IFPRI RWANDA

STRATEGY SUPPORT PROGRAM | WORKING PAPER 11 APRIL 2024

Crop commercialization in Rwanda: Current market participation and drivers

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The International Food Policy Research Institute (IFPRI), a CGIAR Research Center established in 1975, provides research-based policy solutions to sustainably reduce poverty and end hunger and malnutrition. IFPRI's strategic research aims to foster a climate-resilient and sustainable food supply; promote healthy diets and nutrition for all; build inclusive and efficient markets, trade systems, and food industries; transform agricultural and rural economies; and strengthen institutions and governance. Gender is integrated in all the Institute's work. Partnerships, communications, capacity strengthening, and data and knowledge management are essential components to translate IFPRI's research from action to impact. The Institute's regional and country programs play a critical role in responding to demand for food policy research and in delivering holistic support for country-led development. IFPRI collaborates with partners around the world.

1. INTRODUCTION

Rwanda's agricultural has experienced a major transformation in recent years as rising agricultural productivity has generated a marketable surplus in excess of what is directly consumed by households. Sales of this surplus results in increased farm revenue and welfare gains. Over time, households have increasingly shifted from production and sales from lower value "food" crops to higher value "cash" crops, further increasing their incomes, food security, resilience and wealth, and accelerating rural economic development. Further, as crop sales increase, markets develop and if there is investment in market infrastructure, market transactions may become more efficient. Ancillary services such as processing and assembling of products are also emerging, promoting further development of supply chains.

In theory, a farmer with perfect information, competitive markets, and no transaction costs would choose to produce the crop that maximizes her profit, selling some of their crops and using the revenue to purchase food and other consumer goods to maximize overall household welfare. In this framework, low levels of commercialization as attributable to three potential problems: high transaction costs, risk and a lack of assets.

Transaction costs reflect markets in the real world characterized by costs of getting to the market, finding a buyer, negotiating a price, and selling the product. These transaction costs are particularly important for smaller-scale farmers living in rural areas.

Smallholder farmers are also particularly risk averse in their livelihood decisions because a negative income shock can have dire consequences for their welfare. This is not to say that producing a food crop for own consumption doesn't involve some risk: including shortages or unexpected variations of rainfall, or harvests that are too small to feed the family. However, producing crops for the market also involves multiple risks, including aforementioned weather issues, drops in the price of cash crops, and the increases in the price of purchased food. High-value crops, such as vegetables, introduce greater production risk (particularly if they are perishable) and higher price risks because their prices tend to be more volatile. Thus, commercial crop production is likely to be riskier, which discourages farmers, particularly those that are more risk averse.

Finally, commercial crops may involve initial investments that are out of the reach of subsistence farmers. For example, switching from maize to vegetables is likely to involve higher costs for seed, fertilizer, and labor. Similarly, switching from a food crop to a perennial crop like coffee requires a three-year wait before the first harvest. Even if the investment is profitable, the farmer may not have the savings or access to credit needed to cover initial costs. Market failures such as lack of information on the part of lenders about creditworthiness of the farmer may also limit farmers' access to credit.

In this paper, we explore the current levels and participation of crop commercialization by Rwandan smallholder farmers. Our basic unit of analysis is total crop sales divided by the total value of crop production, either at the household or specific crop level. Overall, our findings suggest that approximately 80 percent of farmers participate in crop market sales and sell an average of 33 percent of their total production. However, there is a wide variety of percentage sales by crop and, in general, higher-valued crops are sold by more commercialized farm households. We also find that value of crop production per hectare rises with greater commercialization, suggesting that developing greater market commercialization, particularly with more valuable crops, may increase household incomes and aid in the economic transformation.

2. DATA AND METHODOLOGY

2.1 Data

The analysis of Rwanda smallholder farmer crop commercialization is based on a survey of 2,020 households conducted in late 2022. A two-stage stratification cluster sampling method was used to ensure representativeness of smallholder farmers at the national and provincial levels. The first stage consisted of selecting Enumeration Areas (EAs) based on probability proportional to size (PPS) from the 2012 Population and Housing Census, adjusted for subsampling effects. In the second stage, the sample was restricted to landholdings of less than 10 hectares, a relatively high cut-off, as approximately 92 percent of our sample have less than one hectare.

We constructed estimates of rainfall using satellite imagery data (the Climate Hazards Group InfraRed Precipitation with Station data, (CHIRPS)) together with rainfall estimates at the Rwandan village level.[1] Rainfall variation is also used as a proxy for crop risk.[2]

2.2 Methodology – measuring commercialization

For this research, we identify three measures of crop commercialization. The first measure is a basic bivariate variable that simply identifies if an agricultural household sells any of their crop. While not often used as a measure of commercialization, we provide this as a general measure of smallholder crop market participation.

The bivariate variable we refer to as *Market Index 1* (MI_1), simply measures if farmers sell any of the crops they produce. While MI_1 does provide an overall measure of simple participation by farmers, it is not an adequate measure because it cannot determine the extent to which farmers participate. MI_1 is determined mathematically as the following:

$$MI_{1h}= \sum_{i..n} \frac{(P_iX_i>0)}{P_iQ_i} = 1, \sum_{i..n} \frac{(P_iX_i=0)}{P_iQ_i} = 0 \text{ , } MI_1=\frac{\sum MI_{1h}}{N}$$

Where i is the marketed share of crop i summed from i crops, P_i is the price of crop i, X_i is the quantity of sales of crop i, and Q_i is the quantity produced of crop i.

A second measure is the percentage of value of crops sold, by total value produced, averaged by household. This measure is often used in crop commercialization literature and provides a measure of the extent to which the typical household participates in crop sales. Categorical variables derived from this indicator are also used to better understand how farmers vary commercially by other important agricultural variables.

The average farmer's sales is determined by MI_2 below.

$$M_h = \frac{\sum_{1..n} P_iX_i}{\sum_{1..n} P_iQ_i}, \qquad MI_2 = \overline{M_h} = \frac{\sum_h M_h}{n}$$

M_h is the amount of total marketed crops divided by total value of crops produced by a household (h).

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[1] The Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) is a database of rainfall covering 40 years and the spanning the area between 50° S and 50° N. The resolution of the data is 0.05°, so that each pixel is about 5.5 x 5.5 km. The CHIRPS data are generated by the Climate Hazard Center (CHC) at the University of California at Santa Barbara and the United States Geological Survey with funding from the United States Agency for International Development (USAID), the National Aeronautics and Space Administration (NASA), and the National Oceanographic and Atmospheric Administration (NOAA) (CHC 2021).

2 CHIRPS was used over Rwandan Meteorological Agency data because uniform longer-term panel data was useful for improved identification of trends.

A final measure, at the individual crop level, measures the total individual crop sold divided by total production of that crop. This measure is used for the commercialization of a crop and can vary significantly between the average sold at the household level and the average of sales by crop that we discuss later.

For MI_3 a value is created for each individual crop i, such that:

$MI_{3\mathrm{i}} = \frac{\sum_h \sum_i P_{hi} X_{hi}}{\sum_h \sum_i P_{hi} Q_{hi}}$ for crop i.

The difference between MI_2 and MI_3 is that MI_2 gives equal weight to each household value, while MI_3 gives greater weight to households with larger sales values. To distinguish between the two, we refer to MI_2 as the household average marketed share, while MI_3 is the ratio of total sales to total production by crop (Minot et al. 2023). If the two measures are equal, then households are providing approximately the same sales amount per household. However, this is almost never the case as the value of MI_2 is typically less than MI_3 because larger producers generally sell more. For clarity, we provide an example of determining our general indicators adapted from Minot et al. (2023). Suppose that there are five semi-subsistence farmers and one larger, more commercial farmer, as shown in the table below.[3]

Table 1. Measuring market participation

Farmer (h) N=6	Value of production $\sum_i P_i Q_i$	Value of sales $\sum_i P_i X_i$	Market Participation (MI_{1h}=0,1)	Marketed share MI_2
1	10	2	1	20%
2	10	2	1	20%
3	10	2	1	20%
4	10	2	1	20%
5	10	2	1	20%
6	50	40	1	80%
Total	100	50	1	
MI_3 =Sales/Production, 50/100=50%			**MI_1=100%**	**MI_2=30%**

All three indexes provide insight into commercialization. MI_1 depicts simple market participation, while MI_2 represents the marketed share of the average farmer, and MI_3 indicates the share of total output that is sold, which is disproportionately influenced by larger landholding farmers, who tend to sell a larger share of their output. For this example, all farmers participate in crop sales (MI_1), sell an average of 30 percent (MI_2), with the total amount of crop sold being 50 percent of production (MI_3).

3 MI_1 is Xi >0 for all households (1+1+ 1+1+1+1)/6 or 100% market participation. MI_2 is the average of household-level marketed shares in the last column: MI2 = (20+20+20+20+20+80)/6 = 180/6 = 30%, for MI_3 we divide value of sales by value of production MI_3 = 50/100 = 50%.

2.3 Double hurdle models – joint decision making in agriculture commercialization (participation and crop sales)

In order to better understand the various contributing effects of inputs into commercialization we use an econometric model to project how various independent variables contribute to smallholder commercialization. While simple statistics can depict relationships between two variables, econometric models, control for a variety of potential influences to better understand and isolate individual variables of interest, controlling for relevant variables. These commercialization drivers are important for understanding motivations of how Rwandan farmers engage in market activity. Identifying these relationships is important for potential interventions to enhance market activity and expediting the agricultural transformation.

We use an econometric model, referred to as a double hurdle model (DH), because we believe it best incorporates the joint commercial economic decisions made by Rwanda smallholder farmers. The first step estimates the decision to participate or not (our market index MI_1), or the probability of observing a zero outcome and is called the *participation decision*. This step uses a binary outcome econometric model, such as a probit or logit model, to estimate the likelihood of non-participation by individuals. The second step of the model estimates the conditional outcome for those who have decided to participate and is often referred to as the *quantity decision*. For the purposes of this paper, we call this the *level of sales decision*. This step employs a regression model, such as an ordinary least squares equation, to explain the characteristics of the individuals who have chosen to participate and measure the relative degree of their participation. This step focuses on determining the variables, via estimated coefficients, that influence the magnitude of the outcome and is referred to as the quantity decision.

For purposes related to commercialization, we assume that Rwandan smallholder farmers make these two separate, but interrelated decisions regarding crop marketing. In the first instance, farmers decide whether they are going to market any crops and then, if they choose the affirmative, they then decide how much will be sold. We believe these are realistic assumptions because a sizable minority of farmers do not sell any crops (22% in our sample) making a robust sample size for the binary, participation decision. In addition, a basic review of marketing percentages of those selling crops (the remaining 78%) reveals an evenly distributed percentage sales values between 1-100 percent, indicating the potential for a more normally distributed regression error structure. Mathematically (adapted from Engel and Moffatt 2014), the first step or participation decision takes the following form:

$$y_i^* = \beta_1 x_i' + e_{1i}$$

$$y_i = \begin{cases} 1, & if\ y_i^* \\ 0, & otherwise \end{cases}$$

The participation equation models the decision to engage in the activity (in our case to sell any crops) and is represented by the unobserved latent variable y_i^* for person i and is a function of a vector of explanatory variables x_i' that influences the dependent variable through a vector of estimated coefficients β_1 and an error term e_{1i} . The second equation represents a binary probit model that estimates commercial crop participation and y_i is analogous to MI_1 in our market index methodology. If y_i^* is greater than zero than the model predicts a positive participation in crop sales. The second set of econometric equations depicts the amount of crop sales and is presented by the following.

$$y_i^* = \beta_2 x_i'' + e_{2i}$$

$$y_i = \begin{cases} y_i^*, & if\ y_i^* > 0 \\ 0, & otherwise \end{cases}$$

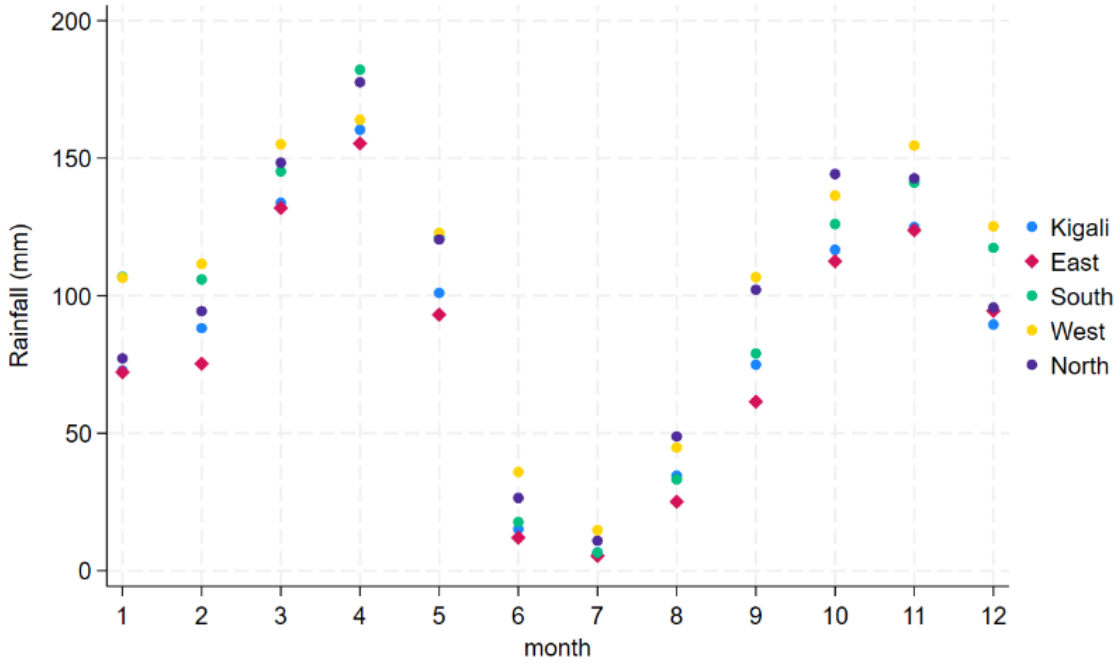
The sales equation estimates coefficients β_2 from the given explanatory variables x_i'' (which includes an overlap of similar variables but not necessarily the identical variables in the participation equation) of those that have been estimated to participate $y_i^* > 0$. An error, e_{2i} is assumed. Therefore, the sales model estimates the percentage sales after it has been determined that the individual will participate in crop commercialization and is a truncated standard regression (OLS) that uses those farmers who sell at least one percent of their crop value.

3. RESULTS

3.1 Rainfall

CHIRPS data was averaged over the last 43 years (1981-2023) by month and region to show variations in projected rainfall (Figure 1). Clearly there are rainfall patterns that vary across the months. In addition, there is some variation between regions as well. April has the largest average rainfall with all regions having an average of 150 mms or more; July has the lowest average reported rain. The Western Province typically has the highest rainfall monthly average, and the Eastern Province has the lowest monthly average.

Figure 1. Monthly rainfall averages by region



Source: Authors' calculations.

Table 2 provides detailed province-level rainfall data. The first column depicts average seasonal rain over the nine months that covered the three seasons of our 2022 commercialization survey. Rainfall is relatively consistent across most regions but about 15 percent lower in the Eastern Province. The previous five-year average is consistent with our 2022 rainfall suggesting that our survey had relatively similar rainfall compared to multi-year averages. The last two columns measure the coefficient of variation,[4] or relative percentage variation, by inter-annual percentage variation and

4 The coefficient of variation (CV) is derived by taking the standard deviation and dividing by the mean to create an absolute measure of variability to compare across different variables.

intra-annual variation. On average, there is a 10 percent variation in rainfall with slightly higher variations in the East and Kigali City. As would be expected, intra-monthly variations are significantly higher than annual variations and the highest value is also found in the East. Our brief analysis predicts that the Eastern Province has both the lowest average annual rainfall as well as the highest variability. These rainfall patterns have potential impacts on commercialization, as well as implications for location of irrigation schemes.

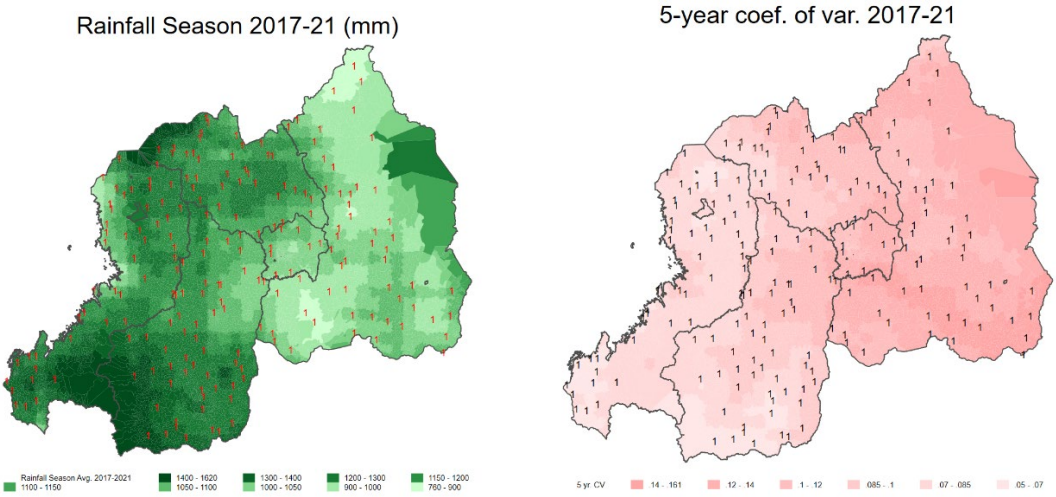
Table 2. Rainfall averages and variations by province

Province	2022 Season (mm)	5-year Average (mm)	Coef. of var. (5-year annual average)	Coef. of var. (5-year monthly average)
Kigali City	1,049	1,054	13%	45%
South	1,207	1,225	9%	37%
West	1,192	1,211	8%	32%
North	1,168	1,168	10%	41%
East	957	1,008	13%	47%
Total	1,123	1,150	10%	40%

Source: Authors' calculations.

Figure 2a and 2b provide 5-year averages of rainfall, by season, as well as variation over the five-year period. The goal is to provide a recent expectation of rainfall amount and variation and contrast these averages to the 2021-2022 period. Both relative amounts and variation show some regional differences. Overall average rainfall ranges from approximately 800 to 1600 millimeters per annual crop season and is highest in the southwest part of the country. In addition, while all coefficients of variation are relatively low (below .5). Values are lowest in the western part of the country and increase towards the east. The Eastern Province typically has lower rainfall averages and higher variations.

Figure 2A & B. Average five-year rainfall and intra-annual variation by village



Source: Authors' calculations.

3.2 Crop Commercialization, demographics, and commercialization indexes

Table 3 provides a general overview of demographic and agricultural variables as they relate to categorical variables of percentage of crops sold, averaged at the household level (MI_2). The first 6 rows provide some basic demographics. Notably, there are declining numbers of female headed households in higher categories of market participation and a slight increase in both age and education of the household head. In addition, mobile phone ownership generally increases, and dietary diversity is higher with larger percentage crop sales. As expected, crop sales are positively related to land size holdings and the number of crops produced, although there is a decline in crops produced in the highest sales category. Input use and extension access rises, as well as livestock holdings increase, with crop sales. There is a large increase in marketed crop sales related to irrigation use that will be discussed later. Mean travel time to markets is approximately the same for all categories at about 70 minutes walking time.

Table 3. Household characteristics by level of sales

	0% Sold	1-25% Sold	25-50% Sold	50-75% Sold	75-100% Sold	Total
Female HHH	38%	34%	28%	25%	18%	30%
HHH's age	48	48	49	49	51	49
HHH years of education	3.2	3.5	3.8	4.0	4.5	4
Household size	4.3	4.4	4.6	4.5	4.2	4
Household own mobile phone	63.6%	76.1%	76.2%	81.1%	78.6%	74.6%
Household dietary diversity score	2.7	3.2	3.3	3.5	3.7	3.2
Total landholding (ha)	0.1	0.2	0.4	0.5	0.7	0.4
Number of all crops produced	2.6	3.9	4.4	4.4	3.7	3.9
Inorganic fertilizers use	33.5%	49.7%	59.0%	65.9%	76.7%	55.3%
Organic fertilizer use	95.2%	97.3%	95.6%	92.7%	88.7%	94.7%
Access to extension	62.0%	74.0%	76.4%	78.9%	75.7%	73.2%
Access to fertilizer/seed (SNS)	28.6%	39.4%	44.8%	39.1%	42.7%	39.2%
Tropical livestock unit	0.4	0.6	0.7	0.7	0.9	0.6
Irrigation application	1.8%	5.8%	10.6%	14.2%	22.7%	9.4%
Mean distance to market (min.)	70.9	72.8	71.7	70.9	74.0	72

Source: Authors' calculations.

Table 4 details our first two market indexes (MI_1 and MI_2) by general categories of interest. In the most aggregate form of market participation (MI_1) was created by asking farmers whether or not they participated in any crop sales. Table 4 aggregates these responses using basic categorical variables of interest (province, age and sex of household head and land size). Approximately 78 percent of all respondents indicated that they sell at least a small portion of their crops, with participation in markets relatively consistent across all general variables of interest, except for landholdings. Market participation is correlated with land size, with participation ranging from 60 percent for

those in the smallest land category and more than 98 percent of those holding one hectare or more selling crops. Overall, there is wide participation in crop sales for all categories shown with over half of each category in Table 4 selling some portion of their crops. While 22 percent of our sampled farmers do not sell any crops, it can also be emphasized that over three-quarters of all farmers do participate in marketed crop sales.

In terms of household average marketed sales (MI_2), an average of about one-third (33.3%) of all crops grown by households are sold. At the regional level, the Northern Province has the lowest percent of market sales and the South has the highest, with about a 9 percentage point difference. Again, there are large differences by land size, with 21 percent of crops sold by the typical farmer who has less than 0.1 hectare and about 60 percent, or three times the percentage, of crop sales by those with greater than 1 hectare.

Table 4. Aggregate (MI1) and percent average participation (MI2)

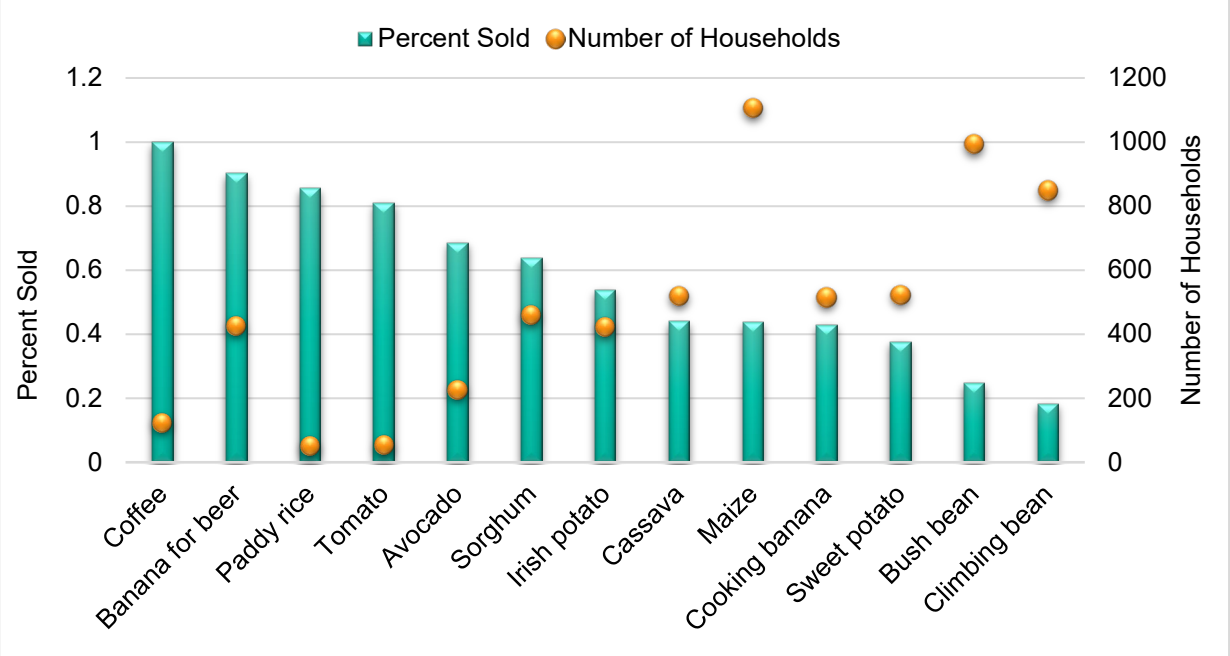
Variable	(%'s) MI_1	(%'s) MI_2
Province Name		
Kigali City	70.0	33.0
South	80.0	34.4
West	73.0	30.5
North	76.1	28.5
East	80.1	38.1
Youth HHH (< 35 years)		
No	78.2	33.8
Yes	74.3	31.4
Female HHH		
Male	79.8	35.6
Female	71.7	28.0
Plot Size		
<0.1 ha	60.1	20.8
0.1-0.3 ha	82.9	33.7
0.3-0.5 ha	87.0	41.9
0.5-1 ha	90.6	43.7
>=1 ha	97.6	58.1
Total	**77.5**	**33.3**

Source: Authors' calculations.

Figure 3 presents individual sales by crop (MI_3), to show the relative importance of commercialization by individual crop. In total, data on 13 crops are presented in Figure 3 depicting the total amount sold divided by total crop production for each crop using the left axis for values. The right

axis indicates the relative number of farmers who produce the crop. Interestingly, many of the most commercialized crops, including coffee, rice, tomato, and avocado, are largely sold at higher percentages but are produced by ten percent or less of our surveyed farmers. The exception to this pattern is banana for beer, which is produced by over 20 percent of our sample, with about 90 percent sold. Sales of sorghum, Irish potato, and cassava range between 40 to 60 percent and are produced by about 20 percent of farmers. Cooking banana, sweet potato, bush and climbing beans are less commercialized but more commonly produced. Maize is a bit of an exception as it is commonly produced by over half of our sample and about 44 percent of the total crop is sold.

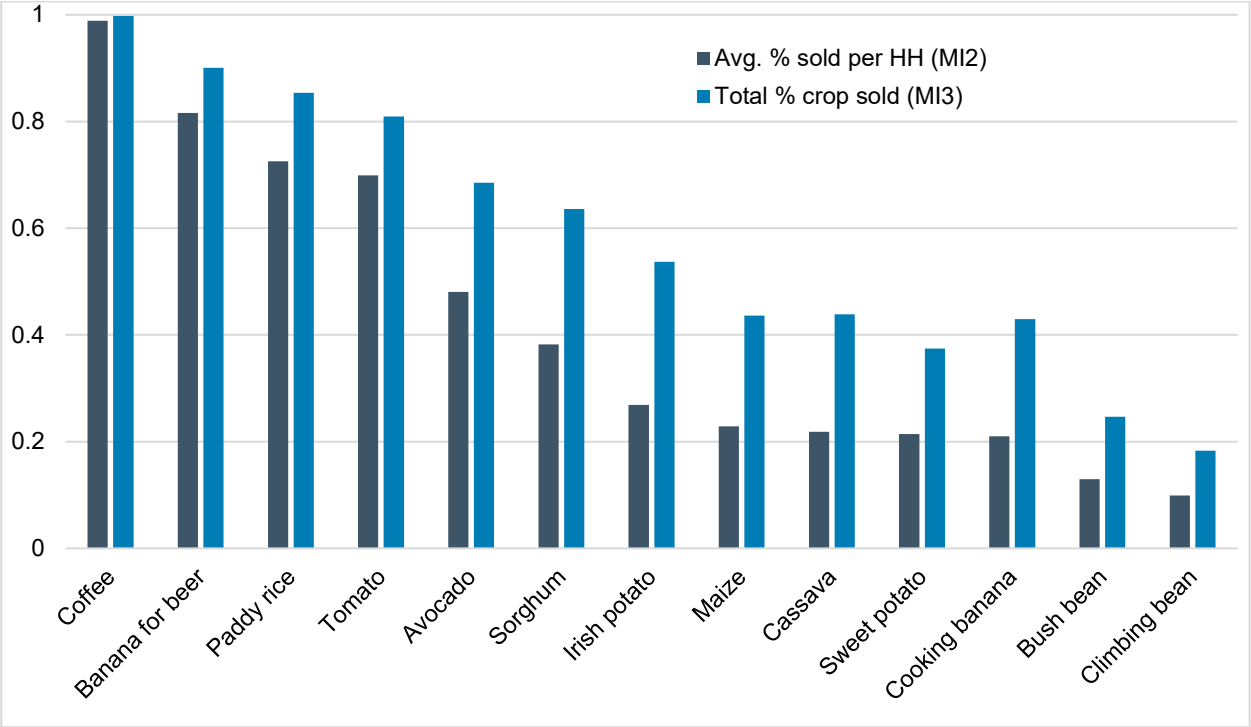
Figure 3. Average Sales by crop (MI3)



Source: Authors' calculations.

Figure 4 contrasts crop sales using both MI_2 and MI_3 perspectives. However, in the case of the MI_2 average, household sales were averaged by a single crop rather than by overall household sales averages. In other words, we took the household sales of a particular crop and averaged it by all those households that produced the crop, to determine a typical household's sales. The purpose is to show overall percentage crop sales (MI_3) versus the "typical" crop sales per household. In all cases, MI_3 is greater than MI_2 which indicates that larger farm households tend to sell more of a particular crop than smaller households. For example, the typical household sells 23 percent of its maize production, but the overall sales of maize are nearly double that value (44 percent). This reveals that maize is widely consumed by households but sold more commercially by larger producers. Somewhat similar to maize, cooking bananas, sweet potatoes, bush beans and climbing beans have relatively low average household crop sales versus total crop sales. These crops have an average of less than 50 percent of total crop sold (MI_3) and close to 20 percent or less household average sold. This indicates large amounts of own consumption by farmers who grow the crop. Crops located on the left side of the figure are more commercialized and have similarly high values for both measures, suggesting that households that cultivate these crops market most of their production.

Figure 4. Average household sales (MI2) versus average total sales (MI3) by crop



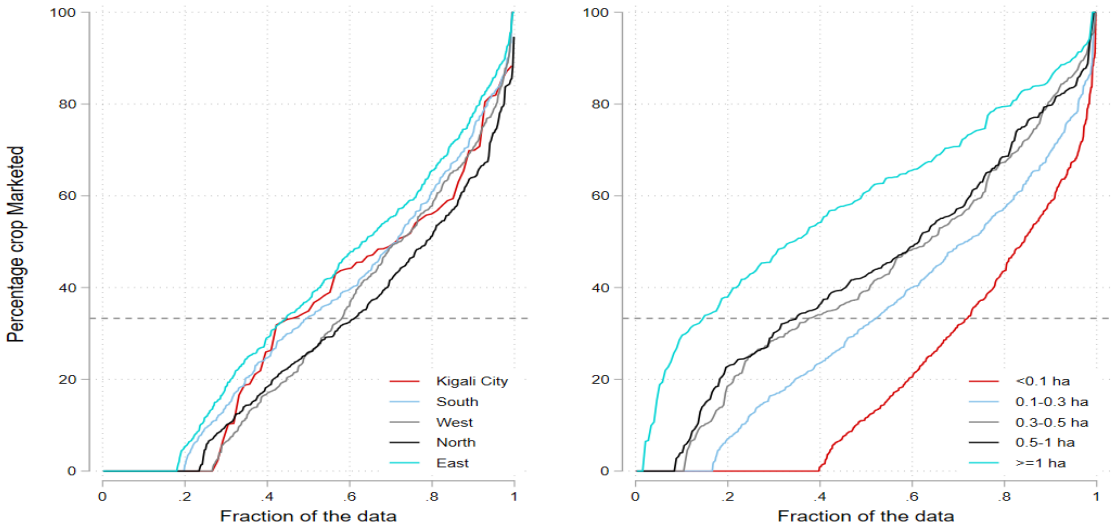
Source: Authors' calculations.

Overall, the three market index indicators suggest a range of commercialization by households and by crop. While market participation is close to 80 percent and a typical household sells about one-third of its crop production, some specific individual crops are much more likely to be sold than others and larger farms disproportionally sell more of a crop than smaller farms, particularly in the case of commonly consumed crops.

Figures 5a and 5b depict the distribution of crop sales by region and land size using the MI_2 index. In Figure 5a, the flat portion of the line, at the bottom left, indicates that approximately 20 to 25 percent of farmers in all regions sell no crops and are not engaged in any crop commercialization (i.e. MI_1=0). The horizontal dashed line indicates the average share of crops sold (33.3 percent), (MI_2) and shows that about 40 percent of farm households in Kigali are below the average (0.5 on the x-axis). More than 70 percent of farmers with less than 0.1 hectares have below average shares of crop sales (Figure 5b).

Figure 5b depicts household crop commercialization by land size category and shows wide variations in crop sales. Virtually all households, with one hectare or more, sell something, though 40 percent of those with less than 0.1 hectare sell no crops. The two categories of 0.3 to 0.5 hectares and 0.5 to 1 hectare are similar in their distribution across the figure. Overall, while province designation makes little difference in typical crop sales, land size is very important. However, this does not mean that smaller land sizes are not commercialized, as shown below.

Figure 5A & B. Distribution of household crop sales by region and land ownership



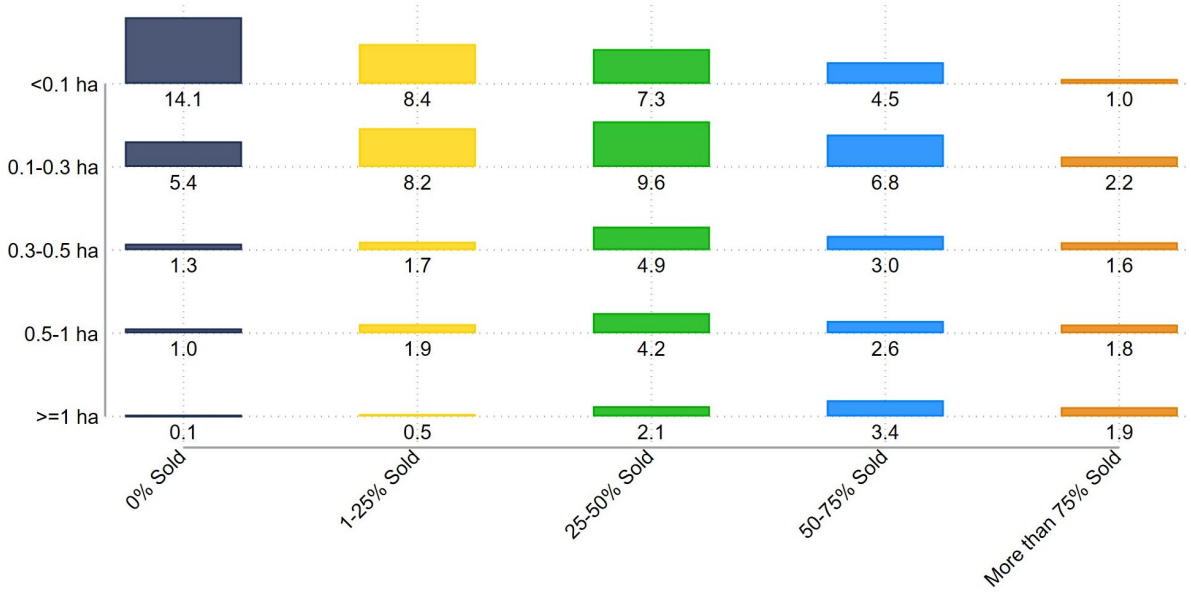
Source: Authors' calculations.

3.3 Landholdings, crop choice, and relative income generated

Figure 6 cross tabulates our categories of land holdings with commercialization categories using our entire sample. If the sampled agricultural households were evenly distributed between land-holdings and crop percentage sales, we would expect a four percent value in each of the possible 25 categories in the figure. Overall, the distribution is skewed towards the top left suggesting that many of those surveyed have less than 0.3 hectares and sell less than 50 percent of their crops. More specifically the six categories in the top two rows and three columns comprise over half of all respondents (53%).[5] The bottom rows indicates that while higher land holdings are less common, they are disproportionately located in higher crop sales categories. The highest crop sales category has at least one percent in each landholding category and shows that smallholder farmers in the higher commercialization categories sell a large amount of their production. While supporting statistics clearly indicate that households with higher land holdings sell a higher share of their crops, this is not universally true and even farmers with the lowest land holdings can sell most of their production. More specifically, the top right category (less than 0.1 ha and more than 75% crop sold) indicates that one percent of our sample is highly commercialized on less than 0.1 hectares.

5 A random distribution would contain only 24 percent of all values (6 x 4%=24%).

Figure 6. General distribution of land size and relative sales by percentage

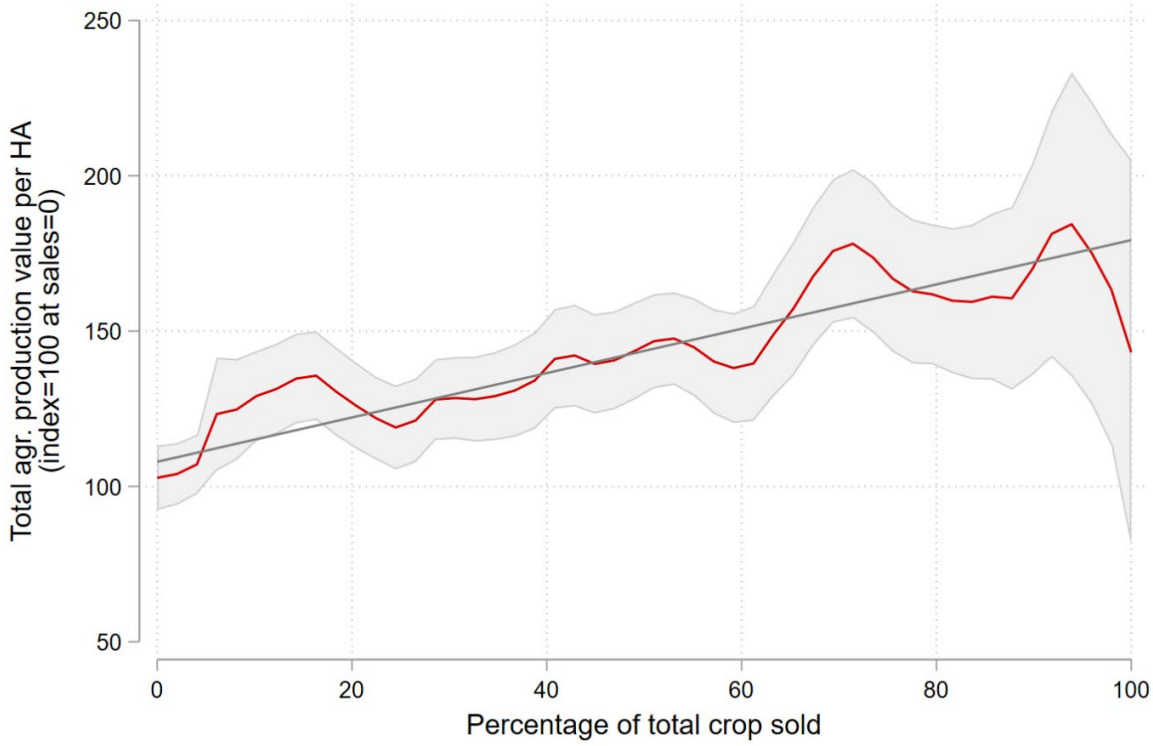


Source: Authors' calculations.

While participation in crop sales reveals some important insights about who markets crops, it is also important to note the relative commercial viability of market participation. For this section we first start with determining total value produced (including own consumption) and dividing by land size to determine value produced per hectare. By controlling for land size, useful direct comparisons can be made. Figure 6 presents the average value per hectare by increasing levels of commercialization (i.e. percentage crop sales) along the x-axis.

Figure 7 demonstrates a strong positive relationship between production value per hectare and percentage of crops sold. This is a key relationship for commercialization as it indicates that crop value increases with household average crops sold. However, while increasing value per hectare is important, the source of this increased value can emanate from higher prices of crops sold, increased production, or a combination of the two. The fundamental question is whether the increase in value per hectare is from farmer's increasing production of the same crops produced by those less commercialized or are they switching to higher value crops (i.e., crops with higher prices)?

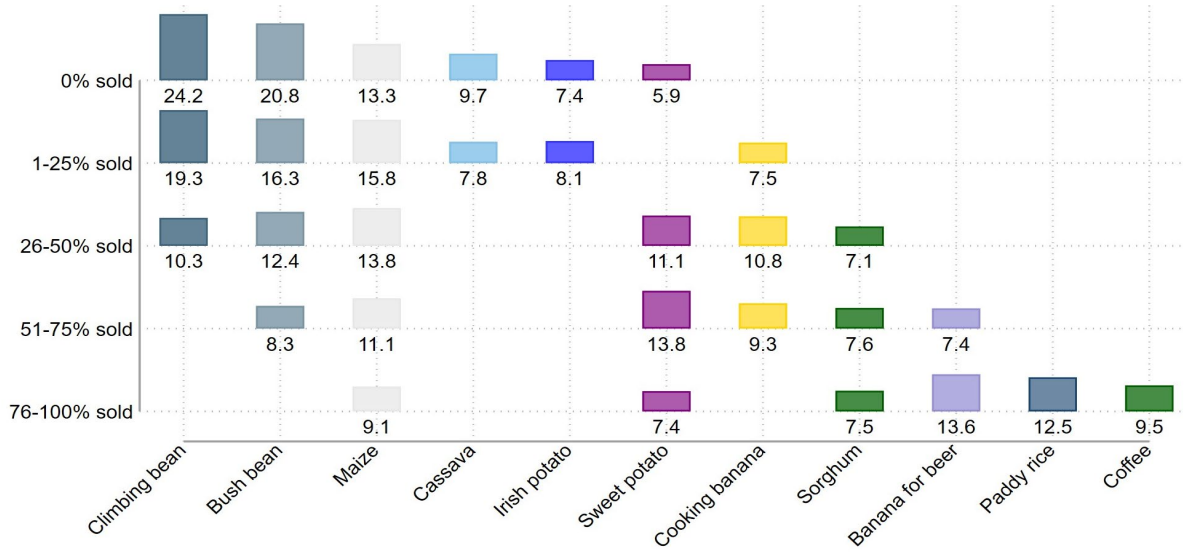
Figure 7. Value index per hectare by level of crop commercialization



Source: Authors' calculations.

Figure 8 shows the percentage farmers by share of crop sales for the six crops with the most production. (Table 5 presents this information for all crops produced for each level of commercialization.) For example, the top row identifies, of those selling zero percent, the top crops include climbing bean (24.2% of all value produced in this category), bush bean (20.8%) and maize (13.3%). The figure demonstrates that as one moves down the rows, i.e., higher marketed sales, the main produced crops are those that produced almost exclusively for sale, such as sorghum, banana for beer, rice, and coffee. For example, crops, like beans, are more commonly directly consumed and are predominantly located in the lower percent crop sold categories. On the other hand, crops at the higher percentage sold categories, like rice and coffee and are more valuable cash crops. There are a couple of exceptions, including maize and sweet potato, which are produced by most of our commercial categories. This suggests that crops like maize are both consumed directly by those that have low levels of crop sales and are sold by those farmers who sell more of their production.

Figure 8. Main crops produced by level of commercialization (by percentages)



Source: Author's calculation.

Table 5. Average value of crop production by level of commercialization

Crop Name	Commercialization category						All House-holds
	0% sold	1-25% sold	26-50% sold	51-75% sold	76-100% sold	Total	
Maize	13.3	15.8	13.8	11.1	9.1	12.6	1,105
Bush bean	20.8	16.3	12.4	8.3	5.8	12.7	995
Climbing bean	24.2	19.3	10.3	6.8	2.1	12.6	849
Sweet potato	9.7	7.8	5.5	4.1	3.2	6.1	524
Cassava	7.4	8.1	5.8	6.3	3.8	6.3	520
Cooking banana	4.8	7.5	10.8	9.3	6.6	7.8	515
Sorghum	3.9	5.5	7.1	7.6	7.5	6.3	460
Banana for beer	1.8	2.0	5.5	7.4	13.6	6.0	426
Irish potato	5.9	6.6	11.1	13.8	7.4	9.0	423
Soybean	1.5	1.5	1.8	1.1	0.4	1.3	240
Dessert banana	0.8	1.4	3.2	3.2	5.2	2.8	240
Avocado	0.8	1.7	1.4	0.9	0.8	1.1	227
Coffee	0.1	0.2	1.6	5.1	9.5	3.3	124
Tomato	0.0	0.2	0.7	1.4	2.2	0.9	53
Paddy rice	0.0	0.1	1.0	3.4	12.5	3.4	50

Tea	0.0	0.0	0.4	1.8	1.5	0.7	19
Others	5.0	6.0	7.6	8.3	9.0	7.2	

Source: Author's calculations.

Table 6 provides an index of the value per hectare for the principal crops indicated in Figure 8 relative to the value per hectare of bush beans). The values are generally consistent with our findings, with coffee and rice being the most valuable crops produced per hectare. Banana for beer is lower than expected but may be due to our methodology of determining output per season and these bananas are more of a perennial crop causing our methodology to underestimate the harvest value per hectare. Maize has a relatively low value per hectare and its widespread production, across all levels of crop commercialization, suggests that it is a food crop with some commercial popularity because it is so widely grown and consumed.

Table 6. Estimated value per hectare by selected crop*

Crop	Index value per hectare
Coffee	6.2
Paddy rice	5.9
Irish potato	3.3
Sweet potato	2.9
Climbing bean	2.0
Sorghum	1.8
Cooking banana	1.8
Cassava	1.4
Banana for beer	1.4
Maize	1.3
Bush bean	1.0

Note: * Relative to the value of bush beans.

Source: Authors' Calculations.

Table 7 depicts the ratio of the household's individual crop sales divided by the same crop's production, averaged across all the households that produce that crop, for each of the five commercialization sales categories. In the case where the value is less than one, farmers in this category are selling less than they produce as designated in the individual commercialization category. As would be expected, larger deviations from 1 would more likely occur in the lower percentage categories where the sales amount is more likely to vary widely by crop. For example, in the lowest sales percentage category (1-25%) farmers are consuming a high percentage of the bush and climbing beans. Because almost no banana for beer, coffee and tomatoes are consumed, and these farmers sell only a quarter of what they totally produce in value terms, these crops are disproportionately sold as compared to other crops. As the categories of percentage increases, almost all crops are sold and the values approach one for all crops. However, values for climbing

and bush beans are approximately 0.5 across all categories, suggesting significant direct consumption of beans at all levels of commercialization.

Table 7. Sales to Production Index by Crop

Crop Name	Commercialization proxy category				
	1-25% sold	26-50% sold	51-75% sold	76-100% sold	Avg. Of Columns
Maize	1.1	0.9	0.9	0.9	1.0
Bush bean	0.6	0.5	0.6	0.6	0.6
Climbing bean	0.4	0.5	0.6	0.5	0.5
Sweet potato	1.1	0.8	0.7	1.0	0.9
Cassava	0.9	1.0	0.9	0.9	0.9
Cooking banana	0.7	0.8	0.8	0.9	0.8
Sorghum	1.3	1.2	1.2	1.0	1.2
Banana for beer	5.0	2.2	1.4	1.1	2.4
Irish potato	0.9	1.1	1.0	0.9	1.0
Soybean	1.2	0.8	0.8	0.8	0.9
Dessert banana	3.1	1.7	1.2	1.1	1.8
Avocado	3.3	1.9	1.1	1.1	1.8
Coffee	6.6	2.6	1.6	1.2	3.0
Tomato	3.8	1.6	1.3	1.1	1.9
Paddy rice	1.6	1.2	1.3	1.1	1.3
Tea		2.6	1.6	1.2	1.8
Others	1.1	1.1	1.1	1.0	1.1

Source: Authors' calculations.

Irrigation is shown to be a significant contributing factor to crop sales in our sample. Table 8 presents the overall levels of crop marketing by households divided according to household use of irrigation. Importantly, it should be noted that most of our sampled households are using traditional irrigation methods. While only nine percent of farmers reported having at least one plot that was irrigated, the total marketed output per household rises by about 20 percentage points for households with irrigation. More detailed exploration is needed but preliminary findings suggest high participation in the East where rice is a major crop, and in the South where many households grow vegetables.

Table 8. Irrigation and levels of crop sales by region

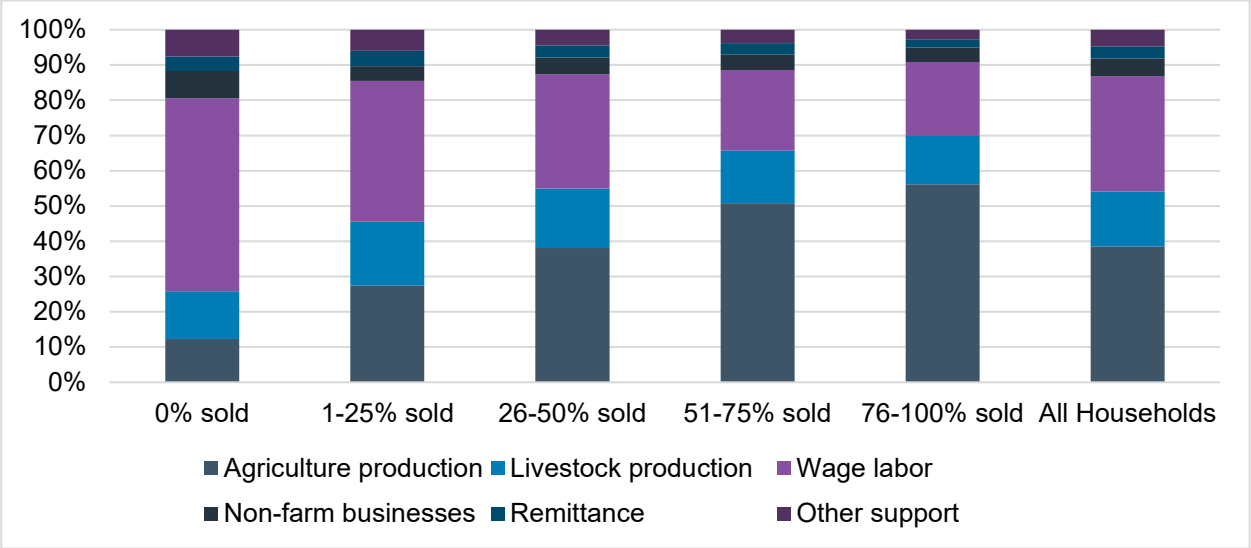
Province Name		Not Irrigate	Irrigate	Total
Kigali City	Mean	29.6%	53.6%	33.4%
	Obs.	65	12	77
South	Mean	31.9%	48.1%	34.4%
	Obs.	464	85	549
West	Mean	29.7%	50.2%	30.6%
	Obs.	448	20	468
North	Mean	27.9%	32.9%	28.4%
	Obs.	344	33	377
East	Mean	35.5%	71.0%	38.1%
	Obs.	492	39	531
Total	Mean	31.5%	50.7%	33.3%
	Obs.	1813	189	2002

Source: Authors' calculations.

While it is important to understand how crop commercialization works, it is also important to place the relative contribution of crop production (total crop value including own consumption) into each commercialization category. As would be expected, Figure 9 depicts crop production value increasing with higher levels of commercial sales. In the non-commercial category, crop production contributes a little more than 10 percent of total income or value because it includes crops that are consumed directly. By far the dominant source of income is wage labor, providing about 55 percent of the total income for this lowest commercial category. Wage labor declines in contribution to about 22 percent for those highest commercial crop sellers. Interestingly, livestock sales, as a percentage of total income, is consistent across all the five categories.

Figure 9 is meant to provide a context of the relative importance of crop production as a source of value (income) for the Rwandan farm household. While all households rely on crop production in our sample, the share of crop production in total income is only about 40 percent for the average household. Clearly, crop production is important, but rural households rely on a variety of sources of income that should be considered in a policy framework.

Figure 9. Household sources of income by commercialization category



Source: Authors' calculations.

3.4 Econometric estimates of determinants of crop choice and market sales

As outlined in the methodological section, we use a double hurdle model (DH) to estimate market engagement of crop sales by small holder farmers. Such a model can help identify barriers to market participation and the main drivers of the quantity of production sold. Understanding these factors can help inform policies aimed at improving market access and sales for smallholders.

The two components of the DH model were constructed using slightly different variables to better reflect the dependent variables of participation and amount of crop sales. Only one variable is unique to participation, a categorical variable regarding renting in land. Our assumption is that renting in land may influence crop commercialization participation but not necessarily the relative sales percentage, and therefore it was not included in the marketed sales equation. Overall, the model uses 23 agricultural variables to determine their relative contributions to participate and quantity of crop commercialization.[6]

As previously mentioned, the double hurdle model divides the econometric model into two components, the participation, and sales (quantity) decisions. Thus, Equation 1 (the first hurdle) includes coefficients that capture the first decision of whether farmers choose to participate in crop market sales. Given that approximately 22% of all households do not sell any crops, we believe this sizable group exhibits robust differences between sellers and non-sellers. The second decision, determined after the decision to participate has been made, is the percentage of total crop value to be sold. The second hurdle (Equation 2) includes coefficients that estimate the determinants of crop sales.

Variables for the models are categorized as follows: household demographics/assets (household size, gender, age, and education of the household head, and asset ownership), farm characteristics and management (land size, hired labor, distance to markets, renting in land, irrigation, fertilizers/pesticides, number of crops planted, inputs, and livestock holdings), environment/geography (province, altitude, rainfall and rainfall variation, altitude, and economic shocks which are primarily weather related), interventions/credit (land consolidation, Twigire Muhinzi/Mworozi (a decentralized

6 Having no economic significance, the constant is disregarded in the discussion.

government extension service), farmer field schools, SNS extension and both agricultural equipment and input credit).

3.4.1 Results

Coefficients of factors influencing both farmer's market participation and degree of market sales are shown in Table 9, along with their statistical significance in Figure 10. The overall results for both participation and market percentage are generally consistent with our expectations and literature on the subject, with previously identified exceptions.

Coefficients on approximately two-thirds (14) of the variables are statistically significant in either the participation or quantity sold equations at the 95% confidence level. In terms of our participation equation (first column of results), nine of our chosen variables are statistically significant and all but one had the expected sign.[7] These variables include rainfall variation, household land size, irrigation, number of crops planted, hired labor, attending farmer field school, purchasing fertilizer, renting in land, and receiving credit for purchasing agricultural equipment. The model of participation, with a slightly different configuration, has ten variables that are statistically significant at the 95% level or higher and of the anticipated sign. These variables include altitude, rainfall variation, household size, female household head, land size, percentage land under consolidation, irrigation, hired labor, inputs purchased, and the amount of credit for input purchases. Somewhat disappointingly, two main categorical variables were determined to have no statistically significant impact on either participation or sales. These variables include province and asset variables. In addition, weather and the agriculture intervention variables provided less significant impacts than anticipated. Addressing these relative shortcomings would need additional research.

Variables that had statistically significant influence on either farmers' market participation or the extent of commercialization, or both, are altitude (meters), land size, variation in rainfall, household size, irrigation, total number of crops produced, hired in labor, participation in farmer field school and purchasing inputs and renting in land. It should be noted that about half of the statistically significant positive contributions involve acquiring more inputs for increasing production. Use of additional inputs (renting in land, labor, fertilizer/pesticides, agricultural credit) seem to reflect a farmer's attempt at increased production/productivity as well as increased monetary outlays that would likely need to be recouped with crop sales. This is consistent with the findings of Ingabire et al., (2017) where the use of improved inputs increased the extent of market participation among smallholder bean farmers in Rwanda's Northern province.

7 Only rain variation was statistically significant but of the wrong hypothesized sign in the participation equation. We would expect that rain variation should have a negative impact on whether to participate and not positive as determined in the model. The reason for this may be partly explained by the Eastern Province having greater marketization rates and greater rain variation.

Table 9. Econometric output

	(Eqn 1-First hurdle)	(Eqn 2-Second hurdle)
Variables	**Market participation**	**Market percentage**
Household demographics/assets		
HH size	-0.0514**	-1.984***
	(0.0209)	(0.369)
Female HHH	-0.111	-5.747***
	(0.0854)	(1.911)
Youth HHH	-0.0520	-2.795*
	(0.0915)	(1.634)
HHH years education		0.141
		(0.246)
2nd asset quintile	0.0491	-1.883
	(0.101)	(2.485)
3rd asset quintile	0.0827	1.486
	(0.110)	(2.582)
4th asset quintile	0.179	-1.195
	(0.127)	(2.336)
Top asset quintile	-0.143	1.843
	(0.146)	(2.492)
Farm characteristics/management		
Total land	0.824***	6.534***
	(0.222)	(1.105)
Hired labor	0.652***	7.711***
	(0.0907)	(1.516)
Dist. to market (mins)	0.00131*	0.00701
	(0.000794)	(0.0147)
Rent-in land	0.226***	
	(0.0781)	
Irrigation	0.503***	9.593***
	(0.177)	(2.039)
Use fertilizer	0.298***	
	(0.113)	

	(Eqn 1-First hurdle)	(Eqn 2-Second hurdle)
Total number crops	0.344***	-0.661*
	(0.0356)	(0.367)
Inputs (10,000 RWF)		0.974***
		(0.131)
Livestock (TLU)	-0.101	-0.156
	(0.0716)	(0.634)
Environment/geography		
South province		-4.608
		(4.212)
West province		-8.062
		(5.318)
North province		-6.874*
		(4.036)
East province		4.484
		(3.958)
Altitude (100 m.)	-0.0101	-0.923**
	(0.0150)	(0.397)
Rain diff (from 5-yr avg.)		0.414
		(0.333)
Var. of rain (5-yr avg.)	0.0193***	-0.673***
	(0.00718)	(0.255)
Shock		-0.198
		(1.483)
Interventions/credit		
Land consolidation (%)	0.229	10.04***
	(0.179)	(3.730)
Twigire Muhinzi/Mworozi	-0.255	-3.516
	(0.182)	(2.784)
Farmer field school	0.373**	-2.078
	(0.171)	(2.755)
SNS extension	0.0751	-1.625

	(Eqn 1-First hurdle)	(Eqn 2-Second hurdle)
	(0.0920)	(1.535)
Credit Agr. Equip.		0.00566
		(0.0763)
Credit Inputs		0.487**
		(0.240)
Credit Agr. Equip. (binary)	0.356**	
	(0.176)	
Credit Inputs (binary)	0.0626	
	(0.198)	
Constant	-1.635***	87.29***
	(0.515)	(13.17)
Observations	1,999	1,999

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Source: Author's calculations.

For further clarity of exposition, Figure 10 places all statistically significant coefficients (at the 95% level of significance) into a matrix of possible outcomes and shows contributions to either one or both of the DH model equations. For example, the variable female household head, represented by the icon in the top left column, indicates that while women household heads are not less likely to participate in overall commercialization, they are statistically significantly less likely to market crops than male headed households (first hurdle insignificant, second hurdle negative). Put another way, male and female headed households are relatively similar in that they both participate in commercialization (controlling for relevant variables), but male headed households sell relatively more crops.

Figure 10. Double hurdle estimated effects on both crop marketing participation and sales

Source: Author's calculations.

The icons located in the solid green top right panel depict positive contributions to both participation and the percentage of crop value sold. These variables include agricultural inputs such as land, fertilizers, labor and irrigation. The statistical significance of these variables suggests that expanding any of these variables would increase both participation and sales. Conversely, increasing household size was the only variable that negatively affected both participation and level of sales. The estimated coefficients are discussed in detail below.

Variables that contributed to both participation and sales

According to our regression results, four variables contributed to both positive crop participation and level of sales. These include land size, irrigation, hired labor and purchase of inputs. All of these are related to important foundational inputs in agriculture (e.g., land, water, labor, and inputs). As anticipated, land serves as a vital production asset, directly impacting surplus production through scale. Therefore, the expansion of cultivated land may increase the level of crop production, consistent with the literature (e.g., Ingabire et al. 2017, Weatherspoon et al. 2021, Gebremedhin and Jaleta 2010, & Tufa et al. 2013). Irrigation also has a significant impact on commercialization although less than 10 percent of our sample farmers had irrigated land. Irrigation provides predictable water access that likely increases productivity and may encourage cultivation of cash crops. Our results indicate that farmers tend to produce higher value crops on irrigated plots such as rice in the Eastern Province and vegetables in the South. These results support the findings of Dube & Guveya (2016) and Tufa et al. (2013), who found that irrigation increases a farmer's level of productivity, resulting in a higher marketed surplus when compared to farmers who depend on rain fed agriculture.

Beyond household size as a potential proxy for labor, none of the literature we reviewed identified hiring in labor as a significant factor in commercialization. However, additional labor may permit increased inputs to agriculture, higher productivity, and greater engagement with markets (in order to generate cash income to pay wages).

The utilization and application of fertilizers, fungicides, and pesticides increases the likelihood of farmers' participation in the market for crop output, implying that when farmers use these agricultural inputs, it enhances their ability or willingness to participate in selling their crops. This could be because the use of these inputs results in higher crop yields, better quality produce, or reduced losses due to pests and diseases, thereby increasing the value of production and making it more viable for farmers to sell their products (Ingabire et al. 2017).

Variables that contributed to positive participation only

Coefficient icons located in the bottom right of Table 10 identify variables where farmers were statistically more likely to engage in commercialization, but the variables did not significantly increase the relative amounts of crop sales. As already mentioned, renting land was not included in the second hurdle equation but would likely be here as well. Renting additional land enables farmers to expand their production capacity, leading to increased crop output for sale and market participation (Weatherspoon et al. 2021). Access to credit for agricultural equipment likely creates the ability to be more productive and increases the need for money to repay loans. Both would likely support choosing to participate in crop commercialization. Research by Barrett et al. (2012) and Reardon et al. (2009) highlight how access to rented land and credit for agricultural equipment boosts production levels and market integration for farmers. Also, these results suggest that farmers who attended farmer field school training were more likely to participate in crop commercialization. Attending a farmer field school can empower farmers with the knowledge, skills, confidence, access to information, adoption of sustainable practices and connections needed to actively participate in crop output. Finally, increasing the total number of crops produced is positive and may suggest that farmers are producing more diversified crops for both their own consumption and sales. The results are consistent with another recent Rwandan crop marketing study where researchers found that diverse crop planting increases the likelihood of market participation (Weatherspoon et al. 2021).

Variables that contributed to positive sales only

Two variables (land consolidation and access to credit for input purchases) were found to only contribute positively to the level of sales but not to whether the farm household chose to participate. Land consolidation in Rwanda enables farmers to better adopt more efficient and productive agricultural practices by providing them with opportunities to invest in irrigation systems, modern machinery, and improved agricultural inputs. These investments further enhance productivity and quality of crops, leading to increased surplus production for sale in the market (Ali et al. 2017). This result contradicts Weatherspoon et al.'s (2021) findings, which suggested that while land consolidation is linked to a smaller share of crops sold in markets, it increases farmer market participation. These mixed results underscore the complexity of this program's impact on smallholder market participation, varying across crops and locations. While additional research would be important to better understand the program, the overall results are mostly positive for commercialization. Finally, it seems plausible that accessing credit for inputs would likely result in increasing sales because of the expected increased crop productivity and the need to generate money for repayment of the loans. Taken together with credit for agricultural tools, both of these credit sources increase participation and sales, but programs tailored for the needs of different types of farmers may be needed.

Variables that negatively contributed to both participation and sales

As mentioned, family size negatively impacts both commercial participation and level of sales, a result that is consistent with other research (Gebremedhin and Jaleta 2010, Tufa et al. 2013). However, other research, including Dube & Guveya 2016, found that additional household members increase the probability of commercialization. Overall, our results suggest that larger family size may result in increased food production rather than production of cash crops for a variety of potential reasons, including risk aversion. This result is not necessarily inevitable as a greater number of household members, especially older children and young adults, could indicate more household labor and increased productivity and therefore potential commercialization. Understanding farmer motivations related to family size and crop choice seems important for designing strategic interventions for enhanced welfare.

Variables that negatively contributed to sales only

The altitude variable suggests that farmers sell less production at higher altitudes. There are a variety of potential reasons for this including different crop compositions, geophysical effects on productivity (slope, land size, rainfall) or greater difficulty accessing markets. Geography and spatial analysis could be performed to better understand some of these effects. Other researchers found distance to markets to be an important predictor of commercialization (Dube & Guveya 2016, Gebremedhin and Jaleta 2010, Tufa et al. 2013) and while our variable of farmer reported distance to markets was statistically insignificant, the altitude variable might reflect some of this effect.

Variability in rainfall could lead to a decrease in crop sales for “defensive” or risk aversion reasons. Farmers face expected challenges such as crop failures or reduced yields due to unpredictable weather, which may limit the expected surplus they have available for sale in the market. Overall, rainfall variation over the previous five years could indicate risk responses and greater reliance on more predicable food crops. This aligns with the conclusions drawn by Minot et al. (2023), who found that fluctuations in rainfall decrease the degree of commercialization among farmers. Minot et al. (2023), argue that such variability introduces a risk factor, leading farmers to curtail their engagement in commercial production to mitigate additional risks.

Regarding the negative estimated impact of crops sold, it is interesting that the model suggests that while female headed households do not participate less in crop marketing than men, they do sell less. This is consistent with a study conducted across-country encompassing Malawi, Tanzania, and Uganda that found that while female farmers engage in less crop market sales, their participation is similar when compared to male farmers (Carletto, Corral and Guelfi 2017).

4. SUMMARY AND CONCLUSIONS

This paper explores agricultural commercialization among smallholder farmers in Rwanda and how increasing crop commercialization would have the potential to enhance the welfare of rural households and accelerate the agricultural transformation. A transition towards cultivating higher-value cash crops could lead to increased household incomes, market development, and overall rural economic progress. However, small-scale farmers often face obstacles such as transaction costs, aversion to risk, and lack of assets—factors that can hinder a more complete commercialization.

The study utilizes a comprehensive dataset from a sample of 2,020 Rwandan smallholder households collected in late 2022, focusing on those with landholdings of less than 10 hectares. To gauge the impact of climatic variables on crop production and perceived risk, rainfall data from the

Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) were incorporated. This, coupled with developed market index measures (MI_1, MI_2 and MI_3) allowed for a detailed assessment of the degree of crop commercialization at both household and specific individual crops.

Our survey revealed that approximately four out of five farmers currently sell crops, which suggests significant market participation by a large number of smallholder farmers. However, average sales by the typical household are only 33 percent which highlights that two-thirds of crop production is either used for own consumption, saved for next season planting, or other uses. While high-value crops are grown and sold, a disproportionate number of smallholder farmers produce lower value food crops for their own consumption.

A key finding of this research is that the value per hectare rises with crop commercialization (Figure 7), and the findings suggest that it is crop choice over productivity that increases market value. In other words, more valuable cash crops are predominately sold by higher commercialized farmers (those that sell a higher percentage of their crop production). While sales are positively correlated with land size, a significant number of smaller landholders (0.3 hectares or less) do sell a large proportion of their crops (>50%). This reveals that varying land size holders participate in commercialization, despite the general trends suggested by the data.

Overall, findings suggest that crop choice, rather than increased productivity, is responsible for higher value. Inclusive policies need to consider farmers across various land sizes and encourage the cultivation of more profitable crops to boost household welfare through agricultural commercialization.

5. POLICY RECOMMENDATIONS

Based on the results of this research we propose the following policy recommendations:

- **The impacts of agricultural interventions could be viewed between the twin goals of either encouraging participation and/or increasing crop sales.** Articulating intervention objectives between these strategies could improve targeted efficiency.
- **Increase access to irrigation**. While irrigation levels are currently at relatively lower levels, this research found it to be highly impactful on commercialization. Predictable access to water likely alters crop choice including reorienting towards higher value cash crops.
- **Improve agricultural labor markets**. Better developed labor markets could facilitate improved access to additional labor and increase commercialization.
- **Expanding farmer capacities via farmer field schools**. Empowering farmers to participate in crop commercialization could likely improve overall sales and improve income.
- **While improved credit access assists overall crop commercialization, different types of credit might better target commercial objectives.** This research suggests that credit for agricultural tools could increase participation and credit for inputs could increase marketed percentages. Depending on intervention goals, these types of credit could be used.
- **Further research regarding how land consolidation improves market sales and participant welfare** seems warranted.
- **Research to better understand larger family motivations related to crop choice** seems important for designing improved strategic interventions to enhance welfare. This is likely due to perceptions of risk.

- **Further explore motivations on why some farmers do not sell crops**. Twenty-two percent of all sampled smallholders did not sell any crops and targeted research on why this is the case would likely improve potential strategies for commercial engagement.

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ACKNOWLEDGMENTS

This paper was prepared under the Rwanda Strategy Support Program (Rwanda SSP), a joint initiative of the Ministry of Agriculture and Animal Resources (MINAGRI) and IFPRI. The study was made possible with the generous funding of the Embassy of the European Union. Any opinions expressed here belong to the author(s) alone and do not necessarily reflect those of the Government of Rwanda, IFPRI, CGIAR, or the funders listed above.

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The Rwanda Strategy Support Program (Rwanda SSP) is managed by the International Food Policy Research Institute (IFPRI). Funding support for Rwanda SSP is provided by the European Union (EU); the United States Agency for International Development (USAID); and the CGIAR Research Program on Policies, Institutions, and Markets. This publication has been prepared as an output of Rwanda SSP. It has not been independently peer reviewed. Any opinions expressed here belong to the author(s) and do not necessarily reflect those of IFPRI, EU, USAID, or CGIAR.

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