

Research Article

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Temesgen Bocher*, Jan W. Low, Kirimi Sindi, Srinivasulu Rajendran

Gender-sensitive Value Chain Intervention Improved Profit Efficiency among Orange-fleshed Sweetpotato Producers in Rwanda

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Abstract: The Rwanda Super Foods project sought to develop a value chain for processed orange-fleshed sweetpotato products to respond to farmer concerns over lack of markets. This study used data collected from five districts in rural Rwanda under supper food project between August and September 2014. The study applied a stochastic profit frontier model to data collected from 846 households growing sweetpotato, among which 327 were value chain participants; 312 were “spillover” households that received planting material from participant households, and the remainder control households with no project links. Results showed that average level of profit efficiency in sweetpotato production systems is 55%; suggesting that an estimated 45% of profit is lost due to the combined effect of technical, allocative and scale inefficiency. The profit efficiency of participant households was 64% compared to 20% of the control households. Moreover, the profit efficiency of the female beneficiary, female spillover, and male beneficiary households was found to be 55%, 70%, and 90% against 17% for male control households, respectively. Findings suggest that an orange-fleshed sweetpotato based value chain intervention can enhance the profit efficiency of the poor and disadvantageous households, if designed with special attention to women’s needs. Thus, policies and programs aiming at improving the livelihood of smallholder should be designed targeting women and resource poor.

Keywords: Gross margin, biofortified crops, stochastic profit frontier, efficiency, economic efficiency, Rwanda

*Corresponding author: **Temesgen Bocher**, International Potato Center (CIP), Nairobi, Kenya, E-mail: t.bocher@cgair.org

Jan W. Low, Srinivasulu Rajendran, International Potato Center (CIP), Nairobi, Kenya

Kirimi Sindi, International Potato Center (CIP), Kigali Rwanda

1 Introduction

Increasing agricultural productivity and production are important avenues to increase food supply and improve the livelihoods of the poor in developing countries (Asfaw 2012; Ghimire et al. 2015; Mendola 2007). Increased agricultural production can be achieved by expanding the area under crop production, increasing the use of improved agricultural technologies such as improved varieties and improving resource use efficiency (Rahman 2003). The first two approaches, however, are less likely to happen in Rwanda; for example because land resources to expand the agricultural frontier are scarce. Similar conditions can be observed in other developing countries (Asfaw 2012; Rahman 2003; Bozoğlu and Ceyhan 2007). The second alternative of using improved agricultural technologies is challenged by limited access and financial capacity to acquire such improved technologies, and the associated increased cost of use for smallholder farmers. Therefore, increasing economic, technical and allocative efficiency in resource use for smallholder farmers becomes key to increase yield, and improve household welfare (Rahman 2003; Bozoğlu and Ceyhan 2007; González-Flores et al. 2014).

In addition, gender differences in agricultural productivity and resource use are a major challenge that hinders productivity. Consequently, reduces food supply. A 2011 FAO report (FAO 2011) showed that man-women yield difference for crop production is estimated to be between 20-30 percent. Addressing this yield gap alone could increase global agricultural production by as much as 4%, which could consequently contribute to reducing the number of undernourished people in the world by 12-17 percent (FAO 2011). An equitable resource distribution and balanced power relationship could fill the observed productivity gap (Fischer and Qaim 2012; Kassie et al. 2011; Kassie et al. 2014; Udry 1996). In sum, a gender-sensitive agricultural intervention is hypothesized to increase the overall productivity and enhance the earning capacity

of the resource poor households. This study explores the impact of gender-sensitive agricultural intervention in improving profit efficiency among sweetpotato producers. Sweetpotato (*Ipomoea batatas* L.) is one of the most important staple food crops in Rwanda, with annual production of 940,000 tons on just 5.2% of the cultivated area. This study investigates the impact of a gender-sensitive orange-fleshed sweetpotato (OFSP) value chain intervention on the profit efficiency, and identifies factors explaining the profit efficiency difference in Rwanda. Gross margin, labor, economic, and financial profitability of sweetpotato production is determined. The objective of the study was to test the hypothesis whether development of a sweetpotato value chain for sweetpotato products, leads to better returns for male and female sweetpotato producers.

2 Methods

2.1 Study Areas

The agriculture sector remains the main contributor to the Rwandese economy. The sector contributes 34% of

the gross domestic product, 80% of employment, and generates 70% of foreign earnings (Muhinda 2013). To contribute to agricultural sector development, the International Potato Center (CIP), in collaboration with the Rwandan Agricultural Board (RAB), is working to develop improved sweetpotato varieties and delivery systems to reach rural producers and urban consumers.

The Rwanda Super Foods project operated from 2010-2014 in four intervention districts: Gakenke, Rulindo, Muhanga, and Kamonyi (Figure 1). These districts were selected because Gakenke and Muhanga are in the Northern Provinces where the climate is cool and sweetpotato can be grown in about 8 months in a year. They were also near to a private sector¹ with a production unit utilizing Orange-flesh sweetpotato as a raw material to produce processed products.

Muhango and Kamonyi were selected because they were in a climatic zone that has the highest potential in terms of sweetpotato production. Participant households were randomly selected using three stage random selection procedures: sectors selected from the five districts, followed by randomly selecting cells, and finally

¹ Urwibutso (SINA) Enterprises



Figure 1: Map of Districts in Rwanda

by randomly selecting villages from the cells. A list of households from the village was compiled in consultation with the group leaders. From that list, individuals were randomly selected to participate in the survey. The same procedure was used to select the non-participants households, although the neighboring villages to the villages we have selected for intervention were given more weight for selection. Moreover, spillovers were randomly selected from list of households, those who received sweetpotato planting materials from beneficiary households but not directly from the project

In literature, efficiency in production systems is mainly computed by employing three approaches: technical, allocative and scale efficiency. If the ratio of marginal product of the input used in the production of output is not equal to the ratio of input prices, the farmer is said to be inefficient in resource allocation. Similarly, if the production of output level is at a level where the price of the product is not equal to the marginal cost of output, then the farmer is classified as scale inefficient (Rahman 2003; Kumbhakar et al. 1989). In the past, the *production frontier* approach was widely used to measure inefficiency (Rahman 2003). However, this approach has been criticized for its inability to yield reliable figures of inefficiency (Ali and Flinn 1989; Tzouvelekas 2001). To deal with this limitation, recent studies have used *stochastic profit efficiency* models, which enable the simultaneous computation of the three measures of efficiency (Rahman 2003; Ali and Flinn 1989; Wang et al. 1996). The *stochastic profit frontier* model assumes that any inefficiency in a production system can be translated into lower revenue or profit. Hence, the profit efficiency of a farmer can be defined as the ability to derive frontier (optimum) output with the given level of input prices (Ali and Flinn 1989); thus, the loss of profit due to not operating at optimal output level is profit inefficiency (Ali and Flinn 1989).

2.2 Empirical methodology

In this study, the stochastic profit frontier model is adopted to examine the level of efficiency among sweetpotato producers in Rwanda and factors explaining differences in profit efficiency. The stochastic profit function is defined (Wang et al. 1996) as:

$$\pi_i = f(P_i, Z_i) \cdot \exp(\varphi_i) \quad (1)$$

Where π_i is normalized profit (revenue less variable cost) of i^{th} farm household divided by price per kg of output price; P_i is the vector of variable input prices incurred by

an individual farmer divided by the output price; Z_i is a vector of fixed inputs; and φ_i is an error term for $i=1, 2, \dots, n$ is the number of farm households in the sample. The error term φ_i has two independent components: one-side error term representing inefficiency and normal random error (Ali and Flinn 1989).

$$\varphi_i = v_i - u_i \quad (2)$$

Where v_i is independent and identical, and normally distributed, $N(0, \delta_v^2)$ two-sided random error term, independent of u_i 's (Rahman 2003; Battese and Coelli 1995). The u_i 's are the non-negative random variables associated with inefficiency in the production function, u_i 's are independently distributed at truncation of the normal distribution with mean $\mu_i = \delta_0 + \sum_d \delta_d W_{di}$ and variance of $\delta_u^2 (|N(\mu_i, \delta_u^2)|)$, where W_{di} is the variable associated with inefficiency of i^{th} farm household. δ_0 and δ_d are unknown parameters to be estimated (Battese and Coelli 1995). The profit efficiency of i^{th} farm household in the context of the stochastic frontier profit function is defined as:

$$E(\varphi_i) = E(v_i - u_i) = E(\exp(-u_i|\varphi_i)) = E\left(\exp\left(-\left(\delta_0 + \sum_d \delta_d W_{di}\right)\right)\right) \Big| \varphi_i \quad (3)$$

Where E is the expectation operator, the result can be achieved by expressing the conditional expectation of u_i given φ_i . This study applied the Maximum Likelihood Estimation technique to estimate the unknown parameters of stochastic frontier profit, and efficiency functions simultaneously. The likelihood estimates are presented as the variance parameters, $\delta^2 = \delta_v^2 + \delta_u^2$ and the $\gamma = \delta_u^2 / \delta^2$. Hence, the logarithmic function of equation 1 can be presented as:

$$\ln \pi_i = \alpha_0 + \sum_{i=1}^4 \alpha_i \ln P_i' + \frac{1}{2} \sum_{i=1}^4 \sum_{k=1}^4 \omega_{ik} \ln P_i' \ln P_k' + \frac{1}{2} \sum_{i=1}^4 \theta_i \ln P_i' \ln P_i' + v - u \text{ and} \\ u = \delta_0 + \sum_d \delta_d W_{di} + \rho \quad 4$$

The maximum likelihood estimates (MLE) of translog stochastic profit function were obtained by using Frontier model in STATA 14.0. Moreover, paired t-test statistics is applied to measure the significance in descriptive analysis of variables.

3 Results

3.1 Descriptive statistics of participant households

To understand key gender differences, households were divided into two groups: the principal person responsible for sweetpotato production was female (Female Principal

Producers or FPP) or male (Male Principal Producers or MPP). The average years of formal education of MPP households is 5.7 years compared with 4.7 years for FPP households (Table 1). Sixty percent of MPP households were involved in sweetpotato marketing versus 67% of the FPP. Figure 2 presents the market of sweetpotato products vines, roots, and bakery products. The average figure shows that there is no significant difference between MPP and FPP households in terms of area under sweetpotato production, access to valley land, and group membership. The average revenue derived from production of different crops in the study area is presented in Table 2. The largest share of farm income for participant households is derived from sweetpotato production (\$64/household/year), followed by beans (\$62/household/year) and maize (\$53/household/year) production. Control households generated larger revenue from the sale of green peas, \$95 per household, followed by beans (\$59), and maize (\$57) production per year. Maize is found to be the main contributor of farm income for spillover households with \$57 annual sale value per household. The result indicated that households in Rwanda were engaged in multiple crop production, of which sweetpotato is one of the major crops in terms of income generation from agriculture.

3.2 Economic profitability of sweetpotato production

Temporarily hired labor accounts for 55% of the total sweetpotato production cost in FPP, and 60% in MPP households. Per hectare production costs, excluding family labor, range from \$164 to \$700 depending on the



Figure 2: Cooperative members explaining their work at a fair, Kigali, Rwanda (credit J. Low)

Table 1: Descriptive statistics of characteristics of study households, entire sample by gender of principal grower

Variable	MPP (n=260)	Std. Err.	FPP (n=586)	Std. Err.	Difference (n=846)	t-value
Education of head (years)	5.67	0.23	4.71	0.14	-0.96***	(-3.64)
Age of head (years)	43.69	0.822	46.68	0.55	2.99**	-3.03
Male adult above 14 years (number)	1.72	0.06	1.49	0.04	-0.23**	(-2.88)
Female adult above 14 years (number)	1.53	0.07	1.90	0.04	0.37***	-4.59
Sweetpotato area (ha)	0.10	0.02	0.09	0.01	-0.02	(-0.70)
Access to valley bottom land (0=no, 1=yes)	0.72	0.03	0.72	0.02	0.00	-0.14
Sells sweetpotato (0=no, 1=yes)	0.59	0.03	0.67	0.02	0.08*	-2.26
Member of a Farmer Group (0=no, 1=yes)	0.49	0.03	0.53	0.02	0.04	-1.03

Source: Authors computation based on project endline survey, 2014 and frontier estimation result. Std Err. Standard error *, **, *** significant at 10%, 5%, and 1%, level; respectively

Table 2: Average revenue from sale of different crops by level of participation in the value chain (\$/household)

Crop	Control (N=298)	Participants (N=627)	Spillover (N=514)	Total (N=1439)
Sweetpotato	59.13	64.02	43.46	56.12
Maize	56.66	53.30	57.34	55.29
Beans	59.40	62.31	44.46	54.88
Irish potato	45.31	34.53	28.90	35.86
Green peas	94.69	29.06	27.52	41.18
Soya	13.74	12.18	14.97	14.01
Total	54.82	42.57	36.11	42.89

*Numbers in parentheses are the total number of transaction made by households. Source: Authors computation based on project endline survey, 2014 and frontier estimation result. N is sample size. Exchange rate at the time of the survey: 688 Rwandan Francs/\$USD

production season (Table 3). Labor productivity estimates for FPP households is in the range of 4.6 in season A to 1.3 in season C (Table 3). The rate of return on investment in sweetpotato ranges from 0.5 in season B to 2.2 in season A for FPP households, while it is in the range of -0.1 to 1.2 for MPP counterparts (Table 3). This result is in agreement with the result of a study by Kassali (2011) in Nigeria who reported a return on investment of 1.1.

The upper section of Table 4 presents the results of determinants of profit. Expenses associated with seed (sweetpotato vines) are positively associated with the profit level. Similarly, sweetpotato area is positively associated with the level of profit. The interaction of labor, seed and square of manure, are negatively associated with the profit. Lower section of Table 4 reports factors that affect the efficiency/inefficiency level of farm households in sweetpotato production. Seed, land and manure are found to have a significant effect on the profit function. Households with larger sweetpotato area are less efficient than those with smaller areas under production, i.e. increasing sweetpotato area leads to loss in efficiency, which is in agreement with a study by Rahman (2003), even though total sweetpotato production is higher. The coefficients of female beneficiaries and female spillovers indicated that compared with control male farmers, both beneficiaries and spillover female producers have exhibited statistically significant higher profit efficiency. Education is found to have a statistically significant negative relationship with the level of efficiency. This can be explained with the higher the years of schooling the more likely farmers seek principal income generating means other than agriculture.

3.3 Profit efficiency and the determining factors

The results demonstrated that the average profit efficiency for sweetpotato producers was 0.55, ranging from a minimum of 0.06 to a maximum of 0.96. These results are in line with other findings in Africa and elsewhere; for example, Kassali (2011) reported a mean profit efficiency of 0.62 for sweetpotato producers in Nigeria, with a range between 0.13 and 0.99. This indicates the possibility of increasing profit by about 45% through increased allocative, technical and economic efficiency of sweetpotato producing farmers. Alternatively, the same level of output can be achieved by reducing the costs of inputs by 45% from the current level. Households with younger heads were more efficient than those with older ones. Similar results were registered in previous studies (Bozoğlu and Ceyhan 2007; Battese and Coelli 1995; Mango et al. 2015). The average profit efficiency of control, participants and spillover households was about 20%, 65%, and 70% (Table 5). About 20% of surveyed households have a profit efficiency below 30%; about 50% below 60%; and only 14% of the farmers have an efficiency of greater than or equal to 70%. Spillover households were found to be about 0.5 point more efficient than the controls. It was unexpected to find higher profit efficiency among spillover households than direct beneficiary households. This might be explained by two factors. First, the spillovers had better access to the productive assets and were already better off, so they could derive more profit than the direct participant households, which included several households that were vulnerable and

Table 3: Estimate of labor cost, productivity and financial profitability of sweetpotato production

<i>Median labor cost \$ Ha-1</i>	a. FPP	b. MPP	% difference (a-b)
Season A ¹	306	214	30%
Season B	164	214	-30%
Season C	700	160	77%
<i>Labor productivity (profit margin/unit labor cost)</i>			
Season A	4.6	2.8	39%
Season B	1.9	0.9	54%
Season C	1.3	-0.6	149%
<i>Return on investment: (Return to family labor/cost of production)</i>			
Season A	2.2	1.2	47%
Season B	0.5	0.3	28%
Season C	1.0	-0.1	109%
Average yearly rate of return	1.2	0.5	

Source: Author 's computation based on project endline survey, 2014 and frontier estimation result. 1USD=688 Rwandan Franc, August 2014

¹ Growing seasons in Rwanda are: Season A- September to January, major growing season; Season B- February to June, second major growing season; Season C- July to September, third growing season

Table 4: Maximum likelihood estimates of profit frontier function

1. Profit function (dependent Inprofit)	Parameters	Coefficient.	Std. Err.	Z-score
<i>Constant</i>	α_0	11.533	3.67	3.14
<i>Ln¹Labor: Logarithmic labor</i>	α_1	-0.799	3.50	-0.23
<i>LnManure: Logarithmic manure</i>	α_2	-0.204	0.81	-0.25
<i>LnSeed: Logarithmic seed</i>	α_3	2.221***	0.84	2.66
<i>LnLand: Logarithmic land</i>	α_4	2.462***	0.77	3.20
<i>LnLabLnMan: Logarithmic labor * logarithmic manure</i>	ω_{12}	-0.617	0.46	-1.35
<i>LnLabLnSeed: Logarithmic labor * logarithmic seed</i>	ω_{13}	-1.773***	0.49	-3.62
<i>LnLabLnLand: Logarithmic labor * logarithmic land</i>	ω_{14}	-0.311	0.37	-0.84
<i>LnManLnSeed: Logarithmic manure * logarithmic seed</i>	ω_{21}	-0.176	0.12	-1.50
<i>LnManLnLand: Logarithmic manure * logarithmic land</i>	ω_{23}	0.117	0.10	1.21
<i>LnSeedLnLand: Logarithmic seed * logarithmic land</i>	ω_{34}	0.046	0.10	0.47
$\frac{1}{2}(\text{LnLabor}^2)$: Half logarithmic labor squared	θ_1	-2.275	1.96	-1.16
$\frac{1}{2}(\text{LnManure}^2)$: Half logarithmic manure squared	θ_1	-0.199**	0.08	-2.55
$\frac{1}{2}(\text{LnSeed}^2)$: Half logarithmic seed squared	θ_1	0.009	0.10	0.09
$\frac{1}{2}(\text{LnLand}^2)$ Half logarithmic land squared	θ_1	-0.305**	0.12	-2.48
Variance parameters				
	δ_v^2	2.759***	0.059	46.16
	δ_u	3.974***	0.119	33.45
2. Inefficiency model (dependent inefficiency)				
<i>Access to valley bottom land (0=no, 1=yes)</i>	δ_1	0.258	0.46	0.56
<i>Male adult above 14 years (number)</i>	δ_2	-0.062	0.19	-0.32
<i>Female adult above 14 years (number)</i>	δ_3	0.178	0.17	1.03
<i>Member Farmer Group (0=no, 1=yes)</i>	δ_4	-0.289	0.47	-0.61
<i>Sells sweetpotato (0=no, 1=yes)</i>	δ_5	0.172	0.38	0.45
<i>Sweetpotato area (ha)</i>	δ_6	1.128***	0.41	2.78
<i>Education of head (years)</i>	δ_7	0.117***	0.04	2.92
<i>Age of head (years)</i>	δ_8	0.048***	0.02	3.14
<i>Female control (0=no, 1=yes)</i>	δ_9	-0.477	0.44	-1.09
<i>Female beneficiary (0=no, 1=yes)</i>	δ_{10}	-3.449***	0.78	-4.45
<i>Male beneficiary (0=no, 1=yes)</i>	δ_{11}	-7.380	6.42	-1.15
<i>Female spillover (0=no, 1=yes)</i>	δ_{12}	-4.886**	2.03	-2.4
<i>Male spillover (0=no, 1=yes)</i>	δ_{13}	-4.637	4.31	-1.08

Number of observation = 846; Sigma = 3.78 (0.17); Wald chi2 (14) = 585.02; Log likelihood = -2411.97; AIC = 4881.93; BIC = 5019.41; Source: Authors computation based on project endline survey, 2014 and frontier estimation result; *, **, *** significant at 10%, 5%, and 1% level; respectively

¹ Ln: natural logarithmic

resource poor. Second, spillover households were self-driven to adopt the sweetpotato technology and, hence, may have adopted improved management practices that they learned from their neighbors more readily. The spillover households are self selected compared to the beneficiary households. However, beneficiaries were

selected because they had children under five and in some cases, they were also vulnerable and needed the assistance to improve their food security.

4 Discussion and conclusion

This study employed a stochastic profit frontier model to measure the profit efficiency level and factors that influence efficiency in sweetpotato production systems in rural Rwanda. In doing so, the study examined the effectiveness of a gender-sensitive value chain intervention in improving productivity of the households where women are the principal sweetpotato growers. The study revealed that sweetpotato farming is an economically and financially profitable business. However, on average farmers were inefficient in terms of resource allocation, utilization and scale of economies. The findings imply that explicit targeting of women and resource poor households can improve their productivity and well-being, even when they have limited access to productive assets. Both farm specific and institutional factors influence the profit efficiency among farmers in Rwanda. There

is statistically significant efficiency difference among households based on their degree of participation in the project. Those who received the complete package of the intervention have shown higher profit efficiency level.

Age, education and area under sweetpotato cultivation were positively associated with the profit inefficiency. Nearly half of the surveyed households operate below 60% efficiency; and only about 15% of the farmers have a profit efficiency of greater than or equal 70%. We conclude that efficiency can be increased by up to 45% without additional resource requirements but only by increasing efficiency in the sweetpotato production system. Clearly, efficiency is likely to be enhanced by designing effective extension service on improved agronomic practices and improving access to quality planting materials; accompanied by promotion activities focused on production, marketing and consumption of the crop.

Table 5: Average profit efficiency score of households by participation

Group	N	Average	Std.Dev.	CV	Minimum	Maximum
Control	207	0.18	0.12	67%	0.06	0.46
Beneficiaries	327	0.64	0.18	28%	0.22	0.96
Spillover	312	0.70	0.09	13%	0.36	0.86
Total	846	0.55	0.25	47%	0.23	0.96
Paired t-Test for equality of efficiency score between groups						
Interactions	Difference	T-statistics				
Control vs. Beneficiaries	-0.45***	-35.75				
Control vs. spillovers	-0.52***	-54.70				
Beneficiaries vs. spillover	-0.065***	-5.94				

Source: Authors computation based on project endline survey, 2014 and frontier estimation result; *, **, *** significant at 10%, 5%, and 1%, level; respectively. CV: Coefficient of variation. The pair-wise comparison of average profit efficiency is computed using paired t-test statistics

Table 6: Percent distribution of profit efficiency by gender and level of participation

Range	Control Female	Control male	Participant Female	Participant male	Spillover female	Spillover male	All
0.00-0.10	33	30	0	0	0	0	8
0.11-0.20	18	36	0	0	0	0	6
0.21-0.30	23	22	1	0	0	0	6
0.31-0.40	21	11	6	0	2	0	6
0.41-.50	5	1	24	0	0	2	8
0.51-0.60	0	0	35	1	9	15	14
0.61-0.70	0	0	27	0	33	35	20
0.71-0.80	0	0	7	0	43	40	18
0.81-0.90	0	0	0	43	13	8	8
0.91-1.00	0	0	0	56	0	0	5
Total	100	100	100	100	100	100	100

Source: Authors computation based on project endline survey, 2014 and frontier estimation result

The findings from this study pinpoint some key sources of inefficiency in the current sweetpotato production system that can be addressed by policies and programs purposely targeting women and disadvantaged households in the Rwandan context. Increased efficiency would result in increased household income, which can be used to purchase household necessities and contribute to poverty reduction.

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