THE EFFECT OF LAND FRAGMENTATION ON THE PRODUCTIVITY AND TECHNICAL EFFICIENCY OF SMALLHOLDER MAIZE FARMS IN SOUTHERN RWANDA

BY

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DECLARATION

I, Mathias Karangwa, hereby declare that this thesis is my original work and has never been submitted to any other academic institution for the award of a degree.

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DEDICATION

This thesis is dedicated to my late mother, Rose Buhinja.

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ABSTRACT

The government of Rwanda believes that land fragmentation is a major threat to efficient crop production in the country due to the fact that continuous subdivision of farms has led to small sized land holdings that may be hard to economically operate. This study analyzed the determinants of the productivity and technical efficiency of smallholder maize farms in Gisagara district with a particular focus on land fragmentation using plot size, number of plots per household and distance from the households' residences to plots as measures of land fragmentation. Gisagara district was chosen because previous empirical studies showed high land fragmentation there. The main objective of this study was to determine the effect of the various dimensions of land fragmentation on the productivity and efficiency of smallholder farms in Rwanda. To attain this objective, hypotheses testing whether the various dimensions of land fragmentation had positive/negative effect on productivity and efficiency of farms were stated and tested.

This study adopted the stochastic frontier approach adopted because being a parametric approach, it deals with stochastic noise, and allows hypothesis testing on the production structure and efficiency. Though smallholder maize farms were found to be technically efficient, their efficiency levels would be improved if land fragmentation effects were mitigated. The main conclusion is that land fragmentation affects the technical efficiency of farms but the various dimensions of land fragmentation affect efficiency differently. The number of plots negatively affected technical efficiency of farms; Distance to plots and size of the plot had no significant effect on technical efficiency of farms.

In terms of productivity, this study found out that farm size positively affected the productivity of farms, having many plots reduced productivity and distance to plots did not have a significant effect on productivity and the interaction term ($avplotdist * noplots$) also had no significant effect suggesting that land fragmentation is probably not a big problem as long as plots are close to homes. Land consolidation is recommended and should be implemented. Education be availed to rural farmers and land titling be done

1.0 INTRODUCTION

1.1 Background of the study

Rwanda is a landlocked country whose size is 26,338 km^2. Arable land is estimated to be 13, 850 km^2, which is just about 52% of Rwanda's total surface area. The rate of population growth was estimated at 3.1% in 1998. By 2006, Rwanda's population stood at nearly 9 million and was growing at a rate of about 2.5% per year, a rate that may double the 2006 population in about 28 years (Republic of Rwanda, 2006).

Like many other African economies, Rwanda's economy largely depends on agriculture. The annual contribution of agriculture to Gross Domestic Product (GDP) was more than 40% from 1990 to 2002 (Table 1.1). From 2003 to 2007, the annual contribution of agriculture to GDP was still above 35%.

Table 1.1: Contribution of Agriculture to Gross Domestic Product (GDP)

Year	Percentage contribution to GDP
1990	45.09
1995	44.35
1999	43.40
2000	44.30
2001	44.12
2002	47.00
2003	38.00
2004	39.00
2005	39.00
2006	39.00
2007	36.00

Source: Republic of Rwanda (2008), Rwanda in Statistics and Figures and Republic of Rwanda (2003), Rwanda Development Indicators.

The major food crops in Rwanda are maize, rice, banana, Irish potatoes, sweet potatoes and cassava. Rwanda's maize yield was in 2003 the lowest compared to the maize yield of Burundi, Kenya, Tanzania and Uganda (Figure 1.1).

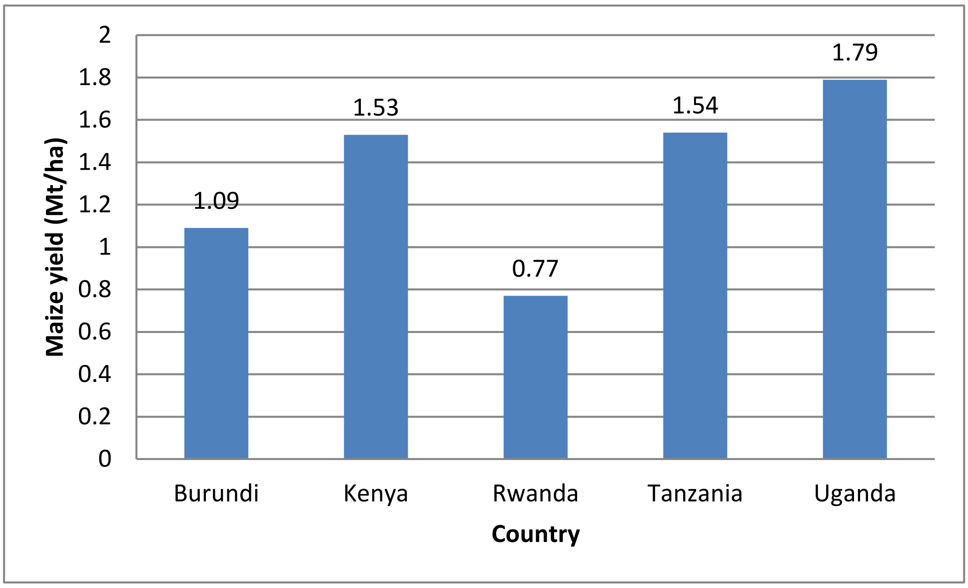


Figure 1.1: Maize yield comparison among neighboring countries

Source: Food and Agricultural Organization, FAO (2003).

However, maize is regarded as a major food crop in Rwanda (Table 1.2) with a 12% increase in its production from 2006 to 2007. It is followed by sweet potatoes (with 9% increase), cassava (with 5% increase) and banana (with 2% increase).

Table 1.2: Food crop production in Rwanda

Crop	Production (tons)		
	Year 2006	**Year 2007**	Percentage Change (2007/2006)
Maize	91813	102447	12
Rice	62932	61701	-2
Banana	2653548	2698176	2
Irish Potatoes	1136489	967283	-15
Sweet Potatoes	777033	845133	9
Cassava	742525	776943	5

Source: Republic of Rwanda (2006). Rwanda Development Indicators

Furthermore, the encouragement to grow maize from the government to constitute cereal reserves to face unexpected hunger periods, contributed to the expansion of maize crop. Currently it is the leading crop and certainly the leading cereal in Rwanda (Republic of Rwanda , 2009)

Even though maize is a major food crop in Rwanda, there are some parts of Rwanda where production of maize is still low. In 2006, Gisagara district produced 795 tons of maize (Figure 1.2), which was less than 1 percent of national maize output.

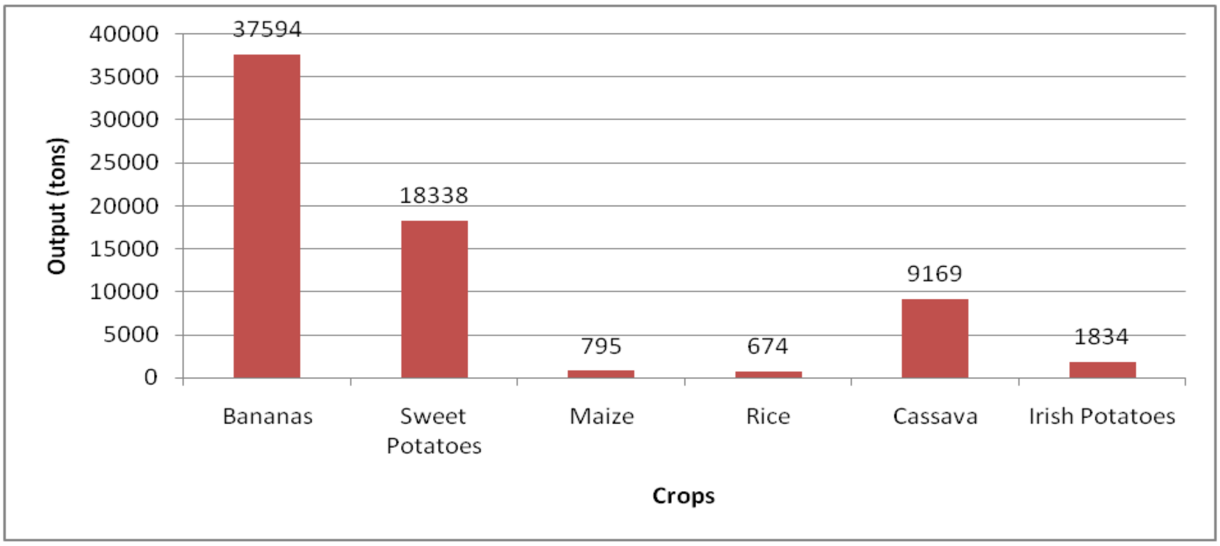


Figure 1.2: Crop production in Gisagara district
Source: Republic of Rwanda (2006), season statistics 2006B.

There are perhaps factors that may be hindering efficient maize production in Gisagara district. It has been presumed that poor land use and management practices (especially land fragmentation) in highly populated areas can lead to inefficiencies in crop production (Gebeyehu, 1995). Gisagara district has a very high population and land fragmentation is so common (Musahara, 2006).

The Rwandan government believes that the cultivation of small fragmented land holdings leads to inefficiencies in agricultural production. Consequently, land reform programs have been introduced and generally include the land law (passed in 2005), the land policy (adopted in 2004) and the villagization policy (the setting up of communal settlements aimed at freeing more land for agriculture). These land reforms strongly encourage land consolidation (Republic of Rwanda, 2004). Under article 20 of the new land law, farmers will have to consolidate their land and/or not fragment land holdings below one hectare since it is argued that to be economically productive, a household farm must not be less than 0.9 hectare, a limit set by the Food and Agricultural Organization, FAO (Mosley, 2004). However, the Rwandan government adopted the land reform programs without carrying out a study to assess the effects of land fragmentation on the productivity and efficiency of farms.

It is not yet clear whether such land reforms will successfully replace the informal rules (especially the customary land tenure system) that encouraged land inheritance and continuous subdivision of farms. Secondly, it is hard to predict that farmers will adopt land consolidation especially because previous studies in Rwanda confirmed that land consolidation does not necessarily lead to efficient crop production (Blarel Benoit, Peter Hazell, Frank Place and John Quiggin, 1992) and land fragmentation was used by farmers as a coping mechanism to deal with problems related to land scarcity and to benefit from regional agro-climatic differences (Marara and Takeuchi, 2003).

Production efficiency studies normally hypothesize that technical inefficiency is influenced by farm-specific and household-specific characteristics. The focus of this study was to especially determine whether farm specific characteristics (with a particular focus on land fragmentation) have negative effects on maize production in Gisagara district. Maize was chosen because it is the most important food crop in Rwanda. Since previous studies reported the existence of higher fragmentation levels in Gisagara district (Musahara, 2006), Gisagara was chosen as a case study.

1.2 Statement of the problem

The efficiency of smallholder farms in Rwanda is highly disputed. Several factors, mainly farm-specific and household-specific characteristics (such as education levels, dependency ratio, access to extension services, possession of land titles among others), can reduce the technical efficiency of farms. This study has a particular focus on the effects of land fragmentation on the productivity and efficiency of farms.

Cultivated land in Rwanda is still small compared to total agricultural land. This implies that land scarcity is not so extreme. There have been claims that land fragmentation results from extreme land scarcity and insufficiency of agricultural land (Mosley, 2004). Agricultural land during 2000-2007 was fixed at 2,294,380 hectares and there has always been a big gap between agricultural land and cultivated land, the latter being always smaller relative to the former. From 2000 to 2007, cultivated land has not reached 1,000,000 ha (Figure 1.3).

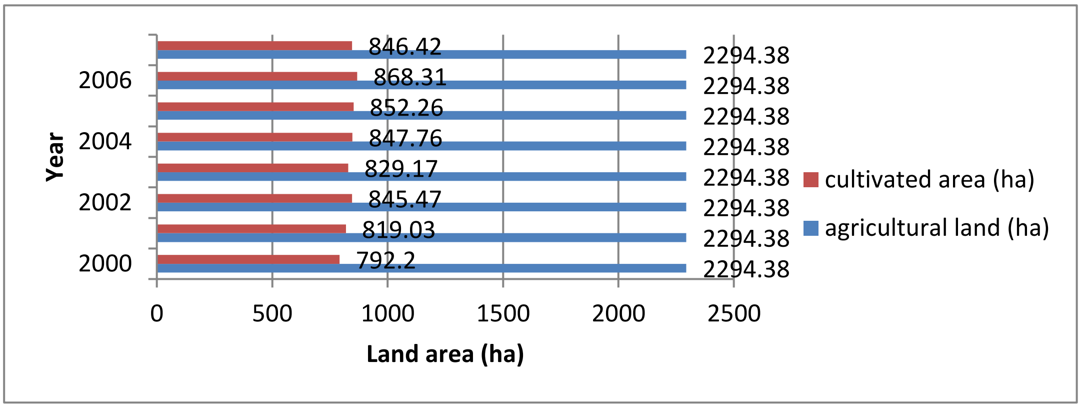


Figure 1.3: Cultivated land in Rwanda ('000 hectares)
Source: Republic of Rwanda (2008), Rwanda in Statistics and Figures

The problem therefore is not that less land is allocated to crop production but the land allocated to crop production is not efficiently used due to practices like land fragmentation.
Farms in Rwanda have over the past been shrinking in size. Land inheritance is common in Rwanda (Bizimana et al., 2004) and has led to continuous subdivision of farms, leading to a fall in average farm size (Mpyisi et al., 2003). In this study plot size, number of plots per household and distance from the households' residences to plots were used as measures of land fragmentation.

By 2002, only 27.1% of Rwandans had farms greater or equal to 1 hectare, but 72.9% had farms that were less than 1 ha (Table 1.4). Therefore, land fragmentation, measured in terms of farm size, was high.

Table 1.3: Farm size distribution in 1984 and 2002

Farm size (ha)	Households	
	Percentage in 1984	Percentage in 2002
< 0.25	7.4	16.8
0.25-0.5	19	26.4
0.5-1.0	30.4	29.7
1.0-2.0	26.7	19.5
> 2	16.4	7.6
Total	99.90%	100%

Source: (Mpyisi et al., 2003).

In 2006, 93.6% of Rwandans had farms of 0.5 hectare or less and only 6.4% of Rwandans had farms of more than 0.5 hectare (Table 1.5). This again shows that land fragmentation, measured in terms of farm size, was high.

Table 1.4: Farm size distribution in 2006

Farm size (ha)	**Percentage**
≤ 0.25	61.3
0.26-0.5	32.3
0.51-0.75	1.6
0.76-1	3.2
> 1	1.6
Total	**100**

Source: Republic of Rwanda (2006), Rwanda Development Indicators

Average farm size decreased from 1.2 ha in 1984 to 0.84 ha in 2002. In 2006, average farm size in Rwanda dropped to 0.72 ha (Table 1.6). An economically productive farm must not be less than 0.9 ha (Kelly and Murekezi, 2000; Mosley, 2004), which is unattainable to many Rwandans.

Table 1.5: Change in average farm size (1984-2006)

	Average Farm size in Rwanda (ha)		
Year	1984	2002	2006
Average farm size	1.2	0.84	0.72

Source: (Mpyisi et al., 2003) and Republic of Rwanda (2006), Rwanda Development Indicators

In terms of geographical dispersion, Rwandans can have up to 5 plots in different locations and a household can have ten plots on average (Musahara, 2006). The most common problems of land fragmentation include the fact that it makes supervision and protection of land difficult; it entails long distances, loss of working hours, the problem of transporting agricultural implements and products; and results in small and uneconomic size of operational holdings (Webster and Wilson, 1980).

However, land fragmentation may also be beneficial to farmers. Bentley (1987) argued that land fragmentation may enable risk management through the use of multiple agro-climatic zones and the practice of crop scheduling. Growing crops in different locations may reduce the risk of losing output due to perils such as floods, fires and destruction of crops by herds. Land fragmentation may also enable the growing of a variety of crops that mature and ripen at different times thereby allowing concentration of labor on different farms at different times (Shuhao, 2005). In Rwanda, some previous empirical studies reported that land fragmentation does not necessarily lead to inefficiency in crop production (Blarel Benoit, Peter Hazell, Frank Place and John Quiggin1992) and that farmers used fragmentation as a coping mechanism to deal with problems of land scarcity and to capture advantages of regional agro-climatic differences (Marara and Takeuchi, 2003).

Previous studies in Rwanda about land fragmentation had mixed results. The relationship between fragmentation and land productivity might not necessarily be negative (as noted, for Rwanda, by Blarel Benoit, Peter Hazell, Frank Place and John Quiggin, 1992; Marara and Takeuchi, 2003). However, a study by Bizimana et al. (2004) in the former Rusatira and Muyira districts of the former Butare province revealed that the number of plots per household negatively affected economic efficiency while plot size positively affected economic efficiency. The authors recommended that land consolidation be adopted as it could help increase the economic efficiency of farms. These studies however did not capture the various dimensions of land fragmentation (plot size, distance to the plot and number of plots per household).

This study applied the stochastic production frontier approach (since it accounts for both measurement errors and stochastic noise) to model the effects of each form/indicator of land fragmentation on the technical efficiency of smallholder maize farms in Southern Rwanda using Gisagara district as a case study.

1.3 Objectives of the study

1.3.1 General objective

The main objective of this study was to determine the effect of land fragmentation on the productivity and technical efficiency of smallholder farms in Rwanda

1.3.2 Specific objectives

- To characterize smallholder maize farms in Southern Rwanda
- To assess the levels of productivity and technical efficiency of smallholder maize farms in Southern Rwanda
- To determine the effect of various indicators/measures of land fragmentation on the productivity and technical efficiency of smallholder maize farms in Southern Rwanda

1.4 Hypotheses tested

This study tested the following hypotheses:

1. Smallholder maize farms in Southern Rwanda are technically efficient

2. Distance from households' residences to plots negatively affects the productivity and technical efficiency of smallholder maize farms in Southern Rwanda

3. The smaller the plot size the lower the levels of productivity and technical efficiency of smallholder maize farms in Southern Rwanda

4. The higher the number of plots owned by the household, the lower the levels of productivity and technical efficiency of smallholder maize farms in Southern Rwanda

5. Number of plots, distance to the plots and plot size reduce the productivity and technical efficiency of smallholder farms in Southern Rwanda

1.5 Justification of the study

This study came at a time when the efficiency of smallholder family farms is highly disputed in Rwanda. There was need to establish whether smallholder farms are efficient and if not to identify the causes/sources of such inefficiency such that appropriate policies can be adopted to address the problem. The findings of this study will suggest key factors that may enhance the productivity and technical efficiency of farms. Unlike previous studies in Rwanda, this study captured plot size, distance from household residence to plots and number of plots per household in the analysis of the effect of land fragmentation on the productivity and technical efficiency of smallholder maize farms in Rwanda.

2.0 ANALYTICAL FRAMEWORK AND LITERATURE REVIEW

2.1 Analytical framework

2.1.1 Land fragmentation definition

McPherson (1982) argues that "when a number of non-contiguous owned or leased farms (or 'plots') of land are farmed as a single production unit, land fragmentation exists". This means that the plots in a farm are spatially separate. Schultz (1953) defines fragmentation as a "misallocation of the existing stock of agricultural land." He points out that a fragmented farm is "…a farm consisting of two or more plots of land so located one to another that it is not possible to operate the particular farm and other such farms as efficiently as would be the case if the plots were reorganized and recombined". Schultz sees land fragmentation as a source of inefficiency.

Dovring et al. (1960) regards land fragmentation as "the division of land into a great number of distinct plots…" when he analyzes land reform in Europe. He points out that the French used two concepts for land fragmentation in their consolidation operation: "*îlot de propriété*" and "*plotle*" (McPherson, 1982). The former referred to a piece of land owned by a single person and surrounded by the property of others. The latter was a plot located apart from the *îlot de propriété*. Land fragmentation meant that farmers owned *plotles* which did not form part of their *îlots de propriété*.

Papageorgiou (1963) emphasizes the role of distance in fragmentation. He notes that fragmentation means a holding consisting of several scattered plots over a wide area. Agarwal (1972), defines land fragmentation as a decrease in the average size of farm holdings; an increase in the scattering of each farmer's land; and a decrease in the size of the individual plots in a farm holding. Binns (1950) sees fragmentation as "…a stage in the evolution of the agricultural holding in which a single farm consists of numerous discrete plots, often scattered over a wide area". According to Binns' definition, land fragmentation represents a stage in agricultural holding's evolution. This suggests that if the holding is evolving towards consolidation, land fragmentation may be a temporary phenomenon.

Generally, even though land fragmentation is defined in different ways, three distinct interpretations can be identified: (1) it implies the subdivision of farm property into undersized units that are too small for rational cultivation; (2) it suggests that the plots are noncontiguous and are intermixed with plots operated by other farmers; and (3) the last type sees distance as an important aspect of land fragmentation.

2.1.2 Causes of land fragmentation

In the literature, researchers have classified the causes of land fragmentation under two broad categories. These are supply-side causes and demand-side causes (Blarel Benoit, Peter Hazell, Frank Place and John Quiggin, 1992; Mc Pherson 1982; Bentley 1987).

2.1.2.1 Supply-side causes of land fragmentation

Proponents of these causes assume that land fragmentation is an exogenous imposition on farmers. Farmers involuntarily accept to hold many plots of land, which are often dispersed. It is also assumed that fragmentation has adverse effects on agriculture, thus farmers cannot freely choose to scatter their land holdings unless otherwise compelled by some other forces. These forces are reviewed in the proceeding paragraphs.

Land inheritance leads to land fragmentation when farmers desire to provide each of several heirs with land of similar quality. Fragmentation goes on increasing through the activity of succession from one generation to another as parents continue to bequeath land to their children. Extreme land scarcity also leads to land fragmentation as farmers in quest of additional land tend to accept any available plot of land within a reasonable distance of their house. When population pressure on land is high and when there are no other off-farm activities upon which the population can earn a living, fragmentation results.

Nature itself may force farmers to own scattered land holdings in a sense that geographical barriers such as waterways and wastelands limit the possibilities for land consolidation. Expansion of the farm under such circumstances requires acquisition of new separate pieces of land which when done, implies land fragmentation. Lastly, egalitarian objectives and state laws may limit possibilities for land consolidation. For example, in China during the 1970s and

1980s, community leaders carried out land redistribution based on equality. Arable land was divided into a number of plots with respect to quality and each household was given a plot (Nguyen et al. 1996). In this case, the land redistribution process led to land fragmentation especially at the village level.

The supply-side causes of land fragmentation explain why a young farmer might begin with a fragmented holding. However, they do not explain the persistence of fragmentation in face of economic incentives for land consolidation. Such persistence indicates that there are other causes of land fragmentation. Supply-side causes of land fragmentation have been criticised due to many reasons.

Firstly, even when land markets afford farmers opportunities for consolidation, fragmentation persists. This persistence implies that the choice to own many plots of land is not always an involuntary one as assumed by proponents of the supply-side causes of land fragmentation.

Secondly, land fragmentation has developed in areas where there is no serious land scarcity, such as in Kenya, Zambia and Gambia (Mc Pherson 1982). Parents continue to bestow their heirs with scattered holdings, a practice that would seemingly be halted if land fragmentation was largely detrimental (Leach 1968).

The argument that land inheritance is designed for equity reasons runs into difficulty when it is observed that sub-division and fragmentation levels are eventually “checked” after reaching certain levels since it becomes practically impossible to continue subdividing very tiny plots, as noted in Mexico (Downing 1977) and in Sri Lanka (Leach 1968).

The criticisms raised above suggest that supply-side causes are not sufficient to explain the existence and persistence of land fragmentation. It is upon this that researchers have conceived demand-side causes of land fragmentation.

2.1.2.2 Demand-side causes of land fragmentation

The proponents of these causes view land fragmentation as a choice variable for farmers. It is presumed that farmers will, given free choice, choose levels of fragmentation that are beneficial to them (optimal fragmentation). Here, farmers believe that fragmentation will bring greater benefits to them compared to costs they are likely to incur. The demand-side causes of land fragmentation are discussed in the proceeding paragraphs.

It is believed that land is not homogeneous with respect to soil type, water retention capability, slope, altitude and agro-climatic location. Farmers will freely choose to operate many plots in different locations to enable them reduce variance in total output and hence final consumption. Scattering of plots reduces the risk of total loss of output due to perils such as floods, fires and droughts, which are so common in Africa (Buck 1964; Johnson and Barlowe 1954). Scattering of plots also enables farmers to diversify their cropping mixtures across different growing conditions (Netting 1972).

When transaction costs in the labour market are high, farmers will choose to scatter plots so as to better fulfil their seasonal labour requirements and consequently obtain higher yields. If the labour market is not working at all, labour supply is fixed by household size. Even if labour markets exist, the costs of supervision may induce farmers to scatter their plots and supervise a small number of workers at a time, rather than watch over a large number of hired workers on a consolidated land holding at peak periods. This approach is most effective when different types of land are used for different crops (hence, when fragmentation facilitates diversification) or when different plots of land offer sufficient diversity in climatic conditions that the same crop can be staggered over a wide range of planting dates.

When there are commodity market failures, farmers may choose a subsistence mode in which several products are raised for household consumption, rather than purchased with proceeds of cash crop sales. This seems most likely to happen when there is uncertainty about relative price movements, especially for important foods such that trade within a village or across villages is costly. Under this case, farmers will prefer to grow each crop on a separate plot of land. Farmers might also want fragmented land holdings if, holding farm size constant, there are diseconomies of scale with respect to individual farm size. When this phenomenon occurs, however, it probably reflects the malfunctioning of labour markets; farmers are unable to procure adequate labour to meet seasonal peaks in the requirements for large farms.

It is quite clear that demand-side causes of land fragmentation consider fragmentation as a deliberate choice made by farmers so as to reduce risks associated with crop production; this is why scholars have deemed it "fragmentation for risk reduction". Critics of demand-side causes of fragmentation assert that it should only persist if other risk-reduction mechanisms, such as insurance, storage or credit, are either not available or more costly (Hyodo 1963; Ilbery 1984; Thompson 1963). The flaws seen in both supply-side and demand-side causes suggest that each side of these causes should complement the other in providing explanations for the occurrence and persistence of land fragmentation.

2.1.3 Effects of land fragmentation

Land fragmentation has both advantages and disadvantages and the debate about which side outweighs the other seems to be a perpetual one. The advantages of land fragmentation are similar to the demand side causes of land fragmentation.

2.1.3.1 Disadvantages or costs of land fragmentation

The costs of land fragmentation are quite many. In this study, the costs of land fragmentation considered are discussed in Shuhao (2005) and Raghbendra (2005). These costs are reviewed in the paragraphs below.

Land fragmentation leads to increased travelling time between fields, hence lower labour productivity and higher transport costs for inputs and outputs. Fragmentation also involves negative externalities such as reduced scope for irrigation, soil conservation investments and loss of land for boundaries and access routes. Farmers may also incur higher costs of supervising workers on each separate farm than when supervision occurred on a large farm.

Fragmentation also involves greater potential for disputes between neighbours. These conflicts arise when farmers do not agree with the current farm demarcations especially because they believe that their neighbours have cheated them by taking some land from their respective farms. Lastly, farmers owning scattered plots that are quite far away from their homes may lose output due to perils such as destruction of crops by herds, fires, floods, thefty and droughts.

Causes of land fragmentation in Rwanda

The major cause of land fragmentation in Rwanda over the past has been population pressure on land (a supply side cause). Due to population pressure, land has been so scarce that people resorted to purchasing and renting of land and even migrations.

In the 1960s, some researchers had started warning of a growing land scarcity in Rwanda. Landal (1970) stated that " it is assumed that by 1975 ceteris paribus, there will be no further land for cultivation lying idle". This became a reality in the 1980s when several Rwandan families started migrating into countries neighbouring Rwanda because they could not get any land for cultivation. There were also internal migrations whereby people moved from areas of high population pressure to areas of low population pressure. Bugesera region, whose population density was 20 persons per square kilometre in 1960 and rose to 120 persons per square kilometre in 1978, is a good example (Clay and Ngenzi 1990).

Indeed, land inheritance has existed in Rwanda for so long. Recently, it has been sons and not daughters who customarily inherit land. However, some traditions enabled women to inherit land. These included ***Urwibutso***; a tradition by which a father would give land to a daughter as a gift, ***Inkuri***; a tradition by which a father would give land to his daughter as a gift when she gave birth (common in Ruhengeri), ***Intekeshwa***; a tradition by which a father gave land to the daughter as a farewell gift upon getting married and finally, ***Ingaligali***; a tradition by which a land chief would give land to women who were abandoned by their spouses. All these led to land fragmentation (Musahara 2006). Currently, laws have been made to incorporate the issue of gender equity in issues related to inheritance of property.

Demographic pressure on land in Rwanda

According to Rwanda Development Indicators (RoR 2003), Rwanda remains one of Africa's most densely populated countries, with more than 340 inhabitants per square kilometre. The rate of population growth was estimated at 3.1% in 1998. It is projected that Rwanda's population will double over the next twenty years; from 8.2 million inhabitants to at least 16 million inhabitants. Population density will certainly rise to 865 inhabitants per arable square kilometre.

In the last 50 years, the population of Rwanda has almost quadrupled. The population in 1934 was just over one and a half million. It had risen to 8.16 million in 2003. Some 40 years ago, density on arable land was 121 persons per square kilometre; the figure rose to 166 persons per square kilometre in ten years later, it is thought to have been approximately 262 persons per square kilometre in 1990; and by 1999, it was well above 350 persons per square kilometre (Baechler 1999). There is thus considerable pressure on land (a fixed factor), and this has made population pressure one of Rwanda's major challenges.

Another important characteristic of the Rwandan population is that a majority of this population lives in rural areas. This rural population largely depends on farming. As population grows rapidly, land becomes scarce. Farmers resort to purchasing and renting of land. Indeed, family planning practices have not been successful in Rwanda; a family produces many children who, after growing up are bequeathed with a portion of land and this leads to land fragmentation.

Impact of population pressure on land distribution in Rwanda

In Rwanda, population pressure on land has resulted into continuous fall in farm size. Table 2.1 highlights the changes in farm holdings that took place between 1984 and 2002.

Table 2.1: Distribution of land owned at the household level in Rwanda by farm size

Farm size Classification by Area Owned	Households		Total land owned	
	% in 1984	% in 2002	% in 1984	% in 2002
Less than 0.25 ha	7.4	16.8	1.0	3.3
0.25-0.5 ha	19.0	26.4	5.9	11.8
0.5-1.0 ha	30.4	29.7	18.4	25.4
1.0-2.0 ha	26.7	19.5	31.8	31.7
Greater than 2 ha	16.4	7.6	42.9	27.8
Total	99.9%	100%	99.7%	100%
Average farm size in Rwanda in ha per household	# Rural households 1,111,897	# Rural Households 1,442,681	1.2 ha	0.84 ha

Source: Mpyisi E. et al. (2003). Note: The symbol # in table 2.1 means "Total number of".

In 1984, some 43.1 % of rural households had farms of 1 hectare and larger. These farms occupied 74.7 % of the total land owned. In 1984 some 16.4 % of households had farms greater than 2 hectares, and this group occupied 42.9 per cent of land.

By 2002, the percentage of households with farms of 1 hectare or larger had dropped to 27.1% but this group still occupied almost 60 percent of land. The percentage of households with less than 0.5 hectares increased from 26.4 % in 1982 to 43.2 % in 2002, but as a group these farms only occupied about 15.1 % of land. The average farm size decreased from 1.2 ha in 1984 to 0.84 ha in 2002.

2.1.4 Technical efficiency definition and measurement

According to Farrell (1957), technical efficiency reflects the firm's ability to maximize the output for a given set of inputs (operate at the boundary of a production possibility frontier), or the firm's ability to minimize inputs used for a given set of output. The measurement of technical (in) efficiency can be classified into two categories: input-orientated measures and output-orientated measures. This study applied the output-orientated measure but reviewed literature about the two measures.

2.1.4.1 Input-orientated measure of technical efficiency

The input-orientated measure of technical efficiency seeks to answer the question: "By how much can input quantities be proportionally reduced without changing the output quantities produced?" Farrell (1957) illustrated the definition of the input-orientated measure of technical efficiency using a simple example involving firms, which use 2 inputs (x1 and x2) to produce a single output (y), under the assumption of constant returns to scale (to enable the representation of the production technology on a single isoquant). Knowledge of the unit isoquant (represented by the line SS' in figure 2.1) of the fully efficient firm permits the measurement of technical efficiency.

If a given firm uses quantities of inputs defined by point P to produce a unit of output, the technical inefficiency of that firm could be represented by the distance QP which is the amount by which all inputs could be proportionally reduced without a reduction in output. This is usually expressed in percentage terms by the ratio QP/OP which represents the percentage by which all inputs could be reduced, keeping output constant. The technical efficiency of a firm is most commonly measured by the ratio $TEI = OQ/OP$ which is equal to $1 - QP/OP$. Technical efficiency takes on either 1 or 0 or values between 1 and 0 and hence provides an indicator of the degree of the technical inefficiency of a firm. A value of 1 indicates that the firm is fully technically efficient while the value of 0 indicates that the firm is fully technically inefficient. For example the point Q is technically efficient because it lies on the efficient isoquant.

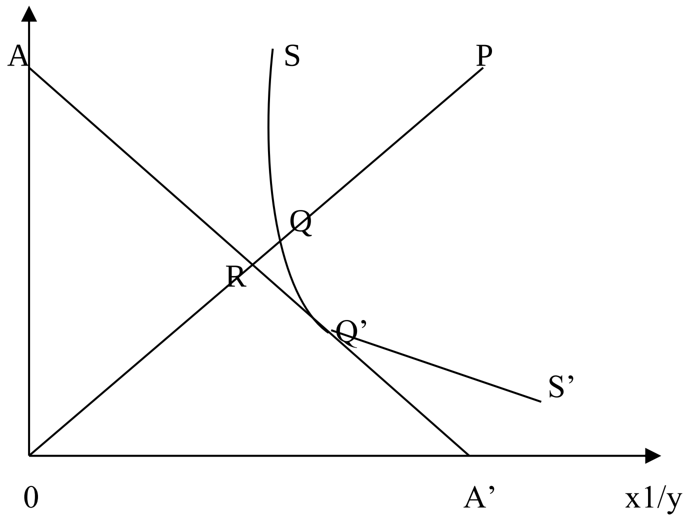


Figure 2.1: Technical efficiency and allocative efficiency under input-orientated measure

If the input price ratio represented by the line AA' is also known, allocative efficiency of the firm can also be calculated. Allocative efficiency of the firm operating at point P is defined as $AEI = OR/OQ$. The distance RQ represents the reduction in production costs that would occur if production were to occur at the allocatively (and technically) efficient point Q' instead of the technically efficient but allocatively inefficient point, Q. The total economic efficiency is defined to be the ratio $EEI = OR/OP$ where the distance RP can also be interpreted in terms of a cost reduction. Note that the product of technical efficiency (TE) and allocative efficiency (AE) provides the overall economic efficiency (EE). That is EEI= TEI× OR/OQ = OR/OP. Note also that TE, AE and EE are bounded by 0 and 1.

The efficiency measures explained above assume that the production function of a fully efficient firm is known. In practice this is not the case, and the efficient isoquant must be estimated from the sample data. Farrell (1957) suggested the use of (a) a non-parametric piecewise-linear convex isoquant constructed such that no observed point lies to the left or below it as shown in figure 2.2, and (b) a parametric function such as the Cobb-Douglas production function, fitted to the data, again such that no observed point should lie to the left or below it.

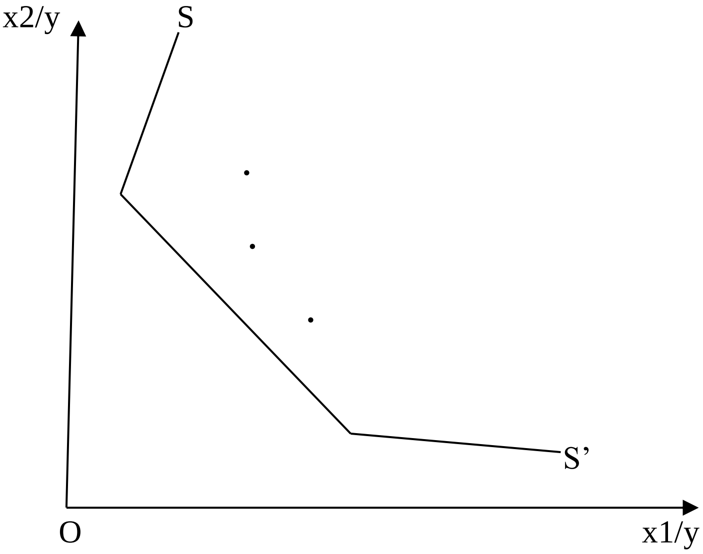


Figure 2.2: Piece wise linear convex isoquant

2.1.4.2 Output-orientated measure of technical efficiency

This addresses the question: "by how much can output quantities be proportionally expanded without altering the input quantities used?" This can be illustrated using a decreasing returns to scale (DRS) technology represented by f(x) and an inefficient firm operating at P.

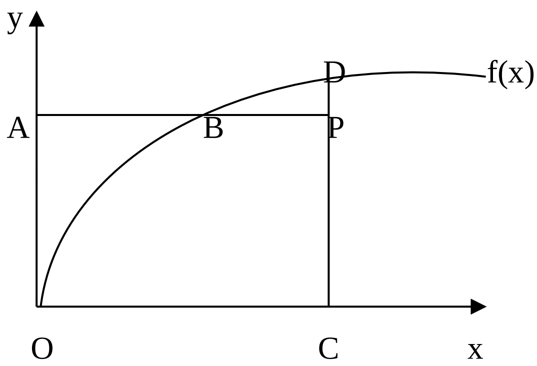


Figure 2.3: Decreasing Returns to Scale (DRS)

The Farrell input-orientated measure of technical efficiency would be AB/AP while the output-orientated measure would be CP/CD. The two measures of technical efficiency can only be equal if constant returns to scale (CRS) exist but will be unequal if both increasing returns to scale (IRS) and decreasing returns to scale (DRS) exist. The CRS case is presented in figure 2.4 below:

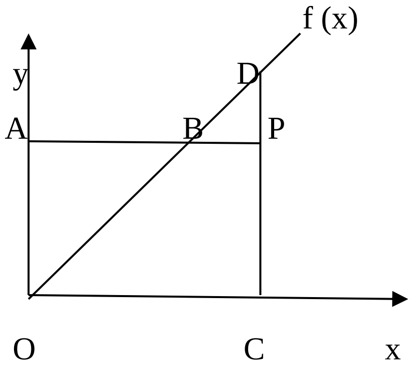


Figure 2.4: Constant Returns to Scale (CRS) case

In the CRS case, we observe that $AB/AP = CP/CD$ for any inefficient point P we may choose. One can consider the output-orientated measure of technical efficiency further by considering a case where production involves 2 outputs (y1 and y2) and a single input (x). Again if we assume CRS, we can represent the technology by a unit production possibility curve in 2 dimensions. This example is illustrated in figure 2.5 below.

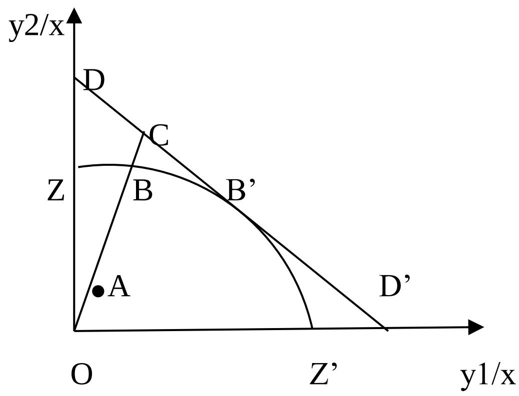


Figure 2.5: Technical efficiency (TE) and allocative efficiency (AE) from output-orientation

The line ZZ' is the unit production possibility curve. The distance AB represents technical inefficiency (TIE). That is, the amount by which outputs could be increased without requiring extra inputs, hence a measure of output-orientated efficiency is: $TE0 = OA/OB$. If we have price-information, then we can draw the isorevenue line DD' and define allocative efficiency

(AE) to be: AE0 = OB'/OA which has a revenue increasing interpretation. Further, one can define the overall economic efficiency (EE) as the product of these 2 measures:
EE0 = OB'/OB = TE0× AE0 = OA/OB × OB'/OA. Again, all the 3 measures are bound by 0 and 1. Note that point C is unattainable at the current level of technology.

2.2 Literature review

2.2.1 Effect of land fragmentation on the productivity and technical efficiency of farms

The literature on land size and land productivity is large and has been around for decades. In recent times Binswanger et. al. (1995) argued that there was an inverse relationship between the two whereas Banerjee and Ghatak (1996) questioned this result. Carlyle (1983), Heston and Kumar (1983), Bentley (1987), Blarel Benoit, Peter Hazell, Frank Place and John Quiggin, (1992), Jabarin and Epplin (1994) focused on the impact of fragmentation on yield and productivity. The debate basically focused on the impact of fragmentation on the ability of farmers to minimize risk. These studies perceived land fragmentation to have a negative impact on productivity and yield.

The countries where the relationship between land size and technical efficiency has been studied include the Philippines (Herdt and Mandac 1981; Dawson and Linagard 1989), Brazil (Taylor and Shonkwiler 1986), Tanzania (Shapiro 1983), Pakistan (Ali and Chaudhry 1989) and India (Huang and Bagi 1984; Kalirajan 1981; Junankar 1980; Sidhu 1974; Lau and Yotopoulos 1971; Battese, Coelli and Colby 1989; Tadesse and Krishnamoorthy 1997). The studies used the stochastic production function approach and concluded that the large variation in yield across farmers was due to differences in technical efficiency, which was largely influenced by farm size and ecological and socio-economic factors such as gender, age, education, extension services, access to credit, among others.

Raghbendra et al. (2005) investigated the impact of land fragmentation on technical efficiency of rice farms in India using the stochastic frontier method and confirmed that there was a significant positive relationship between farm size, average farm size and yield while the number of plots and yield were inversely related. Therefore fragmentation measured in terms of number of farms per household had a negative impact on yield.

Shuhao (2005), using the stochastic frontier method, investigated the impact of land fragmentation on rice production in China and found out that land fragmentation played an important role in explaining technical efficiency. Given the number of plots, increase in average plot size had a significant positive impact on technical efficiency. Distance to the plots, however, had no significant impact on technical efficiency. This implied that farm households with large average distances to the plots were as efficient as farm households with small average distances to the plots. Bizimana et al. (2004) used a block-recursive regression analysis to investigate the effect of land fragmentation on economic efficiency of farms in Rwanda's Butare district. They concluded that land fragmentation reduced the economic efficiency of farms. However, this study did not capture the various dimensions of land fragmentation.

Land fragmentation and productivity/efficiency in Rwanda

Blarel (1989) made research about the effects of land fragmentation on the productivity of farms in Rwanda. To him, land fragmentation has no negative effect on the productivity and efficiency of farms. He argued that farmers operating small farms intensify their farm operations through a more rigorous use of available family labor, a substitution toward higher yielding crops, sowing seeds more densely and growing more crops in associations. Small farms also benefited much from conservation investments such as terraces, living fences, and mulching. He discussed other determinants of productivity/efficiency of farms and concluded that Rwandan farmers were far more likely to invest in the fields for which they had land titles than in fields rented from others. Indeed, higher yields occurred on parcels operated under short-term use rights than under ownership rights.

Blarel Benoit, Peter Hazell, Frank Place and John Quiggin (1992) found out that 40% of Rwandan households owned 8 or more parcels. They still concluded that land fragmentation seemed to have a negative effect on the productivity and efficiency of farms. Place and Hazzel (1993) confirmed that peasants make long-term investments (planting trees, trenching, de-stumping, and green fencing) and short-term investments (continued mulching and manuring) in land if they had secure long-term ownership rights on that land. But these investments do not guarantee that output will be high since other factors such as technology and availability of financial credit affect productivity and efficiency.

Byiringiro and Reardon (1996) found out that farm size and productivity/efficiency were inversely related whereas farm size and labor productivity were positively related. To them, small farms invest twice as much per hectare in soil conservation compared to large farms. They however, discovered that soil erosion severely reduces farm yields in Rwanda.

Studies carried out in Southern Rwanda revealed that the relationship between fragmentation and land productivity might not necessarily be negative (Blarel Benoit, Peter Hazell, Frank Place and John Quiggin, 1992; Marara and Takeuchi, 2003). However, a study by Bizimana et al. (2004) in the former Rusatira and Muyira districts of the former Butare province revealed that the number of plots per household negatively affected economic efficiency while plot size positively affected economic efficiency. The authors recommended that land consolidation be adopted as it could help increase the economic efficiency of farms.

However, most studies carried out in Rwanda about land fragmentation did not capture all forms/indicators of land fragmentation. Blarel Benoit, Peter Hazell, Frank Place and John Quiggin (1992) used the Simpson index as a measure of fragmentation yet it does not capture the effect of distance travelled to reach the plots. Marara and Takeuchi (2003) only considered the number of plots per household while Bizimana et al. (2004) considered plot size and number of plots per household. This study attempted to include plot size, distance from household residence to plots and number of plots per household in the analysis of the effect of land fragmentation on the productivity and technical efficiency of smallholder maize farms in Rwanda.

3.0 METHODS AND PROCEDURES

3.1 Theoretical model

3.1.1 Indicators of land fragmentation

Different researchers have used several measurement units in their attempt to measure land fragmentation. Common measures include the Simpson index (SI), the Januszewski index (JI) and average farm size.

The Simpson Index (Blarel Benoit, Peter Hazell, Frank Place and John Quiggin, 1992), which is defined as:

$$SI = 1 - \frac{\sum_{i=1}^{n} a_i^2}{\left(\sum_{i=1}^{n} a_i\right)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

Where n is the number of plots, and a_i is the area of each plot. This index is located within the range of 0 to 1. A higher SI value corresponds with a higher degree of land fragmentation. The value of the Simpson index is determined by the number of plots, average plot size and the plot size distribution. It also does not take farm size, distance and plot shape into account.

Average farm size (Nguyen et al. 1996) defined as:

$$P = \frac{S}{N} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

Where S is the *size of the farm* and N *is the number of plots*. When N is large, average plot size, P is small. This implies that as fragmentation increases, average farm size reduces and vice-versa. This measure of land fragmentation simply looks at the way in which a farm is subdivided into a given number of plots. The drawback of using average farm size as a measure of land fragmentation is that it only considers subdivision of the same piece of land (farm) due to inheritance only.

The Januszewski index (Raghbendra et al. 2005) defined as:

$$JI = \frac{\sqrt{\sum_{i=1}^{n} a_i}}{\sum_{i=1}^{n} \sqrt{a_i}} \text{.....................................}(iii)$$

Where n is the number of plots, and a_i is the area of each plot. This index is located within the range of 0 to 1. The smaller the JI value the higher degree of land fragmentation. The JI value combines information on the number of plots, average plot size and the size distribution of the plots. It has three properties: fragmentation increases (the value of the index decreases) when the number of plots increases, fragmentation increases when the average plot size declines, and fragmentation decreases when the inequality in plot sizes increases. The index, however, fails to account for farm size, plot distance, and shape of plots.

Single-dimension indicators of land fragmentation (Shuhao, 2005): There are three indicators/measures of land fragmentation; (1) plot size, (2) number of plots per household and, (3) the distance from household residences to plots. This study used these three measures of land fragmentation because we wanted to capture explicit effects of each single-dimension indicator on the productivity and technical efficiency of farms.

3.1.2 Measuring technical efficiency

Choosing between a parametric (stochastic frontier model) and a non-parametric (Data Envelopment Analysis) approach to measure efficiency has been controversial. Each has its strengths and weaknesses (Coelli and Perelman, 1999). The parametric analysis deals with stochastic noise, and allows hypothesis testing on production structure and efficiency. However, this method has to specify a functional form for the production frontier and imposes a distributional assumption on the efficiency term. The non-parametric method does not impose such restrictions, but it assumes the absence of measurement or sampling error. The choice between these approaches, therefore, depends upon the objective of the research, the type of farms that are analyzed, and data availability.

The stochastic frontier method has been used for both cross-sectional and panel data. In Tanzania, Mbelle and Sterner, (1991) applied the model to analyze the importance of foreign exchange in industries. Other studies include among others, those of Battese and Coelli (1995); Raghbendra et al (2005); Hyuha et al. (2008) and Bagamba (2007).

This study used the stochastic frontier approach - a parametric method - to analyze the effect of land fragmentation on the technical efficiency of smallholder maize farms in Southern Rwanda. The main reason for this choice is that maize production in Rwanda is subject to weather disturbances and heterogeneous environmental factors like soil quality. Moreover, the respondents might not always answer all the questions precisely, due to for example having varied perceptions, and this will affect measured efficiency (Chen *et al.*, 2003).

3.2 Theoretical considerations

There are two approaches used to estimate technical efficiency: the one-step approach and the two-step approach. The two-step procedure using the stochastic frontier production function generally involves first estimating the production frontier then predicting the technical efficiency of each firm. In the second step, the predicted technical efficiency variable is regressed against a set of variables that are hypothesized to influence the firm's efficiency (Kalirajan, 1981).

However, the two-stage procedure lacks consistency in assumptions about the distribution of the inefficiencies. In step one, it is assumed that inefficiencies are independently and identically distributed in order to estimate their values. In step two, estimated inefficiencies are assumed to be a function of a number of firm-specific factors, violating this assumption (Coelli, 1996). To overcome this inconsistency, Kumbhakar et al. (1991) suggest estimating all the parameters in one step. In the one-step procedure, the inefficiency effects are defined as a function of the farm-specific factors and incorporated directly into the maximum likelihood (ML) estimate. This study used the single-step procedure.

In this study, a farm specific stochastic production frontier involving outputs and inputs was defined as follows:

$y_i^* = f(x_i)\exp(v_i)$ .... (1)

Where y_i^* is the maximum possible stochastic potential output from the i[th] farm; x_i is a vector of m inputs and v_i are statistical random errors assumed to be distributed as $N\ (0, \sigma_v^2)$. The production realized on the i[th] farm can be modeled as follows:

$y_i = y_i^*\ \ \exp(-u_i)$ .... (2)

Where $\exp(-u_i)$ is defined as a measure of observed TE of the i[th] farm assuming that $u_i \geq 0$. When u_i takes the value zero, the i[th] farm is technically efficient and realizes its maximum possible potential output. Thus TE can be defined as a ratio between the firm's realized output and the firm's stochastic/potential output as shown in equation 3:

$TE = \exp\ (-u_i) = \frac{y_i}{y_i^*}$ .... (3)

Substituting equation (1) into equation (2) and taking logs on both sides gives:

$lny_i = \ln f(x_i\ ; \beta) + v_i - u_i$ .... (4)

Where y_i denotes the production of the i[th] farm (i = 1, 2,…, n); x_i is a (1 x k) vector of functions of input quantities used by the i[th] farm; β is a (k x 1) vector of unknown parameters to be estimated; v_i *'s* are random errors assumed to be independently and identically distributed with $N\ (0, \sigma_v^2)$ and they are independent of the u_i *'s*. The u_i is a one-sided error term representing the technical inefficiency (TIE) of farm i.

Subtracting v_i from both sides of equation (4), the production of the i[th] farm can be estimated as:

$lny_i^{'} = \ln f(x_i\ ; \beta) - u_i$ .... (5)

Where lny_i' is the natural logarithm of the predicted output of the ith farm, x_i is the natural logarithm of the ith input β is a set of parameters and $-u_i$ is the measure of observed technical efficiency of the ith farm.

Define the efficient level of production as:

$$ln\hat{y} = \ln f(x_i \ ; \beta) \text{ .... (6)}$$

Where $ln\hat{y}$ is the natural logarithm of the output of the technically efficient farm, x_i is the natural logarithm of the ith input and β is a set of parameters.

Then, from equations (5) and (6), computation of technical efficiency (TE) is given in equation 7:

$$lnTE_i = lny_i' - ln\hat{y} = -u_i \text{ or equivalently, } lnTE_i = -u_i \text{ .... (7)}$$

Arguments in equation 7 are defined in equations 5 and 6. From equation 7, it follows that $TE_i = e^{-u_i}$ and when $u_i = 0$, then TE_i = 1 and production is said to be technically efficient.

The distribution of u_i could be half normal with zero mean, truncated normal (at mean, μ), or based on conditional expectation of the exponential ($-u_i$). There are no a priori reasons for choosing a specific distributional form of u_i because each has advantages and disadvantages (Kebede, 2001). The half normal and exponential distributions have a mode of zero, implying that most firms being analyzed are efficient. The truncated normal allows for a wide range of distributional shapes, including non-zero modes, but is computationally more complex (Coelli, 1996).

This study used the technical inefficiency model proposed by Battese and Coelli (1995), and defined the technical inefficiency effects as follows:

$$u_i = z_i \delta + w_i \text{ .... (8)}$$

Where z_i is a (1 x m) vector of explanatory variables associated with the technical inefficiency effects; δ is an (m x 1) vector of unknown parameters to be estimated; and w_i's are unobservable random variables. The parameters indicate the impacts of variables in z on technical inefficiency. The frontier model may include intercept parameters in both the frontier and the model for the inefficiency effects, provided the inefficiency effects are stochastic and not merely a deterministic function of relevant explanatory variables (Battese and Coelli, 1995).

Battese and Corra (1977) parameterised the variance terms of u and v as:

$$\delta^2 = \delta_v^2 + \delta_u^2 \text{ and } \Upsilon = \frac{\delta_u^2}{\delta^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where σ^2 is the variance of output conditioned on inputs. This says that the production uncertainty comes from two sources: pure random factors and technical inefficiency. Hence if Υ, the proportion of uncertainty coming from technical inefficiency, is equal to zero, then it actually means there is no technical inefficiency. This can be used to test whether technical inefficiency is present in the firm. Further, the null hypothesis that the impact of the variables included in the inefficiency effects model in equation (8) on the TIE effects is zero is expressed by H0: $\delta' = 0$, where δ' denotes the vector, δ , with the constant term, δ_0, omitted (Battese and Broca, 1997).

3.2.1 Model specification

According to Battese and Coelli (1995), the functional form of the stochastic production frontier needs to be specified. In practice, both the Translog and the Cobb-Douglas forms are usually adopted. The Translog form is more flexible in permitting substitution effects among inputs, and is claimed to be a relatively dependable approximation to reality while the Cobb-Douglas form is simple and commonly used.

Kopp and Smith (1980) argue that functional specification has a discernible, though rather small, impact on estimated efficiency. Taylor *et al.* (1986) also argue that as long as interest rests on efficiency measurement and not on the analysis of the general structure of the production technology, the Cobb-Douglas production function provides an adequate representation of the production technology. Therefore, following Nguyen *et al*. (1996), a stochastic Cobb-Douglas production function was estimated because of its simplicity. We define the empirical form of the stochastic production function in equation 10:

$$\ln(maizeout) = \beta_0 + \beta_1 \ln(hhsize) + \beta_2 \ln(seed) + \beta_3 \ln(maizearea) + v_i - u_i \ldots\ldots(10)$$

The variables included in the stochastic production model and their expected signs are summarized in table 3.1.

Table 3.1: Variables in the stochastic Cobb-Douglas production model

Variable	**Definition**	**Measurement unit**	**Effect**
Land area planted with maize in season A (September 2008-February 2009)	maizearea	Hectares	+
Household size in season A (September 2008-February 2009)	hhsize	Number of persons in the household	+
Quantity of maize seed* used for maize production in season A(September 2008-February 2009)	seed	Kgs	+
Maize output in season A(September 2008-February 2009)	maizeout	Kgs	Dependent

*Maize seed includes both the improved and local varieties. However, Rwandan farmers generally use the improved variety.

Household size was used as a proxy for labor because larger households are always likely to have many people to participate in agriculture. During the survey, it was found out that hired labor is not so much used. Therefore observations with hired labor as outliers were excluded from the sample. All inputs in the Cobb-Douglas production function are expected to have a positive impact on maize output since an increase in each (or all of) the inputs can lead to increased output.

The technical inefficiency (TIE) model was defined in equation 11:

$$TIE = \lambda_0 \ + \lambda_1 \ age + \lambda_2 \ education + \lambda_3 \ dependratio + \ \lambda_4 \ noplots + \ \lambda_5 \, plotsize + \lambda_6 sex + \lambda_7 \ extension + \lambda_8 \, distmkt + \lambda_9 \ avplotdist + \ \lambda_{10} \ dummytitle + \lambda_{11} \ agroclimate + \varepsilon_i \ \ldots\ldots \ (11)$$

Where by ε_i is an error term which can be assumed to be distributed as truncated normal, half normal or exponential distribution. Note that instead of using indices (such as the Simpson index), single dimension indicators (number of plots per household, average plot size and average distance walked to reach a plot) were used to measure land fragmentation. This allowed for obtaining the explicit effect of each single dimension indicator on productivity and technical efficiency. The variables included in the technical inefficiency model and their expected signs are summarized in table 3.2.

Table 3.2: Variables in the technical inefficiency model

Variable	**Label**	**Measurement unit**	**Expected sign**
Age of household head	Age	Years	+/-
Education level of household head	education	Years spent in school	+/-
Dependency ratio	dependratio	Dependency ratio	+
Number of plots per household	noplots	Number of plots owned by household	+/-
Plot size	plotsize	Hectare	+/-
Average distance from plots to homestead	avplotdist	Kilometers	+
Number of extension visits received by household in season A	Extension	Number of visits	-
Distance to the nearest market center	Distmkt	Kilometers	+
Dummy for land title	dummytitle	D=1 for have title, 0 otherwise	-
Dummy for agro-climatic zone	agroclimate	1 for Bwanamukali, 0 for Mayaga	-
Sex of the household head	Sex	1=Male, 0=female	+/-

TIE	Technical inefficiency		Dependent

Most studies have associated farmers' age and farmers' education with technical efficiency. Farmers' age and education are reported by many studies as having a positive effect on technical efficiency (Amos, 2007; Ahmad et al., 2002; Kibaara, 2005). Age may have a positive effect on technical efficiency if due to experience; older farmers tend to adopt better farming methods than young farmers. A higher level of education can lead to a better assessment of the importance and complexities of production decisions, resulting in better farm management. Educated farmers learn faster and utilize well extension information (Basnayake and Gunaratne, 2002).

In other studies the effect of age and education is ambiguous (Shuhao, 2005). Dependency ratio is reported to have significant negative effects on technical efficiency (Bagamba, 2007) while the farmers' gender (sex) can have ambiguous effects on technical efficiency (Tchale and Sauer, 2007).

Although studies by Amos (2007), Raghbendra, Nagarajan and Prasanna (2005), and Barnes (2008) found the relationship between land holding size and efficiency to be positive, a clear-cut conclusion on the influence of this variable on efficiency has not been reached as discussed in Kalaitzadonakes et al (1992) work. On the other hand, effect of the number of plots on efficiency has been hypothesized to be either negative (Raghbendra et al, 2005) or positive (Marara and Takeuchi, 2003) or ambiguous (Shuhao, 2005). It was hypothesized that the effect of number of plots on efficiency was ambiguous.

Distance from plots to residence is expected to negatively affect efficiency (Byiringiro and Reardon, 1996) Extension visits are expected to increase efficiency and distance to the nearest market is expected to reduce efficiency (Bagamba, 2007). Land ownership rights (possession of land titles) has been assumed to encourage soil conservation investments and therefore expected to increase productivity and efficiency (Musahara, 2006). This study expected agro-climate to have a negative effect on inefficiency since Bwanamukali is more fertile and receives more rainfall than Mayaga.

Age had been expected to have a quadratic effect on technical efficiency. However, results showed that age and its square had the same sign and were both not significant (once the square of age was included in the model) but age was significant (once the square of age was excluded from the model). Thus, the square term of age was excluded from the model.

The analysis of productivity for several crops can be made by regressing marginal value products against farm-specific and household specific characteristics. For a single crop, marginal physical products can be used (Byiringiro and Reardon, 1996). This study used marginal physical products as the dependent variable and all dimensions of land fragmentation as the independent variables. To analyze the productivity of smallholder maize farms, the following double-log regression model was specified:

$$mp\_area = \alpha_0 + \alpha_1 farmsize + \alpha_2 noplots + \alpha_3 avplotdist + \alpha_4 avplotdist * noplots + V_i \text{......................(12)}$$

Where mp_area is the natural log of the marginal product of land under maize, $farmsize$ is the natural log of the size of the farm owned by a household, $noplots$ is the natural log of the total number of plots owned by the household, $avplotdist$ is the natural log of the average distance between households residences to plots and V_i is the error term that is assumed to be independently and identically distributed with zero mean and constant variance. The interaction term $avplotdist * noplots$ was included to show what happens when a household has many/few farms that may be distant/close to each other.

Apriori, it was expected that farm size is positively/negatively related to the productivity of farms as there is mixed literature about this. Number of plots and distance between plots are both expected to constrain productivity. The interaction between distance and number of plots can be negative if a household has many plots that are located far apart from each other, otherwise this interaction may have insignificant effect as long as plots are near each other.

3.3 Data and sources

3.3.1 Study area

This study was carried out in Rwanda's Southern province, particularly in Gisagara district. A district is an administrative unit that comes next to the province (the highest local administrative unit) while a sector is an administrative unit that comes next to the district. There are 13 sectors (Nyanza, Kigembe, Kansi, Kibirizi, Muganza, Mugombwa, Mukindo, Musha, Gishubi, Mamba, Gikonko, Ndora, and Save) in Gisagara district. More information about Gisagara district is provided in appendix 2 and appendix 3. Gisagara district was purposively chosen because land fragmentation is so common there (Bizimana et al., 2004 and Musahara, 2006).

3.3.2 Sampling methods

In this study, a two-stage sampling technique was used to select the sample. Stage one involved a random selection of sectors. Out of the 13 sectors, 7 were randomly selected and these were Save, Kibirizi, Kansi, Musha, Gikonko, Gishubi and Mamba. Simple random sampling was applied at stage one.

A sampling frame (a list of households) was obtained for each sector and at stage two respondents were selected from each sector using systematic random sampling (whereby the first k^{th} household was selected randomly) as shown in table 3.4 below. A sample size of 280 households was selected.

However, after excluding outliers, a sample size of 241 households remained. Primary data for this study were collected using a structured household questionnaire (see appendix 1). The structured household questionnaires were administered to respondents by enumerators under supervision of the researcher. The field survey was conducted from 20th May 2009 to 25th June 2009.

Table 3.3: Systematic random sampling procedure

Sector	**Total Households (N_i)**	**Desired Sample size (n_i)**	**k th interval ($\frac{N_i}{n_i}$)**
Kibirizi	5530	40	138
Kansi	4055	40	101
Gikonko	4420	40	111
Gishubi	5084	40	127
Mamba	6677	40	167
Musha	4853	40	121

Save	5640	40	141
Total	**36259**	**280**	

Source: the sampling frames were obtained from each sector's official reports

3.3.3 Data analysis

Data collected were coded, entered and cleaned using the Statistical Package for Social Scientists (SPSS) computer program. The data were then transferred to Stata in which econometric analyses were carried out. Diagnostic tests (to check for normality, multicollinearity and outliers) were then carried out. As a result, 39 outliers were removed leaving a sample size of 241 households. Descriptive statistics (percentages, means and standard deviations) were generated.

A Cobb-Douglas stochastic production function was estimated using the single-step procedure suggested by Kumbhakar et al. (1991) that produces maximum likelihood estimates of the stochastic production function. This procedure is superior to the two-stage procedure because it does not violate the assumption that the inefficiency effects are independently and identically distributed (Battesse and Coelli, 1995).

4.0 RESULTS AND DISCUSSION

In this chapter the results of the study are presented and discussed. First, we characterize smallholder maize farms in Gisagara district and later analyze their productivity and technical efficiency.

4.1 Characterization of smallholder maize farms in Gisagara district

A total of 241 household heads from Gisagara district were retained as the sample (after excluding 39 outliers). The number of households managed by males was quite higher than the number of households managed by females (Table 4.1). This however did not tempt us to expect that sex would have a positive effect on technical efficiency since its effect has been reported in the literature to be ambiguous (Tchale and Sauer, 2007).

Table 4.1: Gender decomposition of households

Sex of the household head	Frequency	Percentage
Female	102	42
Male	139	58
Total	**241**	**100**

Source: *Survey data, 2009*

Generally, almost 80 percent of households in Gisagara district had 30 or more years (Table 4.2). The implication is that if old age had a significant positive effect on technical efficiency, then a majority of households would be efficient. However, some literature considers age to have an ambiguous effect (Shuhao, 2005**)**.

Table 4.2: Age frequency distribution of household heads

Age of household head	Frequency	Percentage
18-30	49	20.3
30-42	76	31.5
42-54	60	24.9
54-66	40	16.6
66 and above	16	6.6
Total	**241**	**100**

Source: *Survey data, 2009*

In many studies, education has been hypothesized to positively influence technical efficiency of farms (Amos, 2007; Kibaara, 2005). Education levels of household heads of Gisagara district were low given that those who attained either secondary or university education were only 9.13 and 90.87 percent either had no education or attained primary education. However, almost 66 percent attained some education (Table 4.3).

Table 4.3: Distribution of household heads according to education level

Education level of household head	**Frequency**	**Percentage**
No education	82	34.02
Primary	137	56.85
Secondary	20	8.30
University	2	0.83
Total	**241**	**100**

Source: *Survey data, 2009*

Households with a dependency ratio of 0.5 or larger were almost 71 percent (Table 4.4). Since higher dependency ratio has been reported to reduce efficiency levels (Bagamba, 2007.

Table 4.4: Dependency ratio of household heads

Dependency ratio	**Frequency**	**Percentage**
0	26	10.8
0.1-0.5	45	18.7
0.5-0.9	155	64.3
1	15	6.2
Total	**241**	**100**

Source: *Survey data, 2009*

Access to extension services has been reported to positively influence technical efficiency of farmers especially because farmers acquire information about better farming practices and agricultural technologies (Bagamba, 2007; Shuhao, 2005). In Gisagara district, access to extension services was low given that only 19 percent received 1 extension visit or more during season A of 2008/09 (Table 4.5).

Table 4.5: Extension visits received by households

Extension visits	**Frequency**	**Percentage**
0	195	81
1-5	40	16.6
6-10	5	2
11-15	1	0.4
Total	**241**	**100**

Source: *Survey data, 2009*

Possession of land titles helps to improve land tenure security and makes land owners feel confident to make long-term investments in their land which in turn may enhance their productivity and technical efficiency (Blarel, 2001; Musahara, 2006). In Gisagara district, the number of households with land titles was higher than those without titles (Table 4.6).

Table 4.6: Possession of land titles

Land title	**Frequency**	**Percentage**
Have title	138	57.3
Have no title	103	42.7
Total	**241**	**100**

Source: *Survey data, 2009*

Gisagara district is divided into 2 agro-climatic zones, Bwanamukali (which receives more rainfall and is more fertile) and Mayaga (which receives less rainfall and is less fertile). The number of households who belonged to Bwanamukali was higher than that of Mayaga (Table 4.7).

Table 4.7: Households per agro-climatic zone

Agro-climatic zone	**Frequency**	**Percentage**
Bwanamukali	139	57.7
Mayaga	102	42.3
Total	**241**	**100**

Source*: Survey data, 2009*

Access to the market has been reported to positively influence the productivity and technical efficiency of farms (Bagamba, 2007). At least 67 percent of total sampled households travelled less than five kilometers (Table 4.8) to reach the market while at least 33 percent of total sampled households travelled five kilometers and above.

Table 4.8: Households and distance to the market

Distance to the market (Km)	Frequency	Percentage
<5	161	66.8
5 and above	80	33.2
Total	241	100

***Source**: Survey data, 2009*

Distance from the households' residences to plots has been reported to negatively affect the productivity and technical efficiency of farms (Shuhao, 2005; Byiringiro and Reardon, 1996). In Gisagara district, almost 94 percent of households travelled an average distance of less than two kilometers to reach their plots (Table 4.9). Thus, distances were not so constraining. Note that in the table 4.9, the single household with plot distance of 19-20 km was treated as an outlier and dropped.

Table 4.9: Households and average plot distance

Average plot distance (Km)	Frequency	Percentage
< 2	226	93.78
2-4	12	4.98
≤ 4	2	0.83
Total	240	99.59

***Source**: Survey data, 2009*

It has been argued that a plot that is averagely less than one hectare cannot be economically productive (Mosley, 2004). On average, at least 88 percent of households in Gisagara district had plots of less than one hectare (Table 4.10).

Table 4.10: Average plot size per Household

Average plot size category	Number of households	Percentage
≤ 0.25	133	55.2
0.26-0.5	53	22.0
0.51-0.75	28	11.6
0.76-1	7	2.9
above 1	20	8.3
Total	241	100

***Source:** Survey data, 2009*

The number of plots can have positive effects (Shuhao, 2005; Marara and Takeuchi, 2003) on technical efficiency. However, other studies have reported that the higher the number of plots the lower the technical efficiency levels of farmers (Raghbendra, 2005). Households with 2 or more plots were 54.36 percent of total sampled households (Table 4.11).

Table 4.11: Number of plots per household

Number of plots	Number of households	Percentage
1	110	45.64
2	85	35.27
3	33	13.69
4	7	2.9
5	5	2.07
7	1	0.41
Total	**241**	**100**

***Source**: Survey data, 2009*

4.2 Analysis of productivity and technical efficiency of farms in Gisagara district

As expected, results in table 4.12 show that each of the inputs; maize area, seed and hhsize (a proxy for labor) has a significant positive effect on maize production.

Table 4.12: Results of the stochastic Cobb-Douglas production function

Variable	Overall sample (n=241) Coefficient	z	P
Lnmaizearea	0.0046442*	1.70	0.090
Lnhhsize	0.012267*	1.68	0.093
Lnseed	0.9917386***	214.38	0.000
Constant	1.445452***	73.68	0.000
Log likelihood = 286.40888			
Wald chi2 (3) = 48836.00			
Prob > chi2 = 0.0000			

***Source:** Survey data, 2009;* ***, **, * imply significance at 1%, 5% and 10% respectively.

Seed is significant at 1 percent while maize area (land) and household size are significant at 10 percent. Our results were consistent with empirical studies. Byiringiro and Reardon (1996) estimated a Translog production function to analyze the determinants of production in Rwanda. They found out that land and labor had positive significant effects on production. Msuya et al.

(2008) found out that land, expenditure on materials (including maize seed) and family labor positively affected maize productivity in Tanzania. The coefficients in the stochastic Cobb-Douglas production model show partial elasticities and seed has the highest output elasticity. The total elasticity of production (Returns to scale) is close to 1, implying constant returns to scale.

4.2.1 Marginal physical products

Maize seed had the highest elasticity, followed by area under maize (land) and then household size (a proxy for labor). Therefore, maize seed and land were very important determinants of maize productivity (Table 4.13). Maize seed has the highest marginal physical product. Household size has the lowest marginal physical product. This is perhaps due to the fact that a larger household may have many of its members as children or very old and therefore not very productive. The low marginal physical product for land could be due to the fact that land in Rwanda is scarce and therefore farmed intensively. Land has lost fertility due to over-cultivation and yet farmers have limited access to fertilizers (Musahara, 2006).

Table 4.13: Productivity analysis

Variable	**Elasticity**	**Mean**	**Marginal physical product**
Maizearea	0.0046442	0.400145	1.2
Hhsize	0.012267	4.385892	0.23
Seed	0.9917386	25.16598	3.9
maizeout	Dependent	100.029	Dependent

Source*: calculated from survey data, 2009*

Following Debertin (2002), marginal physical products were computed (table 4.13) for the inputs used in maize production as follows:

$$\frac{\mathrm{dlny}}{\mathrm{dlnx_i}} = \beta_i = \text{partial elasticity} \approx \frac{dy}{dx_i} * \frac{\bar{x}_i}{\bar{y}} = MPP_{xi} * \frac{\bar{x}_i}{\bar{y}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (12)$$

Equation 12 can be manipulated to give marginal physical product as shown in equation 13

$$MPP_{xi} = \beta_i * \frac{\bar{y}}{\bar{x}_i}; \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (13)$$

Whereby $(i = 1, \ldots, n)$ while $\bar{y}$ and $\bar{x}_i$ are arithmetic means of maize output and the i^{th} x input respectively.

In the technical inefficiency model, only four variables were significant. A negative sign in the inefficiency model implies negative effect on inefficiency or positive effect on efficiency. Variables that reduce inefficiency increase productivity/technical efficiency. Results show that possession of land titles, education and age reduce inefficiency while average number of plots increase inefficiency (Table 4.14). A likelihood ratio test of hypothesis 1 was carried out. Using the likelihood ratio test, hypothesis 1 was not rejected. The likelihood ratio test of the null hypothesis gave us the following results: $chibar^2$ (01) = 0.66 and Prob>=$chibar^2$ = 0.66 and it was concluded that smallholder maize farms in Gisagara district were technically efficient.

This study was mainly interested in finding out the effects of the various dimensions of land fragmentation on the productivity and technical efficiency of smallholder farms and not to assess the technical efficiency differentials among households with respect to farm-specific and household-specific characteristics. The study therefore did not assess technical efficiency differentials among households with respect to the various dimensions of land fragmentation.

Table 4.14: Results of the technical inefficiency model

Variable	**Overall sample (n=241) Coefficient**
Noplots	0.2408187*
Avplotdist	0.0510016
Dummytitle	-0.9186486*
Plotsize	-0.328226
Sex	0.4057642
Age	-0.0343792**
Education	-0.2553555**
Extension	-0.115289
Agroclimate	-0.4302309
Dependratio	0.639182
Distmkt	-0.0149615
Constant	3.20605**
Likelihood-ratio test of sigma_u=0: chibar2(01) = 0.66	

***Source**: Survey data, 2009;* ***, **, * imply significance at 1%, 5% and 10% respectively.

The number of plots per household (land fragmentation) increases inefficiency of smallholder maize farms. So, hypothesis 4 was not rejected. Similar findings were obtained in Rwanda by Bizimana (2004). The inverse relationship between the number of plots and technical efficiency could have been due to the problems involved in managing many plots such as supervision of workers (Shuhao, 2005; Raghbendra, 2005).

Average distance from household residences to plots is not statistically significant and thus, hypothesis 2 was rejected and concluded that distance from residences to plots did not individually reduce the efficiency of farms. This is consistent with the findings of Shuhao (2005) and Msuya et al. (2008). Distance to reach plots was insignificant perhaps due to the fact that distances are very short (see Table 4.9)

Plot size was also statistically insignificant and therefore did not individually reduce efficiency of farms. Therefore hypothesis 3 was rejected. The implication is that households who operated smaller plots were as efficient as those who operated larger plots. This finding is consistent with the work of Kalaitzadonakes et al. (1992).

The joint test of the significance of all the indicators of land fragmentation gave the following results: chi^2 (3) =5.14 and Prob > chi^2 = 0.01617, implying that the indicators were jointly significant and therefore jointly increased inefficiency of farms. Given this finding, hypothesis 5 was not rejected and it was concluded that all indicators of land fragmentation reduced the productivity and technical efficiency of smallholder maize farms in southern Rwanda.

The dummy variable for land title was significant at 10% and reduced inefficiency. This implies that farmers who had land titles were more efficient than those without titles. This could have been due to the fact that land ownership rights (possession of land titles) encourage soil conservation investments and may therefore increase productivity and efficiency (Musahara, 2006).

Age of the household head was significant at 5% and reduced inefficiency, implying that households headed by old people were more efficient than those headed by young ones. This was perhaps due to the fact that older household heads had farming experience and adopted new technologies than young ones (Amos, 2007; Ahmad et al., 2002; Kibaara, 2005).

Education level of the household head was significant at 5% and reduced inefficiency of farms. The same result was obtained in Rwanda by Bizimana (2004). This could have been due to the fact that educated farmers made better assessments of the importance and complexities of production decisions and/or learned faster and utilized well extension information, resulting in better farm management (Basnayake and Gunaratne, 2002).

This study did not estimate the sub-samples (sector samples) due to the fact that the sectors had smaller samples and thus estimating them by use of maximum likelihood (ML) could not have satisfied the asymptotic property of the ML estimator.

Table 4.15: The effect of land fragmentation on the productivity of smallholder farms

Variable	**Coefficient (n=241)**	**T**	**P**
Farmsize	4.459689***	11.46	0.000
Noplots	-0.4521239***	-2.68	0.008
Avplotdist	0.0070904	0.04	0.967
$avplotdist * noplots$	-0.1410118	-0.73	0.468
Constant	-2.303893***	-6.10	0.000

Source: *Survey data, 2009;* ***, **, * imply significance at 1%, 5% and 10% respectively.

This study found out that farm size positively affected the productivity of farms; that is, the larger the farm size, the more the productivity (Table 4.14). This is consistent with some empirical evidence which show that larger farms are economically productive (Kelly and Murekezi, 2000; Mosley, 2004).

Conversely, having many plots reduced productivity. Since distances between plots were short, distance between plots did not have a significant effect on productivity and the interaction term $avplotdist * noplots$ also had no significant effect. Some empirical studies show that having many plots may not be beneficial due to the difficulty of supervising workers, carrying farm inputs to different plots, among other reasons (Blarel Benoit, Peter Hazell, Frank Place and John Quiggin, 1992; Marara and Takeuchi, 2003). The insignificance of the interaction term ($avplotdist * noplots$) suggests that land fragmentation is probably not a big problem as long as plots are close to homes.

The summary statistics for the variables used in the productivity and technical efficiency analysis are presented in table 3.3

Table 4.16: Summary statistics for the variables used in the productivity and technical efficiency analysis

Variable	Mean	**SD**
noplots (average number of plots per household)	1.821577	0.986002
avplotdist (Kilometers)	0.439834	1.57768
agroclimate (1=Bwanamukali, 0=Mayaga)	0.576764	0.495101
dummytitle (1=have title, 0=have no title)	0.427386	0.495729
maizearea (Hectares)	0.400145	2.704584
plotsize (Hectares)	0.658278	4.469591
hhsize (number of persons in the household)	4.385892	1.937688
maizeout (Kilograms)	100.029	132.0307
seed (Kilograms)	25.16598	32.98101
distmkt (Kilometers)	5.35249	6.052358
sex (1=male, 0=Female)	0.576764	0.495101
age (Years)	42.9751	13.95855
education (Years spent in school)	3.037344	2.818587
extension (number of extension visits)	0.605809	1.750657
Dependratio*	0.522199	0.256706

Source: Survey data, 2009; *SD *stands for standard deviation*

*****The dependency ratio was calculated as follows:

$$\frac{\textbf{number of household members aged 15 years and less + number of househod members aged 65 years and above}}{\textbf{total number of household members}}$$

5.0 SUMMARY, CONCLUSION AND POLICY IMPLICATION

5.1 CONCLUSION

In the stochastic production frontier model, this study showed that each of the inputs had a significant positive effect on maize productivity. In the technical inefficiency model, we established that education, age and the dummy variable for land title positively and significantly influenced the productivity and technical efficiency of smallholder maize farms in Gisagara district. The implication is that households headed by older and educated people were more efficient compared to those headed by younger and less educated persons. Households which had land titles proved to be more efficient than those without land titles.

The findings also revealed that land fragmentation (defined in terms of the number of plots per household) had a significant negative effect on the productivity and technical efficiency of smallholder maize. This finding conforms to the findings of Bizimana (2004). The joint test confirmed the significance of the three indicators of land fragmentation (Plot size, Number of plots and distance from residences to the plots). Generally, land fragmentation increased the inefficiency of farmers.

This study had two innovations. Firstly, it managed to model all the indicators of land fragmentation and analyzed their individual as well as joint effects on the productivity and technical efficiency of farms. Secondly, it employed the stochastic production approach which was thought to give more consistent results given its power to deal with measurement errors and other statistical noise.

Though smallholder maize farms were found to be technically efficient, their efficiency levels would be improved if land fragmentation effects were mitigated. The main conclusion is that land fragmentation affects the productivity and technical efficiency of farms but the various dimensions of land fragmentation affect productivity and efficiency differently. The number of plots negatively affected the productivity and technical efficiency of farms; Distance to plots and size of the plot had no significant effect on technical efficiency of farms.

In terms of productivity, this study found out that farm size positively affected the productivity of farms, having many plots reduced productivity and distance to plots did not have a significant effect on productivity and the interaction term ($avplotdist * noplots$) also had no significant effect suggesting that land fragmentation is probably not a big problem as long as plots are close to homes.

5.2 AREAS FOR FURTHER RESEARCH

Any future study should try to capture several inputs such as fertilizers; family and hired labour, pesticides among others. The study suggests that any future research about the subject should use a larger sample size and panel data as well as broaden the model to capture several variables (such as access to credit and belonging to cooperatives and/or farmers' associations) that may be thought to influence the efficiency of smallholder farms in Rwanda. The study also suggests that future studies should try to study the efficiency of farms by capturing all farm activities (all crops and livestock) rather than concentrating on a single (representative) crop. Finally, this study support the view that future studies should concurrently investigate technical efficiency and allocative efficiency (or generally, economic efficiency) of farms. This will perhaps provide more insights about the subject.

5.3 POLICY IMPLICATIONS

The findings of this study revealed that the number of plots per household is individually negatively related to the productivity and technical efficiency and all the three indicators of land fragmentation jointly increase inefficiency. Land consolidation should be implemented in Rwanda.

Policy should also aim at availing education to as many people as possible and availing land titles to farmers as this gives them confidence to invest in their land and perhaps increase their efficiency. While the above policies are currently under implementation, the study recommends that implementation should be done in such a way that a majority of the rural households are not left out.

BIBLIOGRAPHY

Agarwal, S. K. (1972). *Economics of Land Consolidation in India*. New Delhi: Chand.

Ahmad Munir and Ghulam Mustafa Chaudhry and Mohammad Iqbal, (2002). "Wheat Productivity, Efficiency, and Sustainability: A Stochastic Production Frontier Analysis," *The Pakistan Development Review, Pakistan Institute of Development Economics,* vol. 41(4), pages 643-663.

Ali. M and M.A. Chaudhry (1989). *"Inter-Regional Farm Efficiency in Pakistan's Punjab*: A Frontier Production Function study".

Amos T. T. 2007. 'An Analysis of Productivity and Technical Efficiency of Smallholder Cocoa Farmers in Nigeria', *Journal of Social Science,* 15(2): 127 - 133

Bagamba F. (2007). *Market Access and Agricultural Production. The Case of Banana* Production in Uganda. PhD Thesis, Wageningen University.

Banerjee, A. and Maitreesh G. (1996), *"Empowerment and Efficiency: The Economics of Tenancy Reform"*, Mimeo Massassuchets Institute of Technology and University of Chicago.

Barnes A. (2008). 'Technical Efficiency Estimates of Scottish Agriculture: A Note', *Journal of Agricultural Economics,* Vol. 59, No. 2, 370–376

Basnayake, B. M. J. K., and Gunaratne, L. H. P. (2002). 'Estimation of Technical Efficiency and its Determinants in the Tea Small Holding Sector in the Mid Country Wet Zone of Sri Lanka', *Sri Lanka Journal of Agricultural Economics* 4: 137-150.

Battese, G.E., Corra, G.S. (1977), "Estimation of a Production Frontier Model with Application the Pastoral Zone of Eastern Australia", *Australian.Journal of Agricultural Economics,* 21: 169–79.

Battese,G.E., T.J. Coelli and Colby, T.C. (1989), "Estimation of Frontier Production Functions and the Efficiencies of Indian farms Using Panel Data from ICRISAT's Village Level Studies", *Journal of Quantitative Economics,* 5: 327–48.

Battese, G.E., and T.J. Coelli (1995), "A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data", *Empirical Economics*, 20: 325–32.

Battese, G. E., and Broca, S. S. (1997). Functional forms of stochastic frontier production Functions and Models for Technical Efficiency Effects: a Comparative Study for Wheat Farmers in Pakistan. *Journal of Productivity Analysis* **8,** 395-414.

Bentley, J. (1987), "Economic and Ecological Approaches to Land Fragmentation: In Defense of a Much-Aligned Phenomenon", *Annual Review of Anthropology,* Vol.16, pp. 31-67.

Binswanger, H., Deininger K., and Gershan F. (1995), "Power, Distortions, Revolt and Reform in Agricultural Land Relations", in Behrman, Jere and T.N. Srinivasan, eds, Handbook of Development Economics (Amsterdam: Elsevier).

Bizimana C , Nieuwoudt W.L and Ferrer S.R.D (2004), Farm Size, Land Fragmentation and Economic Efficiency in Southern Rwanda", *Agrekon*, Vol 43, No 2

Blarel, B. (1989), *Régime Foncier et Production Agricole dans un Contexte de Forte Pression Démographique*, Washington D.C., World Bank, Agricultural Policy Division, Department of Rural Economy (AGRAP).

Blarel Benoit, Peter Hazell, Frank Place and John Quiggin (1992), "The Economics of Farm Fragmentation: Evidence from Ghana and Rwanda", *World Bank Economic Review*, Vol.6 (2). pp. 233–54.

Blarel, B. (2001), Tenure Security and Agricultural Production under Land Scarcity: The Case of Rwanda in John Bruce and Shem Mighot-Adhola, Searching for land tenure Security in Africa, London, Kendall/Hunt Publishing Company.

Byiringiro, F. and Reardon, T. (1996), "Farm Productivity in Rwanda: the Effects of Farm

Size, Erosion, and Soil Conservation Investments”, *Agricultural Economics*, vol. 15.

Binns, O. B. (1950). *The Consolidation of Fragmented Agricultural Holdings*. FAO Agricultural Studies 11. Rome: Food and Agriculture Organization.

Buck, G. L. (1964), *Land Utilization in China*, New York, Paragon.

Carlyle, W.J. (1983), “Fragmentation and Consolidation in Manitoba”, *Can. Geogr*., 27: 17–34.

Chen, A. Z., W. E. Huffman and S. Rozelle (2003). *Technical efficiency of Chinese Grain Production: a Stochastic Production Frontier Approach*. Montreal, Canada: American Agricultural Economics Association Annual Meeting.

Coelli, T. J. (1996). *A Guide To Frontier Version 4.1 A Computer Program For Stochastic Frontier Production And Cost Function Estimation*. CEPA Working Papers, 96/07, University of New England, Australia. 135pp.

Coelli, T. and S. Perelman (1999). A comparison of Parametric and Non-Parametric Distance Functions: with Application to European Railways. European Journal of Operational Research 117(2): 326-339.

Dawson, P.J., Lingard, J. (1989), “Measuring Farm Efficiency Over Time on Philippine Rice Farms”, *Journal of Agricultural Economics*, 40: 168–77.

Debertin L. D (2002). Agricultural Production Economics. 2nd edition. London. Macmillan.

Downing, T. E. (1977), “Partible Inheritance and Land Fragmentation in an Oaxaca Village”, *Human Organization*, vol.36 (3, fall), pp.235-43.

Dovring, F. and Dovring, K. (1960). *Land and Labor in Europe in 1900-1950*. The Hague: Martinus Nyhoff.

Gebeyehu, Y. (1995), Population Pressure, Agricultural Land Fragmentation and Land Use: A case study of Dale and Shashemene Weredas, Southern Ethiopia, Proceedings of the Fourth Annual Conference on the Ethiopian Economy, Addis Ababa.

Damodar N. G. (2003), *Basic Econometrics*. 4th ed. McGraw-Hill. New York.

Farrell, M. J. (1957). The Measurement of Productive Efficiency. *Journal of Royal Statistical Society* **120,** 253-290.

Fenoaltea, S. (1976). Risk, Transaction Costs, and the Origin of Medieval Agriculture. *Exploration in Economic History* 13: 129-151.

Food and Agricultural Organization, FAO (2003*).World Wheat, Corn and Rice Production.* Accessed on www.world_wheat_production.htm, on 24th/October/2009

Heston, A; Kumar, D. (1983), "The persistence of Land Fragmentation in Peasant Agriculture: An analysis of South Asian Cases", *Explorations in Economic History*, 20: 199–220

Herdt, R.W. and Mandac, A.M. (1981), "Modern Technology and Economic Efficiency of Philippine Rice Farmers", *Economic Development and Cultural Change*, 29(2): 375–99.

Huang, C.J., Bagi, F.S. (1984), "Technical Efficiency on Individual Farms in Northwest India", *Southern Economist Journal*, 51: 108–15.

Hyodo, S. (1963). *Aspects of Land Consolidation in Japan. Land Tenure*. Madison: University of Wisconsin Press.

Hyuha T.S, Bashaasha .B. Nkonya .E. and Kraybill .D. (2008), Analysis of Profit Inefficiency in Rice Production in Eastern and Northern Uganda. *African Crop Science Journal*, Vol. 15, No. 4, pp. 243-253

Ilbery, B. W. (1984), “Farm Fragmentation in the Valley of Evesham”, Area, Vol.16 (2), pp. 159-65.

Jabarin, S. A. and Epplin, F.M (1994, “Impacts of Land Fragmentation on the Cost of Producing Wheat in the Rain-fed Region of Northern Jordan”, *Agricultural Economics*, 11: 191–6.

Johnson, V. W., and Barlowe R. (1954), *Land Problems and Policies*, New York, McGraw-Hill.

Jha, R. and Rhodes M.J. (1998), “*Technical Efficiency, Farm Productivity and Farm Size in Indian Agriculture*”.

Junankar, P.N. (1980), “Test of the Profit Maximization Hypothesis: A Study of Indian Agriculture”, *Journal of Development Studies*.16: 187–203.

Kalirajan, K.P. (1981), “An Econometric Analysis of Yield Variability in Paddy Production”, *Canadian Journal of Agricultural Economics*, 29: 283–94.

Kalaitzadonakes N.G., Wu S. and Ma J.C. (1992). ‘The relationship between technical efficiency and firm size revisited, Canadian *Journal of Agricultural Economics*, 40, pp. 427-442.

Kebede T. A. (2001). *Farm Household Technical Efficiency: A stochastic Frontier Analysis. A Study of Rice Producers in Mardi Watershed in the Western Development Region of Nepal*. Msc. Thesis. Agricultural university of Norway

Kelly, D. and Murekezi (2000), *Fertilizer Response and Profitability*, FRSP/FAO.

Kibaara B. W. (2005). ‘*Technical Efficiency in Kenyan’s Maize Production: An Application of the Stochastic Frontier Approach*’, Colorado State University, USA

King, Russell. (1977), *Land Reform: A World Survey*, London, G. Bell and Sons.

Kopp, R. J. and Smith, V. K. (1980). Frontier Production Function Estimates for Steam Electric Generation: a Comparative Analysis. *Southern Economic Journal* 47: 1049-59.

Kumbhakar, S. C., Gosh, S., and McGuckin, J. T. (1991). A Generalized Production Frontier Approach for Estimating Determinants of Inefficiency in U.S. Dairy Farms. *Journal of Business and Economic Statistics* **9,** 279-286.

Kumbhakar, S. and Hjalmarsson, L. (1993), "*Technical Efficiency and Technical Progress in Swedish Dairy Farms", in H. Fried, K. Lovell and S. Schmidt, eds, The Measurement of Productive Efficiency: Techniques and Applications*, New York, Oxford University Press.

Lau, L.J., Yotopoulos, P.A. (1971), "A test for Relative Efficiency and Application to Indian Agriculture". *American Economic Review*, 61: 94–109.

Leach, R. (1968), *Pul Elya, a Village in Celyon: A Study of Land Tenure and Kinship,* London, Cambridge University Press.

Lusho, S. and D. Papa (1998). *Land Fragmentation and Consolidation in Albania*. Land Tenure Center Working Paper, No. 25. http://www.fao.org/documents/.

Marara and Takeuchi (2003), *Agriculture and Peasants in Rwanda,* A Preliminary Report, Tokyo, Joint Research Program, No. 127.

Mbelle, A. and Sterner, T. (1991), 'Foreign Exchange and Industrial Development', *World Development*, Vol. 19(4), pp 341-347

McPherson, F. (1982*). Land Fragmentation: a Selected Literature Review*. Development Discussion Paper No. 141. Harvard Institute for International Development, Harvard University.

McPherson, M. F. (1983). *Land Fragmentation in Agriculture: Adverse? Beneficial? And for whom?* Development Discussion Paper No. 145. Harvard Institute for International Development, Harvard University.

Mosley, J. (2004). *Land Policy in Rwanda: Issues for U.K policy. All Party Parliamentary Group on the Great Lakes Region and Genocide Prevention*, working paper no.3

Mpyisi E. et al. (2003), Changes in Allocation of Land Holdings, Production and Farm Size in Rwandan Small Holder Sector over the period 1984/1990 to 2002, Kigali, Mimeo.

Msuya, E., Hisano, S., and Nariu, T. (2008). *Explaining Productivity Variation Among Smallholder Maize Farmers in Tanzania*. Graduate School, Faculty of Economics, Kyoto University.

Musahara, H. (2006), *Improving Land Tenure Security for the Poor. A Case Study of Rwanda*, FAO Report.

Netting, R. (1972). "Of Men and Meadows: Strategies of Alpine Land Use", *Anthropological Quarterly*, vol. 45, pp.145-57.

Nguyen, T.et al. (1996), "Land Fragmentation and Farm productivity in China in the 1990's", *China Economic Review*, Volume 7 (2), pp.1-38

Olorunfemi O. Ogundere and Okoruwa V. (2006). *Technical Efficiency Differentials in Rice Production Technologies in Nigeria*. AERC Research Paper 154.

Place, F and Hazell, P. (1993), Productivity Effects of Indigenous Land Tenure Systems in Sub-Saharan Africa, *American Journal of Agricultural Economics*, p.14-15.

Papageorgiou, E. (1963). *Fragmentation of Land Holdings and Measures for Consolidation* *in Greece*. In: Parsons, K. H., R. J. Penn and P. M. Raup (eds.) Land Tenure. Madison: University of Wisconsin Press.

Raghbendra, et al.(2005), "Land fragmentation and Technical Efficiency", *Journal of Indian Agriculture*, vol. 34(12), pp.23-64.

Republic of Rwanda (2003). *Rwanda Development Indicators*. Ministry of Finance and Economic Planning. Kigali.

Republic of Rwanda (2004), Draft of National Land Policy, Kigali, MINITERE

Republic of Rwanda (2006). *Rwanda Healthy and Demographic Survey*. National Institute of Statistics of Rwanda. Kigali

Republic of Rwanda (2006). *Rwanda Development Indicators.* National Institute of Statistics of Rwanda. Kigali

Republic of Rwanda (2007). *Cultivated Land Area in Rwanda*. A report by the Food and Agricultural Organization and Ministry of Agriculture. Kigali

Republic of Rwanda (2008). *Rwanda in Statistics and Figures*. National Institute of Statistics of Rwanda. Kigali

Republic of Rwanda (2008). *Economic Development and Poverty Reduction Strategy* (2008-2012). Ministry of Finance and Economic Planning. Kigali

Republic of Rwanda (2009), Rwanda Agricultural Research Institute, http://www.isar.rw/spip.php?article62

Shapiro, K.H. (1983), "Efficiency Differentials in Peasant Agriculture and their Implications for Development Policies", *Journal of Development Studies*, 19(2): 179–90.

Sharma, K., and Leung, P. 1999. Technical efficiency of the longline fishery in Hawaii: an Application of a Stochastic Production Frontier. *Mar. Resour. Econ*. **13**: 259–274.

Schultz, T. W. (1953). The Economic Organization of Agriculture. New York: McGraw Hill.

Shuhao T. (2005). *Land Fragmentation and Rice Production: A Case Study of Small Farms in Jiangxi Province*, P. R. China. Ph.D. Thesis. Wageningen University

Simmons, S. (1988). Land Fragmentation in Developing Countries: the Optimal Choice and Policy Implications. *Explorations in Economic History* 25: 254-262.

Sidhu, S.S. (1974), "Relative Efficiency in Wheat Production in the Indian Punjab", *American Economic Review*, 64: 742–51.

Tadesse, B. and Krishnamoorthy, S. (1997), "Technical Efficiency in Paddy Farms of Tamil Nadu: An Analysis Based on Farm Size and Ecological Zone", *Agricultural Economics*, 16 (3), 185–92.

Taylor, G.T. and Shonkwiler, J.S. (1986), "Alternative Stochastic Specifications of the Frontier Production Function in the Analysis of Agricultural Credit Programs and Technical Efficiency", *Journal of Development Economics*, 21: 149–60.

Tchale H. and Sauer J. 2007. 'The Efficiency of Maize Farming in Malawi: A Bootstrapped Translog Frontier', Cahiers D'Economie et Sociologie Rurales, n° 82-83

Thompson, K. (1963), *Farm Fragmentation in Greece*, Athens, Centre for Economic Research.

Walker, T. S. and Ryan, J. G. (1990). *Village and Household Economies in India's Semi-arid Tropics.* Baltimore and London: The Johns Hopkins University Press.

Webster C.C and Wilson P.N (1980). *Agriculture in the Tropics*. New York: Longmans.

APPENDICES

Appendix 1

QUESTIONNAIRE ADMINISTERED TO HEADS OF HOUSEHOLDS IN GISAGARA DISTRICT

A. SURVEY QUALITY CONTROL

QUESTIONNAIRE CODE ____ ENUMERATOR ____

SECTOR ______________________________ DENSITY__________ HAB/KM² FAMILY NAME OF RESPONDENT ____

B.1 Distance to the nearest market ………………………………………… km

B.2. Number of persons in the household ……………………………………..

B.3. Sex of the head of household ………………………………………………….

B.4. Age of the head of household ………………………………………………….

B.5. Education level of the head of household ……………………………………… (Years spent in school)

B.6. Number of extension visits received last season (Season A, 2008/09) ……………………………..

C1. Household farm land assets (NB: code assigned to farm throughout sections F to G) ***[Record only for*** Season A, 2008/09***]***

Farm code/ID	**C1A.** Specify location	**C1B.** Distance to residence (Km)	**C1C.** Size (ha)	**C1D.** Title deed 0. No 1. Yes	**C1E.** Mode of acquisition	**C1F.** Cost (If rented in)
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						

Field codes for C1E:	1. Own land – inherited	2. Own land – Purchased	3. Own land – Donated	4. Rented in	5. Borrowed in

D5. Household farm land partitioning and use ***[Record only for*** Season A, 2008/09***]***

Farm code/ID	**D5G.** Crop 1 (specify)	**D5H.** Size (ha)	**D5I.** Crop 2 (specify)	**D5J.** Size (ha)	**D5K.** Crop 3 (specify)	**D5L.** Size (ha)	**D45M.** Grazing (ha)	**D5N.** Fallow (Ha)	**D5O.** Forest (Ha)	**D5P.** Rented out (Ha)	**D5Q.** Specify income	**D5R.** Borrowed out (Ha)
1.												
2.												
3.												
4.												
5.												
6.												
7.												
8.												

E3. Crop production output ***[Record only for*** Season A, 2008/09***]***

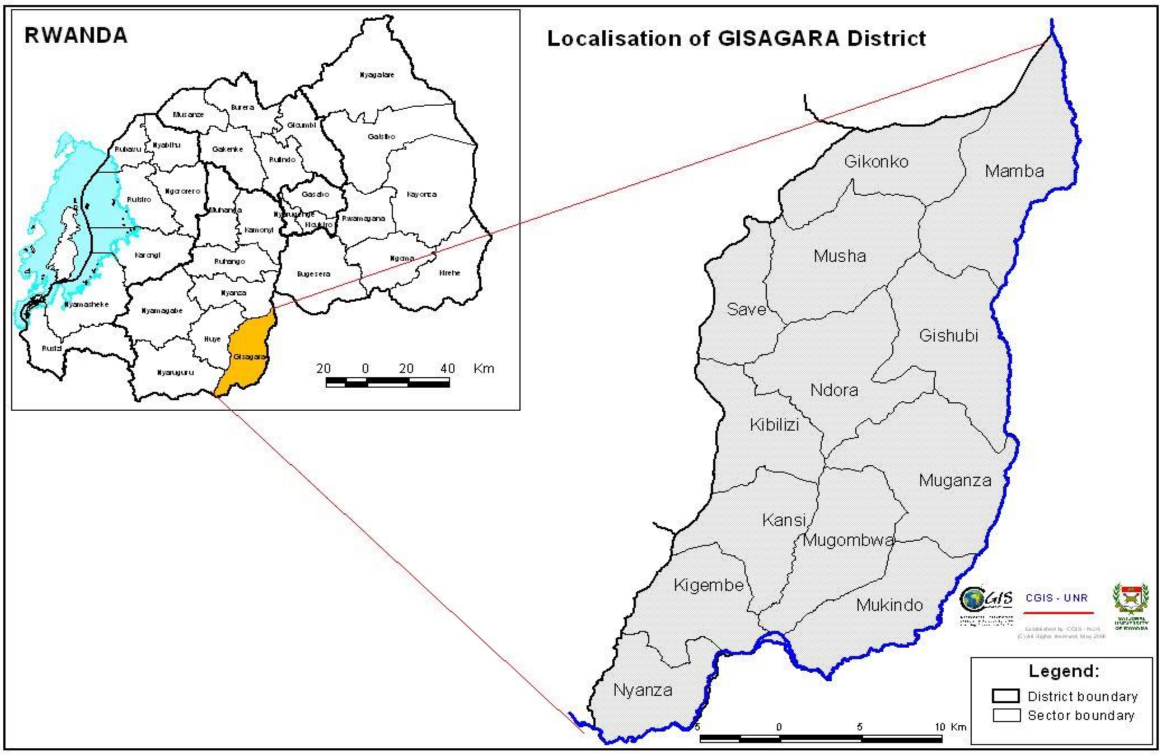
Farm code	Crop 1 (specify here…						Crop 2 (specify here…						Crop 3 (specify here…					
	E3A. Unit of measurement	**E3B.** Qtty	**E3C.** Output in Kg	**E3D.** Per unit Price	**E3E.** Total revenue	**E3F.** Major buyer	**E3G.** Unit of measurement	**E3H.** Qtty	**E3I.** Output in Kg	**E3J.** Price per Kg	**E3K.** Total revenue	**E3L.** Major buyer	**E3M.** Unit of measurement	**E3N.** Qtty	**E3O.** Output in Kg	**E3P.** Price per Kg	**E3Q.** Total revenue	**E3R.** Majo buyer
1.																		
2.																		
3.																		
4.																		
5.																		
6.																		
7.																		
8.																		

G6. Crop production non-labor input ***[Record only for*** Season A, 2008/09***]***

Farm (Insert code)	**F6A.** Crop	Seed				Fertilizer						Field pest chemical/pesticides		Manure		
		F6B. Own saved/gift	Bought		**F6E.** Improved variety 0. No 1. Yes	NPK		DAP		Urea		**F6L.** Litres	**F6M.** Frw/litre	**F6N.** Own (Tons)	Bought	
			F6C. Amount (kg)	**F6D.** Frw/kg		**F6F.** Quantity (Kg)	**F6G.** Value (Frw)	**F6H.** Quantity (Kg)	**F6I.** Value (Frw)	**F6J.** Quantity (Kg)	**F6K.** Value (Frw)				**F6O.** Tons	**F6P.** Va

Appendix 2

Location of Gisagara District in Rwanda



Appendix 3 : Gisagara District's administrative map