MT/ha) with an expected increase to 25 MT/ha. In addition, cassava, coffee and banana are regarded as cash crops in Gakenke. The production potential makes this area a distribution hub for the local, national and East and Central Africa markets (Larochelle et al., 2015).

Research design, sampling and data

The study adopted a quantitative approach. A multistage sampling procedure (Chauvet, 2015) was employed to randomly select 422 farming households from various administrative units: three districts, five sectors, ten cells and 19 villages. Three out of five districts were chosen purposively due to farming intensity and employment provision of the NTAE crops. The proportionate sampling process was adopted at a village level. Households were selected for a face-to-face interview based on the list of FATE beneficiaries.

The FATE survey was conducted between September and November 2019. The survey was translated into the local language, *Kinyarwanda*. A pre-test was carried out to allow the refinement of the tool. Tablets were used by 14 recruited and well-trained enumerators to collect data. The developed questionnaire had two main sections. The first included household-level data (household roster, employment, production, livestock and asset ownership and information on institutional factors). The second concerned the information on SWC and SF at the individual plot level.

Description and measurement of variables

While there are various ways to measure income at a household level, this paper estimated "farm household income" in US dollars[1] (HH_INCOME[2] in USD) by aggregating all receipts (monetary or in kind) by individual household members during a period of 12 months. The survey questionnaire comprised information related to the income of each household member from different sources: agriculture farming (income from crop farming), livestock raising (income from selling livestock and livestock products), off-farm opportunities, renting houses and assets, remittances, interests and dividends. The total household income obtained by summing up different income sources was used to calculate three income quantiles at the 25th, 75th and 95th percentile. Thus, income quantile estimation provided three heterogeneous classes of farming households (Jami, 2018): the poor, middle-income earners and the rich. The distribution borrows from the EICV5 classification of consumption developed by sorting the sample of households by annual consumption values, where consumption was utilised as a proxy for income. The five consumption quintiles were further grouped into the poor (Q1 &2), middle (Q3) and rich households (Q4 & 5). The poor class that combines the poor and extremely poor households accounts for about 42.3% of the population below the poverty line, of which 17.4% are in extreme poverty (NISR, 2018).

Table 1a shows the measurement of dependent and independent variables: control variables or covariates used in the analysis. Socio-economic and demographic factors (age, family size, educational levels, off-farm work, assets and livestock ownership) were hypothesised to motivate household members' decisions to finance SWC investment (Teshome et al., 2016).

Descriptive statistics (mean and SD) of the dependent and independent variables: control variables or covariates are highlighted in Table 1b. One of the limitations was related to the measurement of total household income due to recall and reluctance of farmers to divulge information which could lead to inaccurate measurement and biased estimates. To address these issues, data capture was performed to avoid correlation between the responses with farmers' observed characteristics (Jami, 2018).

Education was provided in years of schooling. In addition, it was assumed that more educated farmers show much interest in investing in SWC measures due to awareness and knowledge of the expected benefits of farm investment. Household size was defined as the number of family labour and hypothesised to have increasing effects due to improved livelihood and job opportunities (Martin and Lorenzen, 2016). Following Njuki et al. (2011), asset ownership was calculated based on the household domestic asset index (HAI). HAI was included as a proxy measure for the economic well-being of a household. The survey comprised various questions regarding ownership of all movable assets (household, land, other farm input and equipment), excluding livestock. The asset index was calculated by assigning a weight (w) to each asset and adjusting it for age. Livestock ownership was estimated with reference to conversion equivalents of SSA livestock into tropical livestock units (TLU). The survey questions indicated the number of animals for the different species kept by the households.

Institutional factors were measured based on walking distance to input and output markets and proximity to town. The short distance was assumed to encourage financial investment in SWC (Teshome et al., 2016). The inclusive market access variable was explained by the development of infrastructure, inputs costs, prices (output) as well as opportunity costs in terms of average walking time. Access to agricultural extension and communication services (AAECS), such as extension, credit and transport, was provided on three levels (limited, medium and wide) significant for productivity-enhancing interventions aimed at smallholder commercialisation and cutting marketing margins. Following Aung et al. (2016), the calculated AAECS score (1–12) was classified into limited AAECS (1–3), medium AAECS (4–5) and wide AAECS (>6).

Other institutional factors related to project supported interventions and cash crops commercialisation have a high propensity to stimulate financial investment. Farm sizes (measured in square metres), slope steepness, plot location and distance of plot to homestead (in Mn

[1] At the time of the survey, 1 USD was equivalent to 950 RWF (Rwandan francs).

[2] HH_INCOME represents three types of financing investment based on three classes. The poor do not invest due to very small farm sizes but earn farm wages. Middle-income earners are self-employed household members who can finance investments to increase productivity. The rich class includes farming households that pay for investment in SWC but also earn a lot from off-farm employment.

Table 1a. Description and Measurement of variables used in the study

Variables	Variable description
Dependent variable	
HH_INCOME	Average annual household income (USD) by all members in a household
Endogenous variable	
SWC_FINVEST	Is 1 if the HH pays labour to finance SWC, 0 otherwise
Socio-economic characteristics	
Gender	Gender of respondents (Female = 0, Male = 1)
Age	Average age of the HH head (years)
Household size	Average family size (numbers)
Education (years)	Years of formal education (Primary one = 1 to university = 15)
Off-farm employment	Off-farm employment (No = 0, Yes = 1)
Ownership of HH asset (log)	Household asset index (HAI)
Livestock ownership	Number of livestock owned by the HH (in TLU)
Institutional factors	
Access to agric-extension and communication services	% Category of AAECS [1 = Limited (51.6%) to 3 = Diverse (40.15%)]
SWC Program	If HH received SWC Program (No = 0; Yes = 1)
Gender program (GPI)	If HH received gender program (No = 0; Yes = 1)
Access to Input market (IM)	Walking distance to nearest input market (Mn)
Access to output market (OM)	Walking distance to nearest output market (Mn)
Proximity to town (PT)	Proximity to town (walking minutes)
Road status (%RS)	1 = very bad (17.77%); 2 = bad (20.85%); 3 = moderately good (19.19%); 4 = good (26.30%); 5 = very good (15.88%)
Plot characteristics	
Number of plots	Number of plots cultivated by the household
Plot distance	Average walking distance home-plot (Mn)
Farm size	Average cultivated farm size (Ha)
Plot location	1 = Hillside (73.74%); 2 = Top of the hill (13.28%); 3 = Valley (12.98%)
Crop commercialization	
Maize	Maize commercial production (No = 0; Yes = 1)
Irish potato	Potatoes commercial production (No = 0; Yes = 1)
Beans	Beans commercial production (No = 0; Yes = 1)
Cassava	Cassava commercial production (No = 0; Yes = 1)
Coffee	Coffee commercial production (No = 0; Yes = 1)

Source: own elaboration.

Table 1b. Descriptive statistics of dependent and control variables or covariates

Variables	Variable description	Mean	SD
Dependent variable			
HH_INCOME	Average annual household income (USD) by all members in a household	1 340.02	60.97
Endogenous variable			
SWC_FINVEST	Is 1 if the HH pays labour to finance SWC, 0 otherwise	0.37	0.02
Socio-economic characteristics			
Gender	Gender of respondents (Female = 0; Male = 1)	0.39	0.02
Age	Average age of the HH head (years)	45.18	0.57
Household size	Average family size (numbers)	4.88	0.13
Education (years)	Years of formal education (Primary one = 1 to university = 15)	3.79	0.17
Off-farm employment	Off-farm employment (No = 0; Yes = 1)	0.27	0.03
Ownership of HH asset (log)	Household asset index (HAI)	1.22	0.03
Livestock ownership	Number of livestock owned by the HH (in TLU)	0.98	0.06
Institutional factors			
Access to agric-extension and communication services	% Category of AAECS [1 = Limited (51.6%) to 3 = Diverse (40.15%)]		
SWC Program	If HH received SWC Program (No = 0; Yes = 1)	0.09	0.01
Gender program (GPI)	If HH received gender program (No = 0; Yes = 1)	0.1	0.01
Access to Input market (IM)	Walking distance to nearest input market (Mn)	27.02	1.76
Access to output market (OM)	Walking distance to nearest output market (Mn)	31.55	1.69
Proximity to town (PT)	Proximity to town (walking minutes)	110.18	6.58
Road status (%RS)	1 = Very bad (17.77%); 2 = Bad (20.85%); 3 = Moderately good (19.19%); 4 = Good (26.30%); 5 = Very good (15.88%)		
Plot characteristics			
Number of plots	Number of plots cultivated by the household	2.52	0.07
Plot distance	Average walking distance home-plot (Mn)	21.02	0.85
Farm size	Average cultivated farm size (Ha)	1.61	1.22
Plot location	1 = Hillside (73.74%); 2 = Top of the hill (13.28%); 3 = Valley (12.98%)		
Crop commercialization			
Maize	Maize commercial production (No = 0; Yes = 1)	0.64	0.02
Irish potato	Potatoes commercial production (No = 0; Yes = 1)	0.57	0.02
Beans	Beans commercial production (No = 0; Yes = 1)	0.78	0.02
Cassava	Cassava commercial production (No = 0; Yes = 1)	0.052	0.01
Coffee	Coffee commercial production (No = 0; Yes = 1)	0.094	0.01

Source: own elaboration.

of walking distance) were expected to induce changes in land management practices in the short term (Helena et al., 2015). In fact, very steep slopes may discourage SWC investment due to expected low return on investment. The more remote the distance from home to the plot, the lesser is an investment in SWC due to increased transaction costs (Gebremedhin and Swinton, 2003).

Econometric model of instrumental variable quantile regression

Instrumental variable quantile regression (IVQR) was adopted to capture the heterogeneous effects of SWC investments on household income. IVQR is important to inform strategies that could reduce the income gap for various classes of smallholder farmers as it is more efficient than two-stage least squares used in previous studies (Verkaart et al., 2017; Wooldridge, 2015). In addition, the IVQR method was chosen to account for endogeneity in large samples, which may yield biased estimates (Chernozhukov and Hansen, 2008).

IVQR was formulated based on a set of regressions as follows:

$$Y_i = D_\alpha(U) + X'\beta(U) \quad U \sim U(0,1) \text{ given } Z \text{ and } X \quad (1)$$

where:

- D – is a binary vector that indicates the status of financing SWC investment; it is instrumented to the treatment group that pays labour to finance investment,
- Y_i – is the outcome of a household income,
- X – is a vector of covariates, and
- Z – is a dummy indicating assignment to treatment group. Z is a non-separable error given by $U|_{x,z} \sim$ Uniform (0,1), with z being a vector of excluded instruments.

In Equation 1, the source of endogeneity was explained by the coefficient of interest, β, which measured the impact of financing SWC investment on household income. However, SWC investment may be impacted by household income. Furthermore, due to the correlation between D and U, SWC investment becomes potentially endogenous, leading to biased estimates of β.

The indicator D is given by:

$$D = \delta(X,Z,Y) \quad (2)$$

where:

- $\delta(.)$ is an unknown function,
- Z – is a vector of instrumental variables such as plot to home distance, AAECS and plot location,
- X – is a matrix of all the variables,
- V – is a vector of unobserved variables and is statistically dependent on U.

The IVQR estimator is assumed to be a linear model of the following form:

$$Y = q(SWC,X,\mu) = \alpha_\tau d + x\beta_\tau + \mu \quad \text{with} \quad d = SWC \quad (3)$$

The objective is to estimate the treatment effects defined by

$$q(SWC,X,\mu) - Q(SWC^0,X,\mu) \quad (4)$$

The endogeneity of SWC investment may originate from different factors, including unobserved heterogeneity, reverse causality or measurement error (Ogutu and Qaim, 2019). Under certain assumptions, this endogeneity problem can be solved by instruments. IVQR was applied to estimate between financing investment (SWC_FINVEST) against instruments (Equation 3). The resulting estimates were incorporated in the standard quantile regression to obtain conditional income quantiles (Equation 5).

The specification of the standard quantile regression and estimation of conditional quantiles for any choice of quantile $\tau \in (0 - 1)$ were based on Koenker and Bassett (1978) and followed Pede et al. (2011):

$$Y_i = \alpha(\tau)d_i + \beta_1(\tau)x_{1i} + \beta_2(\tau)x_{2i} + \ldots + \mu_i, \quad \text{with} \quad i = 1, 2, 3\ldots, n \quad (5)$$

By linearising the standard quantile model (in Equation 5) of household income variable, Y, conditional on a treatment variable, SWC and a vector of control variables, including the constant, x, the following equation was obtained:

$$HH\_INCOME_i = \alpha(\tau)SWC\_FINVEST_i + \beta_1(\tau)Socioecon_{1i} + \beta_2(\tau)Institutional_{2i} + \beta_3(\tau)Plot_{3i} + \beta_4(\tau)Cropcommercial_{4i} + \ldots + \mu_i \quad (6)$$

The treatment variable SWC_FINVEST indicates if households pay labour to finance SWC investment (SWC_FINVEST), μ represents a non-separable error term. SWC_FINVEST is endogenously determined by the linear Equation 5.

Independent endogenous variable and test for instruments

The SWC investment (SWC_FINVEST) was a dichotomous endogenous variable taking values between 0 and 1. It was equal to 1 if the household paid the labour to finance SWC investment and 0 otherwise. In the sample, 38% of households employed farm labour to finance SWC investments, whereas 62% used unpaid labour.

Three variables used as instruments (plot to home distance, AAECS and plot location) were tested for validity based on a two-stage quantile regression procedure outlined in Kwak et al. (2004). For these instruments to be valid, they had to be correlated with the variable "SWC_FINVEST". They also could not directly affect the household income of any class of farmers but through other mechanisms, including SWC_FINVEST. In the first stage, the structural equation with IVQR was employed to estimate the relationships between SWC_FINVEST and instruments. The obtained R-square of 0.07 and F-statistic of 18 indicated that the correlation between SWC and instruments would yield biased estimates in the case of ordinary quantile regression. The estimated SWC_FINVEST parameters were used in the second stage to run individual regressions with standard quantile at the 25th, 75th and 95th percentile.

Empirical results

Descriptive statistics of the class of farming households

Table 2 indicates that the average total household income (dependent variable) was 1,340 USD. On average, middle-income earners had more than twice the household income of the poor. The rich earned three and eight times the household income of the middle-income earners and the poor. There was not much difference in years and number of family labour across the classes of

Table 2. Descriptive statistics of key variables per classes of farming households

Variable description	Poor	Middle-earners	Rich	Overall
Household income (USD) (*n* = 422)	422.26 (6186.54)	981.92 (144.59)	2625.01 (1431.24)	1340.02 (1252.59)
Age of the HH head (years)	47.51 (17.54)	46.97 (14.35)	46.67 (13.25)	47.05 (15.13)
Household size (numbers)	4.71 (0.15)	5.25 (0.25)	4.88* (0.13)	4.73 (2.10)
Sex of household head	0.4893 (0.50)	0.5248 (0.50)	0.5928 (0.49)	0.53 (0.49)
Years of formal education	3.10 (2.82)	3.48 (3.39)	4.81 (4.21)	3.79 (3.58)
Occupation of household members (No = 0,Yes = 1)	0.14 (0.35)	0.26 (0.44)	0.41 (0.49)	0.27 (0.44)
Ownership of productive assets (HAI)	3.52 (1.87)	3.74 (1.93)	4.64 (2.50)	3.96 (2.17)
Number of livestock owned by the HH (in TLU)	0.76 (0.05)	0.78 (0.13)	1.38 (0.06)	0.98 (1.02)
Walking distance to the nearest input market (Mn)	30.30 (31.90)	27.29 (26.10)	23.457 (47.40)	27.02 (36.27)
Walking distance to the nearest output market (Mn)	31.54 (34.10)	38.95 (39.54)	24.114 (28.57)	31.55 (34.80)
Access to AAECS	0.19 (0.39)	0.26 (0.44)	0.31 (0.46)	0.25 (0.43)
Proximity to town (walking minutes)	117.5 (209.52)	113.68 (84.49)	99.285 (62.51)	110.18 (135.36)
Number of plots cultivated by the HH	2.15 (1.37)	2.41 (1.44)	2.79 (2.46)	2.45 (1.847)
Average walking distance from home to plot (in Mn)	38.33 (54.4)	49.86 (50.34)	78.51 (103.8)	55.51 (75.3)
Average farm size in square meters	2,762.83 (2,023.95)	5,983.81 (6,7366.80)	5,409.421 (4,978.80)	2,278.58 (3,8938.40)
Commercialisation of maize produced (No = 0; Yes = 1)	0.56 (0.50)	0.63 (0.48)	0.74 (0.43)	0.646 (0.47)
Commercialisation of potatoes produced (No = 0; Yes = 1)	0.51 (0.50)	0.58 (0.49)	0.6 (0.49)	0.568 (0.49)
Commercialisation of beans produced (No = 0; Yes = 1)	0.76 (0.42)	0.81 (0.39)	0.80 (0.40)	0.78 (0.41)

* Standard deviations are shown in parentheses.
Source: own elaboration.

farmers. The majority of household heads were women in the case of the poor, whereas there were more men heads of households for the rich than middle-income earners. The poor class of farmers was less educated, suggesting lesser knowledge and awareness regarding investment in SWC. The poor having the least access to off-farm opportunities, limited ownership of assets and livestock may contribute little to household income due to lack of resource endowment and the inability of these farming households to cope with natural disasters. The results show less access to input and output and town markets for the poor, indicating that they incurred more costs due to the high opportunity cost of time. The poor had limited AAECS, the class of middle-income earners had medium access, whereas the rich had wide access. These findings imply that the groups still have limited participation and social learning from extension agents. The AACS approach promotes cooperative behaviour and facilitates mindset change and information flow while enhancing technology uptake (Teshome et al., 2016). The poor have small farm sizes and use the shortest distance to plot because they operate near the homestead. These have consequences on their low participation in the commercial production of cash crops such as maize, potatoes and beans.

Classification of farming households per income sources

Figure 2 depicts three heterogeneous classes of farming households obtained using quantile estimation. The results show that agriculture and off-farm earnings made up the highest share of the total household income for the poor. The agricultural income of the poor was four and ten times lower than that of the middle-income earners and the rich due to small farm sizes and lack of productive resources. Wage rates for off-farm activities were far below those of the middle-income earners and the rich because of the poor supply of cheap casual labour in agriculture, construction and transport services. For instance, they mainly serve as bike operators (*Abanyonzi*) or *karani ngufu* (physical transport of the luggage on the head).

On the other hand, middle-income earners get wages from off-farm employment in agribusiness and market-oriented cooperatives (Bigler et al., 2017). On top of this, the rich receive high income from rent of assets and transfers (remittances) and savings and dividends. The results highlight the need to improve resource-use efficiency for the poor to commercialisation and income diversification to close the income gap between these classes.

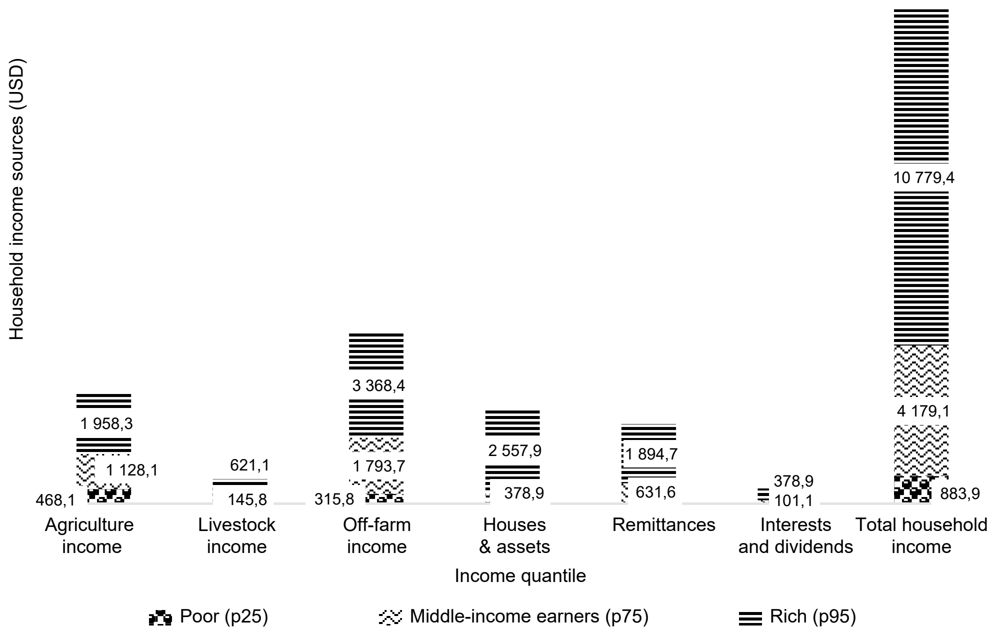

Fig. 2. Description of household income per classes based on quantiles
Source: survey data, 2019.

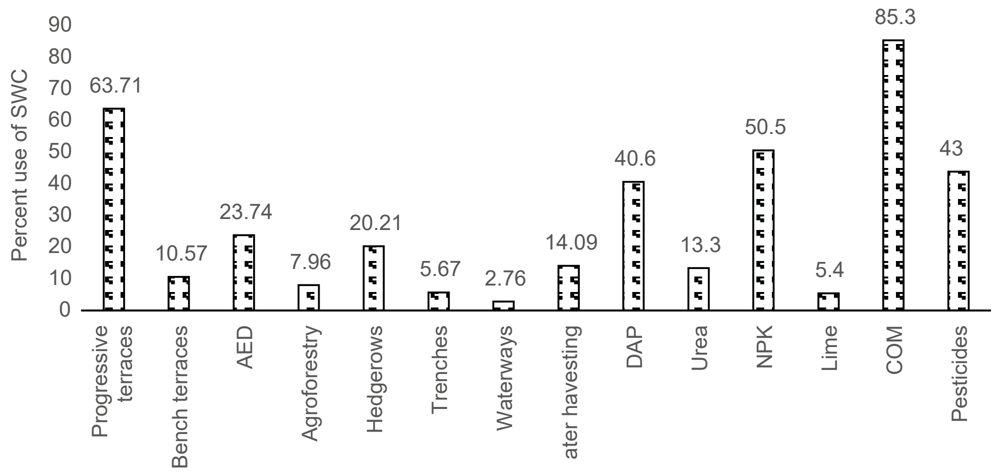

Fig. 3. Plot-level use of SWC and SF measures
Source: survey data, 2019.

The extent of using soil and water conservation and soil fertility measures

A total of 14 practices of SWC and SF measures were identified in the study area. Fig. 3 illustrates the extent of using these conservation measures.

The findings indicate that about 64% of the cultivated plots had progressive terraces (in the form of ridge farming), combined with contour bunds with stones, ditches and *Napier grasses*. Bench terraces could be found in approximately 10% of cultivated plots. Low use could be linked to the gentle slopes of arable farms located at the foot of the volcano park. Bench terraces are constructed on steeper slopes ranging between 25 to 55% (Bugenimana et al., 2019). The findings revealed that anti-erosion or drainage ditches were used in less than a quarter of cultivated plots. They consisted of horizontal terraces that limit soil transformations and increase surface water infiltration into the subsoil (Sobczuk and Olszta, 2010). The study identified that less than 10% of plots included agroforestry trees and shrubs that retain soil nutrients and control soil erosion. Common plant species found in these farms were scattered banana, *French cameron, Napier grasses* and *eucalyptus*. Very few fruit trees were found.

The results on the plot level use of hedgerows on farms were estimated at 20%. Hedgerows with trench were present on about 6% of cultivated plots. Continuous cultivation, machinery and livestock overgrazing led to major losses of hedgerows, and hence decline in soil quality and reduced soil water holding capacity (Froidevaux et al., 2019). In addition, hedgerow losses contributed to changes in farming practices, resulting in a decline of farm species and ecosystem services such as pest control and pollination.

Use of waterways or water channels located on farms was observed in 2% of the plots cultivated. Stone fences and trenches surrounded them to direct water runoffs to large water streams (*Imyuzi*) and connected them to the foot of the park area. According to Fiener and Auerswald (2017), well-established waterways could effectively prevent and reduce sediment delivery caused by park erosion.

The results suggest that nearly 14% used any water harvesting techniques on the farm or in the proximity of their households to prevent heavy and erratic precipitations, which are a source of low crop yield and sometimes total crop failures in the study area. Rainwater harvestings are important to solve water shortages for agricultural and domestic use (Ghimire and Johnston, 2019).

The levels of used SF measures, such as chemical fertilisers, pesticides, organic manure and lime, were highlighted. NPK and DAP were used on 50% and 40% of cultivated plots, respectively. Urea was applied on less than 15 % of the plots. The proportion of plots that used pesticides was about 44%. The use of lime was very low, with 5% of the plots. Lime use was not frequent, maybe because the soil in the region is comparatively fertile and not acidic. Compost and organic manure (COM) was the most frequent measure, found on about 85% of cultivated plots. The use of inorganic fertilisers is still low despite farmers receiving subsidies.

The findings indicate that, unlike progressive terraces and COM, the extent of using other SWC and SF measures is generally low. High use of organic fertilisers indicates farmers' consciousness with organic farming for food production mixed with small quantities of agrochemicals. Improving the involvement of local authorities in SWC extension services could increase awareness of the importance of these techniques for organic farming, soil conservation and water retention in the volcano region.

Instrumental variable quantile regression and household income effects

The IVQR model indicates that most results are robust across the entire sample with 95% confidence intervals. The model fitness test shows that R-square values of 0.2182, 0.2922 and 0.5578 constitute a local measure of goodness of fit for the respective p25, p75 and p95 quantiles. Its fitness is motivated by the familiar R-square of classical least squares regression, which lies between 0 and 1. Thus, the IVQR model indicates the relative success of the corresponding estimates at each specific quantile. The test for correlation between the dependent variable and instruments yielded an R-square of 0.07 and F-statistic of 18, suggesting weak identification of instruments. According to Koenker and Bassett (1978), the dual inference procedure (with a series of quantile regressions) is robust to weak instruments.

The findings concerning IVQR are presented in Table 3. By controlling for all the covariates, financing SWC investment has a significantly positive effect on the average annual household incomes of the poor and middle-income earners. However, the impact of financing SWC investment was not statistically significant for the rich. It could be because the rich have better diversification strategies that undermine income from crop farming; therefore, they have no self-motivation to invest in SWC activities. The effect of financing such an investment leads to a two percentage point increase (0.02) for the poor; and a ten percentage point increase (0.1) for the middle-income earners. This implies that, from an annual average household income of USD 422.26, financing SWC by the poor would lead to an additional USD 21. Middle-income earners would increase the average annual income of 981.92 by USD 98.2. The results reveal that gains received by middle-income earners are close to five times greater than those of the poor. Poor farmers operate on small farms as compared to middle-income earners. Hence, the poor cannot rely on self-production from land, whereby land size is a challenge for production and market. Consistent with findings by Bigler et al. (2017), the poor are more subsistent oriented than middle-income earners who are generally self-employed.

The results reveal that male participation in SWC investment has decreasing effects on household income across the three classes. This could be explained by the fact that farming is becoming less important for men who find more opportunities in the non-farm sector and that investing in SWC can lead to a loss in a household. Unlike women, greater involvement of men in off-farm activities than farming provides higher household earnings and justifies a transitional process in agriculture. For instance, the poor are found as assistant masons (in construction), bicycle taxi drivers or *karaningufu* (in transport), where the daily wage is almost two times higher compared to farm wages. For the middle-income earners, men are in relatively well-paid jobs compared to poor farmers in motorcycle (*bodaboda*) transport, petty trade and construction (as masons). The rich are engaged in small-scale business or fully employed as primary teachers, nurses or local leaders. The results also suggest that the contribution of women to agriculture is increasing as men are migrating to other forms of employment. The findings corroborate the conclusion by Pattnaik et al. (2017) that the process of agriculture transformation should be motivated by men's investment in SWC through income from off-farm activities and women's growing contribution to agricultural labour and income decisions.

The effect of SWC investment on household income increases gradually and significantly with the age of household head for the middle-income earners and the rich. Older age in the highest two classes could be associated with economic stability due to asset accumulation and other earning opportunities. Consistent with Osuji (2019), the increasing effect on income could be linked to farming experience and the ability of old farmers to make investment decisions.

The effect of SWC investment on income decreases with household size for the poor but is significantly positive for the middle-income earners. The poor farmers

Table 3. IVQR results on heterogeneous effect of SWC investments

HH_INCOME	Poor farmers Q1 (P.25)		Middle- income earners Q2 (P.75)		Rich farmers Q3 (P.95)	
	coef.	SE	coef.	SE	coef.	SE
SWC_FINVEST	0.02** *	0.01	0.10***	0.01	0.02	0.02
Sex	–120.60**	51.19	–284.96***	61.64	–400.44***	134.91
Age	0.36	1.78	0.63**	2.14	14.70 ***	4.69
Household size	–40.09***	11.33	80.61***	13.64	–42.22	29.86
Education	5.54	7.70	10.58	9.27	195.91***	20.30
HH occupation	286.33***	54.86	646.58***	66.06	–335.18**	144.58
log of HH asset	227.14***	48.06	197.55***	57.87	378.51***	126.66
Livestock (TLU)	–75.35**	33.57	116.94***	40.42	368.15***	88.47
Access to agricultural extension and communication services						
Medium	–195.79***	67.47	127.37	81.23	1,034.13***	177.81
Diverse	244.34 ***	92.25	111.98	111.07	78.72	243.10
Input market	–2.50***	0.82	–5.29***	0.98	–1.07	2.15
Output market	0.37	0.68	–1.82**	0.82	–7.46***	1.79
Proximity to town	–0.12	0.11	–0.22	0.13	–1.09***	0.29
Road status						
Bad	48.13	69.91	–123.06	84.18	–496.72***	84.24
Moderately good	–14.18	78.35	49.93	94.33	373.28*	206.48
Good	95.97	76.03	–286.62***	91.54	259.64	200.37
Very good	378.86 ***	82.11	524.24***	98.86	975.48 ***	216.39
Farm size	–0.000008	0.000037	–0.000028	0.0000449	–0.0001	0.00001
Number of plots	15.05	11.99	–27.37	14.44	135.47 ***	31.61
Maize	229.97***	46.65	329.23***	56.16	–143.94	122.93
Irish potato	169.78***	52.91	176.53***	63.71	257.80*	139.44
Bean	–3.52	62.10	4.02	74.76	–1,494.12***	163.65
Cassava	–142.16	166.53	368.59*	200.51	–1,724.82***	438.87
Coffee	494.96***	111.68	575.53***	134.46	537.25 *	294.32
_cons	218.94	144.68	199.27	174.20	2,382.30 ***	381.29
Sample, $N = 422$	163		163		96	

*, **, *** implies levels of significance at 10%, 5% and 1% respectively.
0.2182; 0.2922 and 0.5578 indicates R-square values respectively for p25; p75; and p95.
Notes: Access to agricultural extension and communication services (AAECS) include: medium AAECS and Diverse AAECS.
Road status: 1 – bad road, 2 – moderately good road, 3 – good road, 4 – very good road.
Crop commercialization: 1 – maize, 2 – irish potatoes, 3 – bean, 4 – cassava, 5 – coffee.
Source: survey data, 2019.

with many household members may be unable to adequately access the basic needs of life and have fewer opportunities to transform livelihoods. Munanura et al. (2016) consider poor households agents and victims of environmentally degrading activities due to their size and child dependence. The significantly positive effect for the middle-income earners suggests that more family members could serve as a source of employment opportunities.

The SWC investment effects on household income showed positive links with the levels of education for the rich. It implies that educated people in this class can adopt, invest and diversify strategies. Consistent with Aynalem et al. (2019), education may provide better skills for human capital development and motivation for investment in farm and off-farm activities. Thus, it enhances the ability of a household to make rational decisions and provides opportunities for occupational diversification.

The findings revealed that participation in off-farm occupation increases the effects of SWC investment on household income for the poor and middle-income earners. However, the effect of financing SWC on income was negatively associated with the participation of the rich. The results on the rich confirm our previous findings that having great diversification strategies could prompt households not to adopt or invest in farming or SWC activities. The minor effects for the poor could be attributed to differences in employment conditions compared to middle-income earners who can finance such an investment through off-farm linkages, which leads to increased employment, income generation, farm expansion and poverty reduction. On the other hand, the poor farmers rely on farm wages for survival. They do not have enough to sustain households and generate additional income. Hence, they require innovations or the creation of new businesses to improve their standards.

The effects of SWC on household income increases with household ownership of assets across the classes. The impact is the highest for the rich, followed by the poor and then middle-income earners. The rich smallholders are associated with different livelihood strategies that enable accumulating assets, motivating farm investment and increasing productivity and income (Manlosa et al., 2019). Access to income generation and livelihood diversification activities and the creation of access to markets and essential services can increase access to assets for the poor and middle-income earners.

The impact of SWC investment on household income decreases with livestock ownership for the poor but increases for the rich and middle-income earners, respectively. Livestock-holding is a vital livelihood strategy since it provides manure to fertilise the farm as a source of finance for farm investment. Due to lack of land, the poor have limited means to feed their livestock; they cannot grow fodder and look for it on neighbouring farms. Following Tadesse et al. (2019), the intensity of livestock diversification varies between assets for the rich and the poor. Therefore, increasing livestock holding is an essential safeguard to enhancing income and improving the livelihood of the poor and middle-income earners.

The findings indicate a decreasing effect of SWC investment on household incomes with medium access to AAECS for the poor due to limited education skills to grasp extension information. However, there was a positive effect with wide AAECS. This also suggests that the poor may have adequate education extension or information to access investment in complementary innovations that link farm activities to non-farm employment. The SWC impact on income for the rich was positively significant for medium AAECS, signifying that minimum effort for communication, mindset change and technology uptake is required. Probably, it is because this class possesses an advanced level of understanding compared to the poor. Kidanemariam (2015) suggested an association between access to extension programmes and differences in household welfare and investment in productive assets.

The results indicate that the effect of accessing input, output and town markets for SWC investment on household income is negative across the classes due to high costs of transports associated with high opportunity costs of farm investment. However, the results show that middle-income earners and the rich could benefit from easy transport to better markets. Lack of access to proper roads limits the ability of farmers to make high-profit margins. In Rwanda, nearly 40% of the costs of goods are attributed to transport, keeping the prices of inputs high (Kamara et al., 2019). Market linkages create opportunities for non-farm entrepreneurship, influence the income of agricultural households and incentivise the cultivation of crops (Pingali et al., 2019).

SWC investment and having more plots had positive effects on the income of the rich only, mainly due to differences in resource endowment, the scale of operation and farming conditions between this class and the other two. According to Schulte et al. (2018), these factors motivate farmers' investment behaviour and vary significantly with economic and social foundations. The findings reveal decreasing effects of SWC with farm sizes on household income across all the classes, partly due to the inability of the poor to finance farm investments to raise farm productivity. Coupled with agricultural risks, this means that the poor cannot diversify their income due to small farm sizes (Melketo et al., 2020). The rich probably spend more on buying farm inputs (seeds, fertilisers) or incur higher labour costs than the farm returns.

The results show a positive effect of SWC investment and commercial production of potatoes and coffee on household income in the three classes. SWC and maize production effects on income were positive for the poor and middle-income earners. Non-traditional cash crops contribute to the asset-building and economic empowerment of various socio-economic classes of farming households. The negative effect for beans and cassava for the rich is probably due to the high costs of inputs and investment. Staple foods such as beans and cassava have a small market share and show low levels of commercialisation (an average of 15% of the harvest) and market participation (Louhichi et al., 2019; Bigler et al., 2017).

CONCLUSIONS AND POLICY IMPLICATIONS

The study employed instrumental variable quantile regression and cross-section data on a sample of 422 households to improve the understanding of the distribution effects of SWC investment, socio-economic, institutional and plot-related factors on the income of farming households. Financing SWC investment was hypothesised to have income-increasing effects. In this study, quantile estimation helped classify farming households into the poor, middle-income earners and the rich. The results indicated high-income gaps between these classes as explained by differences in household sources of income. The findings demonstrated that low use of SWC and SF measures leads to the ineffectiveness of SWC investment in the area. The results also indicated that the gains from financing SWC investment for middle-income earners were five times larger compared to those of the poor due to the small scale of the farm operation, reliance on the low farm and casual wages and lack of assets for the poor. The effect of SWC investment and covariates (including gender, education levels, household size, age) indicated class differences in knowledge, perception and access to information or innovations to transform agriculture. These results translate into the poor's inability to invest in soil conservation to transform livelihoods due to inadequate access to basic needs of life. The positive effects of age and investment in SWC on household income could be explained by farming experience and economic stability due to asset accumulation and other earning opportunities for the aged middle-income earners and the rich. Increasing effects of off-farm occupation and SWC on income could be justified by differences in employment, which suggest that saving and lending innovations or generation of income opportunities for the poor would reduce income gaps between classes and improve their living standards. The results also indicate that a lack of extension services could translate into poor skills to grasp extension information by the poor. Improved (diverse) extension services for the rich could signal that they require minimum effort for communication, mindset change and technology uptake in SWC. The findings concerning market access demonstrated that the negative effect on income could be due to high costs of transports associated with high opportunity costs of farm investment. The decreasing effects of asset ownership and SWC on income indicate that the poor have limited means of production, unlike the rich smallholders. The latter can accumulate assets and invest in their farms. The effects of SWC investment and commercial production of both NTAEs can contribute to asset-building and economic empowerment of farming households. However, the decreasing effects attributed to SWC and production of maize, beans and cassava could be due to the high costs of inputs and investment. The present study using IVQR estimation showed the robustness of the results but with the following limitations. First, the study used cross-section data, which makes it complicated to deal with possible endogeneity. Future studies could expand this analysis of quantile treatment using panel data and fixed effects, which can improve the identification strategy. The IVQR method would help to assess the practical policy implications of the long-term effects of SWC investment. Second, measuring household income should be expanded to various income and poverty indicators to study the specific impacts of SWC investment. Finally, the results should not be generalised and rather they should focus on smallholders farm investment in the context of Rwanda and Sub-Saharan Africa.

Generally, the findings confirm that the effects of SWC investment and other covariates on household income vary substantially across classes of farmers. Increasing investment in SWC could be beneficial to various groups of farming households. There is a need to increase the use and application of SWC and SF measures in the study area. The policy implication is that promoting linkages between SWC investment and income diversification strategies would increase access to assets for the poor and close income gaps among the three farming classes. Access to infrastructure and market access would suggest programmes that facilitate market linkages from farm to non-farm entrepreneurship and incentivise the cultivation of crops. Participation in off-farm occupation opportunities would require diversification strategies such as saving and lending innovations to help the poor finance investment in SWC. The study suggests improving the efficiency in agricultural extension and communication services by involving local authorities to increase SWC and promote productive diversification. Commercial production of crops requires the introduction of SWC in production and marketing strategies to increase the productivity and commercialisation of cash and staple crops.

ACKNOWLEDGEMENTS

The authors extend the appreciation to the International Centre for Tropical Agriculture (CIAT) under the Feminisation, Agricultural Transition and Rural Employment (FATE) project. FATE is a collaborative research project within an international research partnership between the University of Bern, Switzerland, and the International Centre for Tropical Agriculture (CIAT), Rwanda. The project examines if and under what conditions rural employment in the non-traditional agricultural export (NTAE) industry leads to both increased asset building and individual well-being of women and men in rural households. We thank Professor Saithong Phommavong and Professor Znoj Henzpeter for their constructive inputs during the FATE internal review process.

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