DETERMINANTS OF FARM PRODUCTIVITY AND THE SIZE-PRODUCTIVITY RELATIONSHIP UNDER LAND CONSTRAINTS: THE CASE OF RWANDA

by

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ABSTRACT

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Despite its importance in agricultural development, the oft-observed inverse relationship between farm size and land productivity in developing countries has received very limited attention in Africa. This work tries to fill the gap by analyzing the relationship between farm-size and productivity in Rwanda.

Our results confirm the existence of an inverse relationship between farm-size and land productivity. Smaller farms have a lower opportunity cost of labor and a higher shadow price of land compared to larger farms. These disparities are the results of constraints faced by smaller farms (a) to access land, and (b) to access labor market opportunities. The observed relationship is affected by land quality proxied by erosion (average annual soil loss), percentage of area fertilized and investment in soil conservation, and by the share of high value crops in gross value of output.

Major implications to draw from the study include the necessity to (a) control market imperfections in rural Rwanda; (b) invest in land improvement (fertilization and soil conservation devices); and (c) promote high value crops.

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And lastly, I would like also to dedicate this work to all Rwandans for the difficult time they are enduring. May their mayhem end soon.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Africa is the only developing region where crop output and factor productivity growth are lagging seriously behind population growth. There was a spate of farm-level research on patterns and determinants of productivity in the 1960's and 1970's; the work tended to focus on sample stratification based on farm characteristics -- generally, by one or more of the following: farm size, use of animal traction, access to credit, use of new seed varieties, land tenure status, income (see Eicher and Baker, 1985, for a review). More recent work on productivity in Africa focusing on the land-size stratification have been in the few countries (in particular Kenya, Zimbabwe, South Africa -- where there is a mix of European settlers and African largeholder with large farms, and a large group of African semi-subsistence smallholder) conventionally-perceived as those violating a basic 'stylized fact' of Africa that land in most countries is more equally distributed than in other developing regions. Land reform is also a hot topic in these countries, and productivity studies stratifying by land have a long history (e.g. in Kenya or Asia) of being used to show that smallholder are more productive per unit of land than largeholder.

But there have been other changes in Africa -- since the 1970s studies -- access to land has become increasingly constrained in areas formerly-thought land abundant, factor and credit markets have structurally changed, land markets have developed and last but not least, soils have rapidly degraded. Now countries not in the traditional smallholder vs

European type settlement/plantations are confronted with big issues related to land constraints and productivity. This issue is particularly under-researched yet interesting in areas of Africa where land constraints have been growing rapidly, such as highlands East Africa or semi-arid West Africa which have evolved from land-abundant to land-constrained situations. Land distribution, land market, and land productivity issues have moved to the forefront of the debate in many areas where European farm settlement did not occur, and that were classed as 'smallholder' areas in Africa. It is thus high time to move the land-size productivity debate into other case examples, and to integrate issues of land quality.

The inverse relationship between size of land holding and agricultural productivity has taken an important place in the literature of agricultural economics and agricultural development in recent decades. For various reasons farmers face different productivities of inputs as the size of their holding vary and thus, making their output/input ratios vary systematically with the size of their farms. The debate persists because no fully agreed upon consensus has yet emerged on what is the exact implication of the observed relationship and because of the possible (and sensitive) policy implication that it engenders (Bardhan, 1973; Barrett, 1994). For example, if it is due to a higher efficiency of small farms (low opportunity cost of labor, decreasing returns to scale), then addressing issues of land reform would be the straightforward implication. However, if it is a consequence of imperfect factor markets (smaller farms confront different factor prices from larger farms i.e. smaller farms face a low opportunity cost of labor and high prices of land and capital which is an inverse pattern for that of larger farms) then attention should be directed toward the institutional framework and the functioning of the rural economy.

Lastly, if the relationship is a result of mismeasurement and omitted variables (cropping patterns, agroecologic zones or region effect, etc.) then, a non-interventionist strategy would be the best alternative.

An assumption is that smaller farms in Rwanda will face a low opportunity cost of labor but a high price of land.

This will be a result of an excess availability of family labor on one hand and constraints to access land (inadequate amount of land for optimal farm production) on the other hand. Thus we should observe rising productivities of labor and falling productivities of land as the size of the holding increases.

Theory predicts that farm productivity, measured by marginal factor products, will differ over farms using different levels of inputs; for example, marginal productivity of a given amount of labor will be greater on a farm with a larger landholding. Empirical research in developing countries tends to confirm this prediction; for example, works in India (Bardhan, 1973; Deolalikar, 1981; Rao and Chotigeat, 1981) find that small farms have higher land productivity but lower labor productivity (using more labor intensive techniques). The inverse relationship between farm size and land productivity has been important in land reform debate in developing countries suffering growing land constraints, supporting the smallholder whose technique factor bias uses shrinking land resources more productively. For example, Ellis (1993) argues that smaller farms allocate a substantial amount of their holding to higher value crops and improve more their land (soil conservation devices and fertilization) while larger farms are more oriented toward land extensive practices (livestock grazing, trees, longer fallow) or lower value crops.

However, empirical research has shown that the relationship will depend on the amount of non-labor variable inputs that are used by farmers as substitutes of labor. For example, Adesina et al. (1994) find large rice farms more efficient than smaller ones in Northern Côte d'Ivoire as a differential access to technology. Previous public policies favored larger farms to access input and credit markets and research information more than smaller farms.

Where farmers are economically rational, and faced with perfectly functioning input and output markets, they equate marginal value products (MVPs) to factor prices. Then, where the marginal value product of a given factor is not equal to its price, it is either because the farmers are not economically-rational, or because they face an imperfect factor market which constrains their access to factors of production. Tests of the non-equality between the marginal value product and the factor price have been rare in Africa, where one might posit that only-recent commercialization of the rural economies, and underdeveloped factor markets might cause these two figures to be unequal. For example, Carter and Wiebe (1990) found them unequal in Kenya due to market failures in the system (constraints on access to capital and to land and/or constraints on labor transactions). Due to the little demand for labor outside agriculture we should expect the marginal value productivity of labor to be a fraction of the wage of labor. On the other hand, traditional land rights (inherited land cannot be sold outside the family) coupled with public laws and policies (free land transaction is prohibited) we expect constraints to access land which will make the market price of land (proxied by the rental price) be a fraction of the marginal value product of land.

Another assumption is that smaller farms have better land than larger farms and thus get higher productivities. This difference in the quality of land between smaller and larger farms will exacerbate the inverse relationship between farm size and land productivity.

Effectively, changing productivity is also attributed to land degradation. Land degradation is said to affect the inverse relationship between farm-size and productivity and some authors even argue that the inverse relationship between farm-size and productivity is principally a result of the loss in the quality of land. Bhalla (1988) and Bhalla and Roy (1988) show that by controlling the effect of the quality of land the inverse relationship between farm-size and productivity weakens or disappears. Thus, knowing how land degradation (and in general land quality) affects agricultural productivity and farmers efficiency is of interest for sound policy formulation. In Rwanda, the shortage of land has pushed farmers to crop marginal land easily degradable and long believed not suited for agriculture. Their intensive cultivation combined with non-sustainable methods of production (no or little fertilization and no or few soil conservation investments) has impoverished the land and this has affected negatively farm productivities. However, its effect on the oft-observed inverse relationship between farm size and productivity will depend on the group (smaller vs larger farms) that has the most degraded land. For example, if land on smaller farms is more degraded, the potential inverse relationship will be partly offset but if they have better land, then the observed relationship will be accentuated.

This thesis will try to relate the above theoretical points into an interesting strategic research issue. More explicitly, it will try to dig more into the issue of the inverse relationship between productivity and farm-size and to tie in the effect of land quality. Bhalla and Roy (1988) and Bhalla (1988) argue that conventional production function has been constantly mis-specified due to an under-estimation of the importance of agro-climatic and soil factors while they affect the observed inverse relationship. Bhalla (1988) finds a negative correlation between farm size and soil quality. He argues that:

> *once proper account is made of exogenous land quality variables, the inverse relationship is observed to weaken, and in many cases, to disappear. It is not the case however, that no relationship remains between size and productivity-but the universality of the "stylized fact" is not 100%, but only 30% of the districts in India [Bhalla (1988) p.71].*

Another factor that affects the observed relationship between farm-size and productivity and which is often overlooked, is the crop composition of output. Sometimes, differences in aggregate productivity between small and large farms are attributed to size or returns to scale effects while in reality they are a result of the crop composition of output. Bardhan (1973, p. 1375) notes that if:

> *some sizes of farms tend to grow more high-valued crops, what is essentially a crop-composition effect may be confused in production function studies as a size effect or a returns-to-scale effect in production.*

Ellis (1993) also agrees that among the technical reasons for the inverse relationship between farm size and productivity figure the crop composition of output. Larger farms view land as an abundant factor and thus are more inclined to underutilize it by producing lower value crops or orienting themselves toward land extensive practices than smaller farms do. As a result, smaller farms may have a higher productivity in value terms.

The analysis will be carried out using a case study from a situation that is an archetypical example of this process, and thus a vanguard, Rwanda. Rwanda is an East-African highland nation characterized by steep slopes, abundant rainfall and intense demographic pressure. The Rwandan economy is dominated by a large, predominantly subsistence-oriented agriculture sector which employs 92 percent of the labor force and accounts for nearly 90 percent of its export revenues. That is why knowing the determinant of agricultural productivity is a necessity for future strategic planning aimed at enhancing the agriculture sector. Shrinking farm sizes and the constant specter of food insecurity have driven smallholders to cultivate marginal lands once held in pasture and long fallow and most farmers do not have access to enough fertilizer (organic or mineral). Rwanda's National Agricultural Commission estimates that half of the country's farmland suffers from moderate to severe erosion (Commission Nationale d'Agriculture, 1992). This erosion combined with an intensive use of soil nutrients (without replacement) has engendered severe land degradation.

To assess agricultural productivity in Rwanda, a production function will be estimated from which marginal value products will be derived. Then, the relationship between farm size and productivity will be tested by regressing marginal value products on a quadratic function of land of the holding and other factors considered as major determinant of land quality and crop composition of output.

The thesis proceeds as follow: the second chapter is devoted to review of the literature and the third chapter to methods used in the analysis. Chapter four presents the data and patterns, chapter five, the analysis and discussion of results and chapter six, the conclusions and implications.

Chapter II : LITERATURE REVIEW

Interest in the inverse relationship between farm size and productivity arose in the 1960s out of the observation that for Indian farms, yields are inversely related to farm size (Bardhan, 1973; Rao and Chotigeat, 1981; Deolalikar, 1981). It soon became the most cited empirical observation in third world countries. For example, Bardhan (1973) found a negative relationship between output per acre and farm size in both rice and wheat fields (monocrop situation) in India. He attributed the observed relationship, to the "inverse correlation between (farm-)size and other inputs rather than of scale diseconomies" (p. 1386). His results show that smaller farms use more labor input per unit of land even when there is evidence of constant returns to scale. Moreover, when he fits an equation explaining the variations in labor use per unit of land accross farms, he finds a significant negative relationship between labor and net area sown.

Using cross-regional data from Indian agriculture, Deolalikar (1981) found that the inverse relationship between yields and farm size holds for traditional agriculture but does not hold for agriculture experiencing technological change. In the post-Green Revolution period, land productivity is mainly a function of cash inputs like fertilizer and improved seeds (which being credit-intensive is unlikely to be used by small farms) while it depends less on the amount of labor used (which is possessed in abundance by small farms). These results are confirmed also by Rao and Chotigeat (1981). They show that land and labor have a negative effect on the elasticity of gross value of output per unit of land while capital has a positive effect. The net or global effect depends on which of the two effects is the largest. Specifically, for farms employing more hired labor and using more nontraditional inputs (fertilizers, high-yielding varieties, improved ploughs and tractors), larger holdings have higher productivities.

Feder (1985) analyzed the impact of labor supervision and credit constraint on the relation between farm size and labor and yield. He demonstrates that the negative relationship holds when there is high supervision cost of hired labor by family labor and when access to credit is conditioned by the size of the holding (as collateral). If markets were perfect each family would lease in or lease out as much labor as needed in order to maintain an operational holding which is proportional to the size of the family. Thus, labor input would be identical across farm and consequently yields would not be affected by farm size.

Bhalla and Roy (1988) and Bhalla (1988) incorporated the effect of land quality in their analysis of the inverse relationship between farm size and productivity. Land quality was proxied by soil type, color, and depth in the absence of data on soil fertility. They found agro-ecologic and soil factors to be important determinants of farm productivity,hence their omission would result in specification error.

The earliest studies in Africa were mainly sectoral i.e. studying a particular crop, usually an export cash crop while very few studies were concerned by the overall productivity of smallholder farming. However, several authors tried to assess the farm size - productivity relationship for smallholders (see Eicher and Baker, 1985; and Ellis, 1993 for a review). Some of the recent studies are those of Blarel et al. (1989) in Kenya, Barrett (1994) in Madagascar, and Adesina et al. (1994) in Côte d'Ivoire.

Blarel et al. (1989) observed an inverse relationship in Kenya. They find that an inverse productivity-size relationship exists as a result of market imperfections. Smallholders are limited in their access to capital while largeholders are unable to access labor cheaply (i.e. at the in-house opportunity cost). The authors analyzed this fact by using a size-sensitivity analysis where they regressed the marginal value products on quadratic terms of land size. The results show that the marginal product of capital in maize-beans cultivation falls significantly as farm size increases while the marginal product of labor starts low due to intensive labor application on small farms and rises with the size of the farm.

In his study in Madagascar, Barrett demonstrates that differences in households' marketable surplus, in an environment of uncertain prices, suffice to explain the inverse relationship between farm size and productivity if some small farms are price risk averse. He did not assume labor market imperfections or any differences in the quality of land, cropping patterns or village-level effects.

The study by Adesina et al. in Northern Côte d'Ivoire finds that large rice farms are more economically-efficient than small rice farms. However, the difference is attributed to differential technology between small and large farms as a consequence of previous public policies. Large farms were given preferential access to inputs, credit, and research information. Thus, their results give more weight to findings of Deolalikar and Rao and Chotigeat which showed that capital, not just labor intensity, can explain the difference in productivity observed between smaller and larger farms. Larger farms can add capital to land at a greater rate than they add labor to get higher land productivity than do smaller farms.

Studies on the subject of the inverse relationship between farm size and productivity flourished mostly because there is no really agreed upon explanation that has been given yet. Several studies tried to bring in new issues not yet analyzed but which are believed to be important determinants of the observed inverse relationship (Bardhan, 1973; Bhalla, 1988; Bhalla and Roy, 1988; Barret, 1994). Ellis (1993) and Barret (1994) review major explanations given for the observed inverse relationship. They can be classified in five categories.

First, the observed relation can be a consequence of market failures (imperfections) which is a state where neither participant face in practice competitive markets. Since shadow prices of factors of production vary with the size of the holding, farmers will apply more of the factor to which they have easy access, for which they face a very low shadow price (Blarel et al., 1989). An example is the presence of a dual labor market where smaller farms face a cheaper imputed labor cost (Feder, 1984). Smaller farms apply labor until its marginal value product becomes a fraction of the market wage (see also Carter and Wiebe, 1990). Thus, they get a higher labor/land ratio and therefore a higher per-acre yield.

Second, the relationship can be a consequence of decreasing returns to scale. However, production function estimates in developing countries have usually showed that returns to scale are nearly constant (Bardhan, 1973; Barnum and Squire, 1978).

Third, the relationship can be a consequence of a superior efficiency of smallholders with respect to the intensity of utilization of land as a resource. This includes land use intensity whereas larger farms underutilize their land (they do not farm all the available land); the cropping pattern (crop composition), where smaller farms allocate a higher proportion of their holding to high value crops that usually make use of a substantial amount of their labor force; land quality, where smallholders improve their land (soil conservation investments, manure, mulch) more than do largeholder; and multiple cropping, which is mostly used by smaller farms.

Fourth, there are other factors usually grouped in a region-specific variable. The most common factors are soil fertility or quality, where a region with better land attracts more people; and difference in prices and wages, where for example regions of higher wages attract more settlers (Bhalla and Roy, 1988; Bhalla, 1988). For example, Barrett (1994) shows that the observed relationship in Madagascar is a result of the risk in prices faced by farmers.

We expect that one or more of the explanations above apply to rural Rwanda, and consequently that the inverse relationship will hold. Using marginal productivity analysis based on production functions, we examine the first explanation that the marginal value products differ from market factor prices, indicating constraints to access inputs and hence economic efficiency, and the third explanation showing that smaller farms crop more intensively.

Chapter III: DEFINITIONS, METHOD, CONCEPTUAL FRAMEWORK

3.1. Definitions and Concepts

Productivity is defined as the ability of a unit of an input to produce a certain level of output (Harsh et al., 1981, p.130). Thus, it shows how efficient a farmer is in the use of that particular input given the range of alternative technologies available to him. The productivity measure is given by the *average physical product* of the input which itself is defined as the total physical product divided by the total amount of the input used in production (Ellis, 1993). For example, labor productivity is the average output per unit of labor used. In this paper, special effort will be made to name each individual input productivity each time reference to a particular input will be necessary. *Marginal productivity* is the additional output produced by each additional unit of input.

Productivities are usually multiplied by the output price in order to facilitate comparisons across products, farms or regions, to aggregate over products or simply to compare them to factor prices. For example, the marginal physical product multiplied by the price of the product derived from the additional unit of the input is the *marginal value product of the input*. More on these productivity measures will be discussed below.

Farm productivity can be calculated for one or more crops. For one crop, physical product will be preferred to value product while for multiple crops, aggregation is required using product prices and thus the preference for the value product. Likewise, in the denominator one input can be used, and that will be referred to as the "partial factor productivity," or all inputs can be used giving rise to the notion of "total factor productivity" if all products are used in numerator.

If the farmer is economically rational and there is no constraint in the use of inputs, the farmer should operate at the *economic optimum*, the level of use of inputs where the marginal value product of each input equals its unit cost. This means that the additional return of the input must equal the additional cost of the input. Stated differently, the optimum condition corresponds to the point where the ratio of the marginal value product of the input to the price of that input is equal to one. Then, if the ratio is higher than one, the farmer is applying too little of the input and if the ratio is less than one he is using too much (Ellis, 1993). These cases arise when farmers are constrained in their access to complementary inputs as seen above. For example, a farmer constrained in his access to land or capital (credits for example) will use more labor than required thus driving the ratio of the marginal value product of labor to the wage of labor below one. Or, if for example the marginal value product of seed is above its price, that means that farmers could efficiently use more seed. However, the quantity of additional output obtained for each successive additional unit of seed (marginal physical product) will get smaller as the amount of seed increases (law of diminishing returns) until, eventually, the ratio of the marginal value product of seed to its unit cost (price) will equal one. But for some reasons (such as credit limits), farmers are constrained in their access to seed.

3.2. Methods and Model

Average productivities are calculated by dividing the output of a given farm (or average output of a group of farm) by input used. Calculation of marginal productivities require the estimation of a production function. A production function is a model that relates output to a set of inputs and conditioners; it is output explained by use of variable inputs (labor, land, and fertilizer), and other conditioning factors such as erosion or distance from the farmstead to the parcel. Therefore,

$$\text{Output} = f(\text{Land, Labor, Capital, Conditioners}) \qquad (1)$$

Most models are specified as linear, quadratic or Cobb Douglas forms (Eicher and Baker, 1985) while few use complex forms which allow the analysis of interactions. Also, the scope of the analysis differs from author to author; some try to be general while others go more in depth. However, the scope of analysis is determined by the availability of detailed data.

The marginal value product (MVP) of an input is calculated as the change in value of output associated with an incremental change in the use of that input. This marginal value product is the slope of the production function with respect to the input. It is itself a function which represents the rate of change in the original production function as the use of the factor is varied.

To test the relationship between farm size and productivity, estimates of the function of the marginal effect of a factor on output will be used. These estimates will let us examine how the marginal impact varies when the size of the holding varies (such as how much more productive is an extra unit of labor when the size of the holding increases) or when there are different levels of the conditioning factors (such as how much more productive is an extra unit of land when the erosion level or the share of high value crops is increasing). These estimates will be used also to examine whether marginal value products are equal to marginal factor costs (input prices) in order to determine if use of that input is efficient or somewhat constrained. Thus, a function of the marginal value products will be estimated, involving quadratic terms of land and some conditioners (land quality, crop-mix). The general function will be of the type:

$$MVP = f(\text{land, land quality, crop-mix}) \quad (2)$$

Land quality comprises degree of fertilization (chemical and organic), erosion, and soil conservation investments.

3.3. Regression Specification

3.3.1. Overview of the Country

Rwanda is part of the East African Highlands which is characterized by a temperate and well-watered climate. The vast majority of producers are small-scale, semi-subsistence farmers, who produces principally for own (on-farm) use as food and seeds. The typical farm consists of holdings in several locations and includes usually parcels on the hill crest, on the hill side and increasingly in the valley marsh (World Bank, 1991). Land is becoming scarce due to demographic pressure and constant subdivision favored by traditional land rights (most cultivated land is passed on to the male heirs of a deceased landholder). These traditional land rights and the lack of competitive market do not allow free transfer of land and thus the size of the holding can be considered as fixed in the short run.

Although it has better soils than most of Africa, intensive cultivation of parcels located mostly on high steep slopes and erosion have reduced soil fertility. This soil fertility is traditionally maintained by fallow and extensive use of organic fertilizer (manure and mulch) and in recent years by investments in anti-erosion structures (hedgerow, ditches, terraces). However the pressure on land has reduced the time allotted to fallow.

The production technology is essentially traditional. The basic tools are the hoe and the machete with no animal traction and the amount of chemical fertilizer used (.08 kg/ha) is very insignificant. There is a lack of labor market opportunity and almost all farms rely on family labor only. However, these features do not rule out the use of hired or sale of labor outside agriculture. Thus labor can be taken also as exogeneously determined.

The cultivation of subsistence crops is the dominant agricultural activity of smallholders throughout Rwandan's highlands and the farming system consist of several crops produced in association in several parcels. The basic cropping mix varies by climatic zone but always includes some of the traditional staple food: beans, sweet potatoes, sorghum, and bananas. Main crops are beans, peas, sorghum, maize, soybeans, yams, sweet potatoes, irish potatoes, cassava, bananas, peanuts, rice, wheat, coffee, and tea. Apart from rice, wheat, coffee, and tea, all other crops are usually intercropped. Bananas and coffee are the most significant cash crops. Bananas are usually transformed into banana beer which is then sold. It is also a major source of cash income. Coffee is the major export crop for the country and constitutes also a substantial source of cash income for farmers almost throughout the country.

3.3.2. Data

The Division of Statistiques Agricoles (DSA) of the Rwandan Ministry of Agriculture maintains a comprehensive data sets on farm and livestock enterprise management and income/expenditures derived from a nationwide longitudinal survey on rural households (started in 1990). Thus, the data to estimate our productivity model are drawn primarily from this data base covering approximately 1240 farm households (operating 6,464 parcels). This data set is supplemented by a nationwide agroforestry survey conducted in 1991 by the same Division. Interviews with heads of households and/or their spouses were conducted over a six-week period beginning June 1991[1]. The survey instrument treated both household-level variables (such as farm income, and most expenses) and parcel-level variables (such as soil conservation investments, land tenure, steepness of slope, location on the slope, and distance from the residence).

However, before running our analysis certain modifications and transformations of raw data were required. Major modifications are:

- aggregation of all variables at the farm level. Although most variables were collected at parcel level, an aggregation is required because the output and labor variables were available at the farm level only. A disaggregation could not be made without making

[1] The complete sample frame includes a total of 1,248 households. However, due to military/political tensions in the prefecture of Byumba, along the Uganda border, interviewers were unable to conduct fieldwork in the region, and eight (0.6 %) of the 1,248 sampled households had to be omitted from this study. Sampling weights have been adjusted accordingly.

some serious assumptions like equality in the productivity of each parcel or that labor is equally distributed among all parcels.

- aggregation for the whole year. The data for the variables output and land were collected per season. Thus an agregation of these two variables at year level was necessary in order to be able to use them with for example data on labor transactions which were only available for the entire year.

- homogenization of labor in order to present it throughout in adult equivalent,

- and adjustment for the number of hours worked a year per Prefecture.

The last two modifications were necessary because earlier studies by Uwamariya et al. (1993) and Kangasniemi and Uwamariya (1993) used two different weights for labor (adult and then children and senior citizens) and different hours worked per Prefecture. For useful comparison we adopt a similar adjustment[2].

3.3.3. Background on Regression Specification

A few studies have been done at the household or village level in multi-crop situations (Barnum and Squire, 1978). In general, the dependent variable has been gross or net value of output for the whole farm because lack of detailed data did not allow a separation of output into its various components, per crop or per parcel, or the separation of inputs per crop as a result of the farming system used (mixed cropping) or of the data gathering process.

[2] Appendix C below gives more detail on these adjustments and modifications used. They are extracted from works by Uwamariya et al (1993) and Kangasniemi and Uwamariya (1993).

We also, output aggregate agricultural production in monetary terms. It is computed as the sum of each crop's physical output weighted by the market price prevailing at harvest (71 RWF = 1 US$ in 1990). This aggregation masks, however, differences in the crop composition of output (Bardhan, 1973). A major drawback of this effect is that the effect of crop composition can be confused with the effect of farm size or constant returns to scale if for example some farms tend to specialize in high value crops. Studies in developing countries (Ellis, 1993) have shown that larger farms are more oriented toward land extensive practices (for example livestock pasturing), longer fallow, lesser density of plantation or lower value crops than smaller farms do. Thus, the subsequent use of marginal value products instead of marginal physical products will give more weight to smaller farms. To overcome this problem a variable showing the effect of high value crops has been introduced (see below).

Variable inputs have generally been aggregated in three types (land, labor, and capital). However, these aggregations were not homogeneous across authors due to differences in the specification of their models, measure of variables, and characteristics of the data. For example, land input has frequently been divided in rain-fed vs irrigated land (Bardhan, 1973; Bhalla,1988; Bhalla and Roy, 1988) and labor into own vs hired and/or male vs female (Bardhan, 1973; Jacoby, 1992; Feder, 1985).

Some other factors, which will be referred to as "farm characteristic conditioners" or "agroecological dummies", have been accounted for. We will reserve farm characteristic conditioners to quantitative variables that describe the farm but which are not variable inputs and agroecological dummy to qualitative factors (e.g., belonging or not to an agroclimatic region). They are introduced in order to assess the underlying characteristics that affect the productivity of the farm. These conditioning and dummy variables help control the effect of non-measured (omitted) variables on the error term. Commonly used conditioners are for example the number of parcels, the distance residence/parcel, the age of head of household and education. Very few studies have tried to introduce characteristics of parcels or land (quality) as conditioning factors. The leading studies are probably those by Bhalla (1988) and Bhalla and Roy (1988) who used some soil characteristics (soil depth, color and type) as proxies for land quality. The dummy variable mostly used is geographic region of for example net food deficit, climate, topography or soil quality (Bardhan, 1973; Bhalla, 1988; Adesina et al., 1994).

3.3.4. Description of Variables

In the light of the above descriptions and explanations, our specification should be of the following type (as a reminder, all variables are at farm level, and for the whole year 1990 although some farm characteristics are from 1991):

OUTPUT = f(LABOR, LAND, FERTSHARE, EROSION, SHAREHVC,
PARCEL, FARMAGE, DISTANCE, TENURE,
NORTHWEST, SOUTHWEST, NORTH-C, EAST) (3)

LABOR and LAND are the only variable inputs. Labor is expressed in man-days of work per hectare and includes both family and hired labor. The assumption here is that labor is homogeneous so that it can be aggregated into a single variable. The impact of supervision on total labor availability is neglected. Labor is considered as an exogeneous variable (see above).

Land is expressed in hectares (of cultivated land). It is taken as an exogenous variable because it consists almost entirely of owned land which is set by traditional land rights.

Soil fertility is maintained principally by fallow and use of manure and mulch. Manure and mulch affect the quality of land by improving the texture and nutrient status of land. However, our dataset lacks information on quantities of manure used. As a rough alternative and with the assumption that parcels are homogeneously fertilized, a proxy variable, FERTSHARE, is used. It is the percentage of cultivated on which any of the following are used: organic matter (manure and mulch), chemical fertilizers, lime, and pesticides.

The variable PARCEL is the fragmentation of the farm. It is the number of fragments or parcels into which the farm is divided. This fragmentation variable is viewed as an inefficiency parameter because it impedes the farm operation (farmers lose time commuting between parcels) or might cause a misallocation of factors of production among different parcels.

FARMAGE (in years), EROSION (tons/ha) and DISTANCE from residence to parcel (in minutes) are measured averages for the household and are also conditioners that are hypothesized to affect negatively the productivity of the farm. They affect the quality of land. The older the farm, the lower the fertility, as land fertilization and antierosion devices are scarce; the more erosion the less will be the quality of land as the fertile top soil is washed away; and finally, the higher the distance, the less will be land improvements as more time is spent commuting between parcels.

EROSION is the annual soil loss in tons/ha calculated based on plot characteristics. The effect of erosion is mainly felt when the top soil is removed, thus exposing the subsoil and bedrock. As a result of erosion, soil properties such as nutrient status and texture (which determine the quality of cropping land) deteriorate over time. This deterioration engenders reduced productivity and the need for increased land improvements with manure, mulch and fertilizers (Morgan, 1986). EROSION is calculated using the Universal Soil Loss Equation (Morgan, 1986; Hudson, 1981a). The USLE provides an estimate of the annual soil loss from parcels of arable land under various cropping conditions (Hudson, 1993). The USLE is as follow:

$$\text{Erosion} \equiv R \,.\, K \,.\, L \,.\, S \,.\, C \,.\, P \tag{4}$$

R is the index of the erosive forces of rainfall and runoff. For its estimation, we used the average annual rainfall data for the 78 secteurs in which our sample households resided.

K is the soil erodibility index and reflects the susceptibility of a soil type to erosion. We estimated it using secondary data on soil types for the 12 zones from which our sample is drawn. These two factors were approximated by graphs available in Morgan (1986) and Hudson (1981a).

L is a length factor for the parcel. It is a ratio that compares the soil loss of a parcel with that from a field of specified length (22.6 meters). To calculate L we used the square root of the plot area (with the simplifying assumption that the plots are square).

S is the slope factor which compares the slope of a parcel with that of a field of specified slope (9 percent). We used plot slope data.

C is the C-value, the ratio of soil loss on a plot under a standard treatment of cultivated bare fallow compared to the soil loss expected from the crop mix and cropping practice used on the current plot. The data of the C-value were given by Daniel C. Clay and were derived from Kangasniemi and Reardon (1994).

Finally, P is the conservation practice factor which is a ratio comparing the soil loss from a plot with conservation practice with that from a field with no conservation practice. We evaluated P from DSA Agroforestry data. We classified farms in five categories according to their length of soil conservation investments (grass strips, anti-erosion ditches, hedgerows, and radical terraces). Each category was assigned a coefficient, from 0.35 for farms with no soil conservation investments to 0.10 for farms with the highest length of soil conservation investments. In addition, we took into account the protective effect of mulch. Thus farms with no soil conservation investments (coefficient of 0.35) but using mulch were given a new coefficient of 0.15 while farms with soil conservation investments and using mulch were given a coefficient of 0.10.

Land RENTAL is the percentage of area rented. However, its effect on farm productivity is mixed because (a) farmers invest less effort to improve rented parcels but (b) they choose the best land when renting. The resulting effect on productivity will depend on the factor that carries more weight. For example, on land that has been rented for a few years (quite usual in Rwanda) the productivity will be low while for land recently rented it would be high.

The share of high value crops (SHAREHVC) is the proportion of lucrative crops (banana and coffee) in the gross value of output. The purpose of this variable is to assess the influence of high value crops on overall farm productivity in value terms. Farm A can be less productive than farm B in physical terms but because farm A concentrates more on the production of high value crops, it will show a higher marginal product than farm B in value terms. Thus, the physical effect will be overshadowed by the value weights (prices).

Finally, dummy variables will be used to capture the effect of agro-ecological zones. There are three regional classification schemes that are used for various purposes by researchers and policy-makers in Rwanda. All three are based on differences in soils, altitude, rainfall and vegetation, and as such also show marked differences in cropping patterns, erosion, farm size and other important household and regional characteristics. (1) Delepierre (1974) divides the country in 12 agro-ecological regions. (2) Commission Nationale d'Agriculture (1990) expanded the number of zones to 18. This classification scheme draws upon a more comprehensive data base, particularly for soil characteristics, and has been very useful for targeted, commune- and secteur-level development projects. (3) Clay and Dejaegher (1987) devised a scheme that captures the major delineating characteristics of the first two, while summarizing these differences in just five zones that can be used effectively for national-level socioeconomic (rather than purely agronomic) analysis.

I judge the third classification (five zones) as the most suitable for my research. These agro-climatic zones have intrinsic differences among them and these differences affect the overall agricultural productivity achieved in each zone. Major defining characteristics are given below while productivity implications will be discussed in the following chapter.

The NORTHWEST zone covers the volcanic highlands and the upper parts of the lake Kivu's shore and Zaire-Nile divide. The zone corresponds to the prefecture of Gisenyi, part of Ruhengeri and part of Kibuye. The region has high yields due to its fertile soils derived from volcanic residues and well-watered climate. It also enjoys cool temperatures because of high altitudes. However, it is highly subject to erosion due to steep slopes and a lack of organic matter to hold together soil particles (this is a characteristic of volcanic soils). The region produces most potatoes consumed in the country. Other crops include maize and in lower altitudes, bananas and coffee. Much of the zone is very densely populated, thus with smaller farms, and the typical agricultural working day is longer than elsewhere in Rwanda.

The following three regions, SOUTHWEST, NORTH-CENTER, and SOUTH-CENTER, are regions that can be considered as almost similar, with in general low yields and average land size. Soils are in general poor and degraded and sometimes acidic (Southwest). Most of the region (but more in the South-Center) has well-watered marshes which allow a third cropping season which compensates for lower productivities in the upper land. The most popular crop mix is sweet potatoes, bananas and beans. Three quarters of the area is in the region normally called the Central High Plateau which is the historical center of the country and which is highly populated. The SOUTHWEST zone covers the lower parts of lake Kivu's shore and Zaire-Nile divide and the whole Imbo and Impala regions. The zone comprises the whole of Cyangugu, the southern part of Kibuye and western part of Gikongoro prefectures. The NORTH-CENTER zone is constituted by the northern part of the high plateau which covers the part of Ruhengeri and Byumba and the whole Kigali. The SOUTH-CENTER zone covers the southern part of the high plateau which encompasses the prefectures of Gitarama, Butare and much of Gikongoro.

Finally, the EAST zone corresponds to the eastern plateau or the entire Kibungo and eastern parts of Kigali and Byumba prefectures. It is characterized by low altitudes, gentle slopes and a drier climate compared to the rest of the country. However, it is a region recently colonized and as such still has farms with large size and fertile soils. The region produces more bananas and coffee than any other region.

3.4. Functional Form

Most studies have used linear or log-linear functional forms and very few have tried to use more complex forms. These linear and log-linear forms are criticized, however, for being too restrictive in that they do not allow the analysis of interactions among variables. Thus, no further consideration will be given to those functional forms. Instead, attention will be given to more flexible functional forms, defined by their property of being able to give a second order approximation to an arbitrary twice differentiable function satisfying the appropriate regularity condition[3] (Nakamura, 1984).

[3] The regularity condition requires that the first derivative of each point be defined (regular point) and that each point of the curve be a regular point.

A general form of the function is:

$$Y = f(X_i, Z_j, D_k) \tag{9}$$

where Y is the output function, X_i's variable inputs, Z_j's conditioning factors, and D_ks dummy variables. Our preference is the translog form because it has some desirable properties. First, it is a general production function and as such enables one to use a minimal number of parameters to assess the economic behavior without imposing any restrictions on the function. Second, the translog functional form is the most widely used and is the best for analyzing producers' behavior (Nakamura,[4] 1984; Antle and Capalbo, 1988).

A minor drawback of the translog production function is that it can be tedious to implement in econometric analysis if there are many variables. The computational burden results from its characteristic of taking a quadratic form which implies a rapid increase in the number of variables to be included in the function. To avoid this burden, Nakamura (1984) and Antle and Capalbo (1988) suggest aggregating inputs while Kennedy (1992) and Maddala (1992) suggest running successive regressions and to discard at each step the variables not significant and/or without a certain economic importance for the model. In our analysis we opt for the latter option.

[4] Nakamura refers to Diewert (1973); Fuss, McFadden and Mundlak (1978); and Blackorby et al (1978).

The final specification of our model is:

$$\ln Y = \beta_o + \Sigma_i\beta_i \ln X_i + \Sigma_j\beta_j Z_j + \Sigma_i\Sigma_i\beta_{ii}\ln X_i \ln X_i + \Sigma_i\Sigma_j\beta_{ij}\ln X_i Z_j + \beta_k D_k \tag{10}$$

where βs are the coefficients, i refers to inputs (1 = land and 2 = labor), j = 1...n refers to farm characteristic conditioners and k = 1...m refers to agroecological dummies.

Some of the independent variables might be endogenous. They would need to be instrumented in order to get unbiased results. Clay and Reardon (1994) showed that investments in fertilizer use depend on characteristics of the farm. Following the exogeneity test set out by Rivers and Vuong (1988), we instrumented the variable fertilizer use which was taken as endogenous. Then we integrated the least square residuals in the original production function and run the regression. The coefficient of the least square residuals was found not significantly different from zero (t-statistic) and thus the null hypothesis of exogeneity was retained[5].

[5] For a full description of the test refer to Appendix B.

Chapter IV : DATA PATTERNS

4.1. Description by Farm Stratum

A breakdown by three groups of households, arranged according to their level of cultivable land in hectares (lowest third, second third, and top third) is given in Table 1. The cultivable land includes land sown, and land that can be sown like fallow. The table presents household and farm characteristics of these groups in terms of average indicators (Note that some descriptive variables in the table are not used in our production function).

Total output value increases from smaller to larger farms because larger farms grow more. However yield value (output value per hectare) decreases with an increase in the size of the farm, showing the relative effectiveness of smaller farms in land productivity terms. The land average productivity of the largest third of farms is barely one-third that of the smallest third of farms. Medium and upper-sized class of farms (second and top third or farms above 0.54 ha) generate yields below the sample average of 47,400 RWF/ha. Barnum and Squire (1978) and Ellis (1993) also report a similar pattern in other developing countries (Malaysia, Brasil, India). This difference in yields is probably due, among other factors, to a higher use of labor per hectare on the smallest third group of farms. The amount of labor used is inversely related to the size of the farm with the lower third group of farms applying more than four times more labor per hectare than the upper third group of farms.

Table 1 : Average Strata Characteristics and Input Use[a]

Farm Size Strata[b]	Bottom Tercile Average	Middle Tercile Average	Top Tercile Average	Overall Mean	CV
Output (000's RWF)	21.60	34.30	52.60	36.30	0.88
Yield (000's RWF/ha)	74.40	42.10	26.10	47.40	1.07
Labor (000's m.d./ha)	1.25	0.56	0.27	0.69	0.95
Land (ha)	0.34	0.83	2.38	1.19	0.83
Parcels (per ha)	13.00	7.00	3.00	8.00	0.81
Years of Cultivation	17.90[d]	18.40[df]	20.80[f]	19.10	0.72
Erosion (T/ha)	4.30[cg]	4.70[cg]	4.60[cg]	4.50	1.11
Soil conserv. (meters/ha)	672.80	414.10[f]	344.60[f]	477.20	1.50
Fertshare (%)	68.10[cg]	66.20[cg]	68.10[cg]	67.50	0.44
Fertilizer (kg/ha)	0.08[cg]	0.07[cg]	0.08[cg]	0.08	14.30
Distance (minutes)	8.25	9.08	11.65	9.70	1.11
Rental (%)	9.90[cg]	10.00[cg]	5.60[cg]	8.50	1.93
Share HVC	0.34[d]	0.32[d]	0.36	0.34	0.65
Land per Stratum	0.10[na]	0.22[na]	0.68[na]	1.00[h]	
Gini Coeff. for land				0.383	

[a] *71 RWF = US$ 1 in 1990.*

[b] *Definitions:*

Strata: *Bottom Tercile: ≤ 0.58 Ha; Middle Tercile between 0.58 and 1.45; Top Tercile: > 1.45 Ha.*

CV : *Coefficient of Variation. Ratio of standard deviation over mean.*

Output: *Gross value of agricultural output in RWF in 1990 (valued at season average price).*

Yield : *Gross value of output per hectare (in 1000's RWF).*

Labor : *Available labor for the household in man-day per hectare (total family labor + hired labor - sold out labor).*

Land : *Total cultivable land in hectares (all land that can be sown: cultivated, fallow, etc.).*

Parcel: *Number of non-contiguous fragments of the farm per Ha.*

Farmage: *Average years of cultivation of parcels (arithmetic average).*

Erosion: *Average annual soil loss in Tons/ha calculated using the USLE.*

Soil Conservation: Length per hectare of soil conservation investments for the farm.

Fertshare: *Percentage of total area that receives any kind of fertility improvements (organic and chemical).*

Fertilizer: *Average amount of chemical fertilizers used for the whole sample (kg/ha).*

Distance: *Average distance from residence to parcel in minutes (arithmetic average).*

Rental: *Percentage of total area that is rented.*

Share HVC: *Share of high valued crops (banana and coffee) in total value of output.*

Proportion of Land per Strata: Percentage of cumulated land per Strata.

Gini Coefficient: Measure of inequality. It is the absolute mean difference in land distribution between each pair of class of land, relative to mean land.

$$Gini = \Sigma_i \Sigma_j |L_i - L_j| / (2n^2 L)$$

where L_i - land size for ith class, L_j - land size for the jth class, L - mean size and n - number of classes.

[c] *Between terciles' mean are not significantly different at 10 % level.*

[d] *Bottom and middle terciles' mean are not significantly different at 5 % level.*

[e] *Bottom and top terciles' mean are not significantly different at 5 % level.*

[f] *Middle and top terciles' mean are not significantly different at 5 % level.*

[g] *All terciles' means are not significantly different at 5 % level.*

[h] *Summation of the first three columns.*

[na] *Not applicable.*

The smallest third of farms has on average less than half a hectare (overall 0.34 ha of cultivable land) while the upper third has more than two hectares (2.38 ha of cultivable land) which is seven times more than the cultivable land of the lowest third. However, farms in Rwanda (sample average of 1.19 and upper third average of 2.38 ha) are far below the African average of 7.48 ha/agricultural worker. So, this typology of small and large farms relates solely to the Rwandan context. Land is unequally distributed over farms. The lower tercile occupies only 10 percent of total land while the upper tercile has almost 70 percent of total cultivable land; landholders with a hectare or more of cultivable land represent two fifths of all landholders and control three quarters of all cultivable farmland. The Gini coefficient of the distribution of land is 38 percent. The smallest farms are limited in their access to land and thus view it as a scarce resource while on the other hand they have a large supply of labor (mostly family labor). Thus smaller farms substitute labor for land in agricultural related activities.

Parcel shows farm fragmentation. Small farms are four times more fragmented than large farms. For comparable farms, the productivity will decrease as the number of fragments into which the farm is divided increases. Farmage shows the average number of years of cultivation of farms. The tercile's means do not differ much between them. However, an overall mean of 19 years of cultivation indicate that in general farmers are not acquiring new land and that any increase in production will be achieved only by using land more intensively (use of fertilizers and other land improvements). The variable distance which is the average walking distance from the residence to parcels in minutes show a great variability (high coefficient of variation).

There is no significant difference between the mean erosion level of the three terciles. However, the erosion level is partly[6] determined by the length of anti-erosion devices and the above table shows that smaller farms have the highest length of soil conservation investments per hectare. Soil conservation investments have two kind of actions. First they retain the particles of soil which are washed away and second, they decrease the length of the parcel (and thus slope) on which the run-off water will exercise its effect (thus breaking the speed of the run-off water). Table 2 below gives a breakdown of farm characteristics according to the level of erosion. As expected, farms with the most erosion have the lowest yields, the lowest percentage of area fertilized, the lowest share of high value crops (bananas and coffee requires good soils and the plantations are usually mulched), the lowest length of soil conservation investments, and apply the least labor per hectare.

Improvements with organic fertilizers increase the cohesion of soil particles (texture) thus reducing the impact of rain and run-off water. Though there is no significant difference between the level of organic fertilizer use among the three terciles. Furthermore, the amount of chemical fertilizer used (average of 0.08 kg/ha) is very small and show a great variability (coefficient of variation of 14.30). Thus, taken individually, among the factors determining land quality only soil conservation investments seem to show a significant difference between the three terciles of farm size. However, their exact effect will be assessed below with the analysis of the marginal value products.

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[6] Other factors determining the level of erosion are the erosive forces of rainfall, the soil erodibility, the slope and length of the slope and the crop cover. Refer to equation 4 above.

The top tercile has a higher share of high-value crops than the other two while the bottom tercile shows a tiny difference compared to the middle tercile. The higher investment in high-value crops of the top tercile is explained by their preference to use more hired labor in these plantations. They lower their supervision cost because this hired labor is used in very specific work (maintenance) which is relatively easy to monitor.

Table 2 : Farm Descriptives by Erosion

Classes of Erosion[ab]	1	2	3	Average
Yield (000's RWF/ha)	59.80	47.00	35.20	47.30
Land (ha)	1.13	1.07	1.36	1.19
Labor (man-day/ha)	743.60	702.00	614.70	686.60
Fertshare (%)	75.40	68.50	58.60	67.50
Device (meters/ha)	597.00	466.00	366.00	476.00
Distance (minutes)	8.20	9.40	11.50	9.70
Share HVC (%)	0.45	0.32	0.23	0.34

[a] *Classes of erosion: 1 = less or equal to 1.57 T/ha*
2 = between 1.57 and 4.62 T/ha
3 = higher than 4.62 T/ha.

[b] *For definitions, see Table 1 above.*

4.2. Description by Agro-climatic Zone

Table 3 shows that the *Northwest* region has the highest yields but has a high erosion, a low share of land fertilized and small length of soil conservation investments. The region has small farms, and relies mostly on potatoes and maize compared to other regions which produce a mix of sweet potatoes, bananas and beans. The share of high value crops is low compared to other regions.

The *Southwest, North-Center* and *South-Center* have low yields and average land size, land improvement and share of high-value crops. Though farms in the Southwest region have the highest erosion level compared to all other regions. The most popular crops ranked by their share in gross value of output are sweet potatoes, bananas, and beans.

The *Eastern* region has a low erosion because it has low altitudes and a drier climate. Farms are large in size (average of 1.4 ha) and major crops produced are bananas, beans, and sweet potatoes. The share of high-value crops is very high compared other regions

In sum, the highest productivity will be found in the Northwest and the Eastern zone. They will be followed by the North-Center because it produces a substantial amount of white potatoes and wheat (both have high prices) in addition to coffee and bananas. The regions with the lowest productivity will be the Southwest and South-Center due to their cultivation of less valued subsistence crops (beans and sweet potatoes).

Our model has been specified such that the constant of the function contains the effect of the South-Center region. Thus, omit the Northwest region (due to interaction terms), the sign of the coefficient of other regions will show the direction of change of their overall productivity compared to the South-Center. The North-Center and East should have a positive sign while the Southwest should have a negative sign.

Table 3 : Characteristics of Agro-ecological Zones

Zones[a]	North-West	South-West	North-Center	South-Center	East	Overall Average
Zone Average Altitude (m)	2000	1950	1920	1740	1570	1820
Zone Average Rainfall (mm)	1150	1490	1030	1220	870	1150
Farm Average Erosion (T/Ha)	7.2	7.7	4.5	3.7	1.8	4.7
Land (Ha)	0.8	1.3	1.2	1.1	1.4	1.2
Yields (000's RWF)	68.0	34.6	46.5	37.0	52.7	47.4
Fertshare (%)	59.3	64.8	70.9	66.6	71.3	67.5
Soil Conservation (m/Ha)	375.5	575.3	475.7	465.7	480.1	476.0
Share HVC (%)	0.19	0.29	0.32	0.33	0.47	0.34
Crops	Irish Potatoes, Maize, Beans	Sweet Potatoes, Bananas, Beans	Sweet Potatoes, Bananas, Beans	Sweet Potatoes, Bananas, Beans	Bananas, Beans, Sweet Potatoes	Bananas, Sweet Potatoes, Beans

[a] *Definitions:*

Altitude: *Height from the sea level in meters.*

Rain : *Annual Average over 1989-1991 Rainfall in millimeters.*

Crops : *The 3 major crops produced ranked according to their share in total value of output.*

Other variables are defined as in Table 1.

Chapter V : REGRESSION RESULTS AND PRODUCTIVITY MEASURES

5.1. Econometric Estimation

The choice of particular regressors was based upon intuitive consideration and data availability. So, in order to get a parsimonious specification, several runs had to be conducted, involving fewer variables at each step. Those variables with coefficients having an insignificant t-statistic (at least at 10 %) and without a certain economic importance were dropped out (note that the significance of some variables was affected by the presence or absence of other variables). In other terms, the coefficient of the variable rejected from the equation are restricted to be equal to zero. However, to make sure that the reduced model has the same explanatory power as the full model (all interaction terms included), both models were compared using an asymptotically valid F test as described in Greene (1990)[7]. The null hypothesis that the two models are similar in their explanatory power (or put more simply, of restricting the βs of the rejected variables to be zero) could not be rejected at the 5 percent significative level ($F_{(22,1044)} = 1.18$).

The terms that have been rejected includes the quadratic terms of labor and land, and the interaction terms involving land and labor and the variables Parcel, Farmage,

[7] A full description of this test is given in appendix 4 below.

Distance, Rental and dummies for Southwest, North-Center and Eastern zones. The only significant term among those rejected was the quadratic term of labor. Its inclusion in the equation was making the linear term of labor both negative and non-significant with the consequence that the marginal value products of labor was U-shaped in the farm range of zero and two hectares. However, we believe that labor is not a scarce resource in Rwanda and that at least in this range (zero to two hectares) labor productivity should be declining. For this reason and in order to harmonize with the other variable input (land) which quadratic term had been discarded we rejected also the quadratic term of labor with the result that the linear term became both positive and highly significant. Moreover, the comparison of the two models (restricted and unrestricted) showed also no difference (see above paragraph). Thus, the final specification is as follow:

$$\begin{aligned}
\ln OUTPUT = {} & \beta_0 + \beta_1 \ln LABOR + \beta_2 \ln LAND + \beta_3 FERTSHARE + \beta_4 EROSION \\
& + \beta_5 SHAREHVC + \beta_6 PARCEL + \beta_7 FARMAGE + \beta_8 DISTANCE + \beta_9 RENTAL \\
& + \beta_{10} NORTHWEST + \beta_{11} SOUTHWEST + \beta_{12} NORTH\text{-}CENTER + \beta_{13} EAST \\
& + \beta_{14} \ln LABOR * \ln LAND + \beta_{15} \ln LABOR * FERTSHARE + \beta_{16} \ln LABOR * EROSION \\
& + \beta_{17} \ln LABOR * SHAREHVC + \beta_{18} \ln LABOR * NORTHWEST \\
& + \beta_{19} \ln LAND * FERTSHARE + \beta_{20} \ln LAND * EROSION + \beta_{21} \ln LAND * SHAREHVC \\
& + \beta_{22} \ln LAND * NORTHWEST \qquad (11)
\end{aligned}$$

Fitting this production function (Equation 11) to the data gives the results presented in Table 4. The two major inputs, LABOR and LAND, have positive and significant effects. However, their full effect cannot be ascertained directly with a translog function due to interaction terms which play an important role. The full effect will be discussed below with the analysis of marginal value productivities.

Among the conditioning factors that act as shifters, only the coefficient of FARMAGE has an expected sign and is significant. The older the farm the lower the productivity. This denotes insufficient improvement measures on farmers' parcels while they continuously extract nutrients from those parcels. The coefficient of PARCELs is not significant but has the expected sign. The coefficient of DISTANCE is not significant and has an unexpected sign (positive).

The coefficient of land rental is positive and not significant, which does not contradict our hypothesis of an ambiguous effect. The coefficients of FERTSHARE and Share of High value crops (SHAREHVC) are both positive as expected but only the latter is significant. The coefficient of EROSION has an unexpected sign (positive) and is not significant. However, its full effect will be ascertained below by assessing the sole effect together with interaction effects, and discover that its full effect is negative.

Table 4 : Translog Production Function Estimates[ab]

Variable[c]	Coeff.	Variable	Coeff.
(1) LABOR	0.54^{***} (0.13)	(13) EAST	0.41^{***} (0.06)
(2) LAND	0.38^{**} (0.19)	(1)*(2)	0.01 (0.03)
(3) FERTSHARE	0.60 (0.64)	(1)*(3)	- 0.01 (0.01)
(4) EROSION	0.01 (0.07)	(1)*(4)	0.07 (0.11)
(5)SHAREHVC	2.98^{***} (0.91)	(1)*(5)	$- 0.34^{**}$ (0.15)
(6) PARCEL	- 0.001 (0.002)	(1)*(10)	0.22^{**} (0.09)
(7)FARMAGE	$- 0.003^{**}$ (0.001)	(2)*(3)	$- 0.02^{**}$ (0.007)
(8)DISTANCE	0.002 (0.002)	(2)*(4)	$- 0.10^{***}$ (0.07)
(9) RENTAL	0.001 (0.001)	(2)*(5)	0.13 (0.10)
(10)NORTHWEST	$- 0.56^{**}$ (0.57)	(2)*(10)	0.19^{***} (0.07)
(11)SOUTHWEST	- 0.05 (0.06)	Constant	6.55^{***} (0.76)
(12) NORTH-CENTER	0.18^{***} (0.05)	Adj. R^2	0.54
		F Statistic	60.10^{***}

Note: The dependent variable is the logarithm of gross value of output in 1990 agricultural production in RWF.

[a] *Standard errors are in parentheses.*
[b] *** *significant at 1%;* ** *significant at 5%;* * *significant at 10%.*
[c] *Definitions of variables:*
NORTHWEST, SOUTHWEST, NORTH-CENTRAL, EAST are dummy variables for regions.
Other variables are described as in Table 1.

5.2. Marginal and Average Productivities

The prevailing relationship between farm-size and productivity is ascertained through marginal productivities and average productivities. Both the marginal value product and the average value product of labor increase with an increase of the size of the holding while on the other hand both the marginal value product and the average value product of land decrease (Table 5). These results are in accordance with findings in other countries (Barnum and Squire, 1978; Ellis, 1993).

Nevertheless, Ellis (1993) and Bhalla (1988) point out that the observed relationship can be dependent on how the partition of farms in different classes is done (i.e. the definition of stratum cut-off points). By manipulating the area ranges of the size classes one can get declining productivities for land and increasing productivities for labor while alternative ranges on the same data would show constant or increasing productivities for land and constant or decreasing productivities for labor. Thus, a sensitivity test is carried out to make sure that the relationship observed does not solely depend on the range of size classes chosen. The test consists of regressing the marginal value products on linear and quadratic terms for land and other determinant factors: land quality and crop composition of output (erosion, percentage of area fertilized, and the share of high-value crops in total output).

Table 5 : Marginal and Average Factor Product and Factor Price[a]

Farm Size Strata	Labor (RWF/man-day)		Land (1000's RWF/Ha)	
	MVP	AVP	MVP	AVP
Bottom Tercile[b]	37.1	64.2	28.6	74.4
Middle Tercile[b]	39.7	76.8	16.1	42.1
Top Tercile[b]	58.8	95.7	9.8	26.1
Average	45.3	81.6	18.1	47.4
Market Factor Price[c]	100.0		7.5	

[a] *Definition of Variables:*

Labor and Land are described in Table 1.

MVP : Marginal Value Products. We derived the production function with respect to the factor, replaced each variable by its value and took the average.

AVP : Average Value Products are calculated as Mean output/Mean factor use.

[b] *Bottom Tercile: ≤ 0.58 Ha; Middle Tercile between 0.58 and 1.45; Top Tercile: > 1.45 Ha.*

[c] *Factor prices are median values of wage paid to labor and price paid for land for farms that use them. They are total payments for the factor divided by total amount of factor used (hired labor or rented land) for 1990.*

Table 5 strongly confirms the inverse relationship between farm size and farm productivity for land, and the positive relationship between farm size and labor productivity. Erosion has a very strong and highly significant cumulative negative effect on land productivity, and a less strong effect on labor productivity (but not significant). Application of chemical and organic fertilizer improves significantly land productivity while it does not affect meaningfully labor productivity. The share of high value crops has a very strong positive effect on land productivity, and a positive (but only marginally significant) effect on labor productivity. The Northwest agro-ecological zone affects both the productivity of land and labor positively and significantly due to the characteristic of that zone described above. The variables included in the analysis of the marginal value products are those involved in the interaction term in Equation (11). Although, the adjusted R^2 is reasonable for farm data analysis for land productivity, it is very low for labor productivity. The latter is not surprising as the labor data are poor, essentially constructed from family size and composition data and labor transactions. As land is the scarce factor, we are most interested in the land results. The labor productivity results should be interpreted with caution. However, the F statistics of the analysis of variance of the regressions are all highly significant.

Table 6 : Estimates of Marginal Value Products of Land and Labor[abc]

Variables	MVP of Land	MVP of Labor
Constant	17560.05*** (2172.7)	18.43 (14.07)
LAND	- 9889.49*** (989.5)	17.05*** (6.41)
LAND²	872.75*** (136.0)	- 1.74** (0.88)
EROSION	- 1073.93*** (125.0)	- 1.22 (0.81)
FERTSHARE	51.72*** (19.8)	0.02 (0.13)
SHAREHVC	23993.31*** (2960.9)	32.56* (19.18)
NORTHWEST	21157.34*** (1766.6)	37.19*** (11.44)
Adjusted R^2	0.30	0.02
F Statistic	76.56***	3.24***

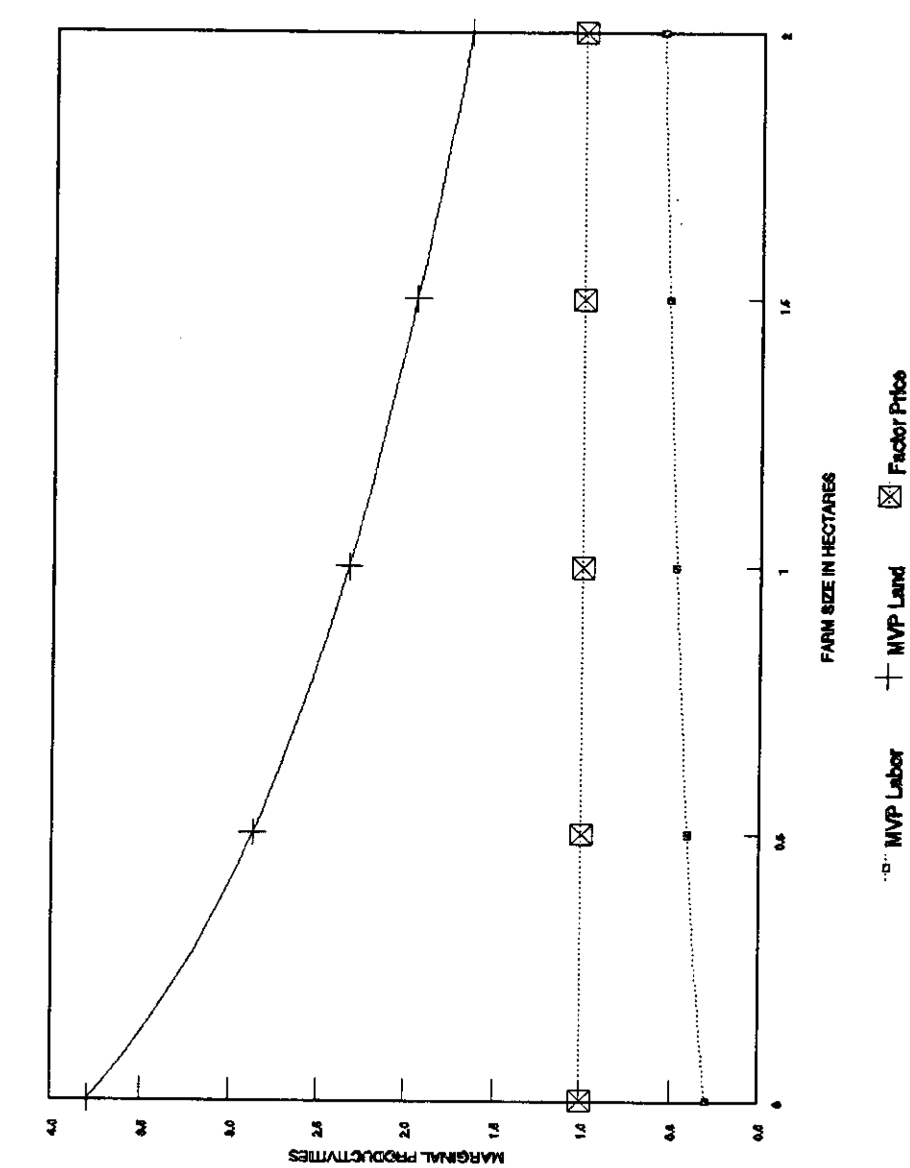
Note: The dependent variables are respectively the marginal value product of land and the marginal value product of labor for column 1 and 2.

[a] *Standard errors are in parentheses.*
[b] **** significant at 1%; ** significant at 5%; * significant at 10%.*
[c] *Definitions of variables are as in the Table 1 and 4 above.*

Three points can then be emphasized, (1) the relationship between farm size and productivity, (2) the levels of the marginal value products compared to factor prices (wage of labor and rental price of land), and finally (3) the effect of land quality and share of high valued crops on marginal value products. These results also are presented in Figure 1 where the marginal value products are compared to factor prices (also Table 8a,b,c,d,e,f and additional figures in the appendices capture the effect of erosion, land fertilized (land quality) and share of high value crops on marginal value products).

First, farm-size sensitivity: The quadratic regression of predicted marginal value products on land shows the direction and size of change of the marginal value product with respect to farm size. The marginal value product of land is strongly inversely related to the size of the farm (Table 6) as the linear term of land shows (negative for MVP of land). The marginal value product of labor, on the other hand, is positively related to the size of the farm (positive linear term). The quadratic terms have also opposite signs for land and labor productivity. It is positive for land meaning that the marginal value product of land decreases with an increase in farm size, but this relationship eventually levels off (reaches a minimum). For labor the opposite pattern holds (it reaches a maximum). These results are similar to those found by Carter and Wiebe (1990) for labor and capital in Kenya. Moving from smaller farms to larger farms, the marginal value product of labor increases by 35 percent while the marginal value product of land decreases by 36 percent (Table 8.a). These results are applicable within the range of farm sizes found in Rwanda (low mean of 0.34 Ha to high mean of 2.38 Ha). Outside these ranges one should be cautious.

Figure 1 : MARGINAL VALUE PRODUCT
OF LABOR AND LAND



Second, the marginal value products: The smallest farms apply labor until its marginal value product is only a fraction of the market wage. This marginal value product increases with the size of the holding. However, all farms overuse labor (relative to the market valuation of labor), since marginal value products of labor are less than the wage of labor at all levels (although the gap is greatest on the smallest farms). Comparatively large farms are allocatively more efficient with respect to labor than are smaller farms.

By contrast, the market price of land (proxied by the rent paid) is only a fraction of the marginal value product of land on the smallest farms and the marginal value product-factor price gap closes as farm size increase. Larger farms appear to treat land as a relatively abundant resource although we are in a land scarce economy. As Carter and Wiebe (1991) note, smaller farms are usually endowed with relatively more labor than capital (and land) and thus face a low opportunity cost of labor and high prices for capital/land while larger farms confront high prices of labor but enjoy low virtual prices of capital/land.

This difference in virtual prices faced by smaller and larger farms arise apparently because of dualism in factor markets. Smaller and larger farms may face two different effective wage rates and/or smaller farms might equate the average value product of labor to the market wage while larger farms might equate the market wage to the marginal value product of labor. Imperfections in the land market are usually a result of local ownership structures (traditional land rights, small farms acquire land by inheritance but usually in inadequate amounts and too fragmented for optimum farm operation while large farms buy land from less resource endowed farmers) and the prevailing local capital market (small farms are financially constrained and borrow at much higher rates)(Ellis, 1993).

Third, land quality and crop mix effects: The shifters or conditioners (erosion, share of land fertilized, and share of high-value crops) in Table 6 have all the expected signs and for land productivity all of them have very strong significant coefficients[8]. Below, we will try to assess the impact of each conditioner when controlling for farm size and holding constant other conditioners or their combinations. However, taken all together, the overall effect of these conditioners on the marginal value products will depend on which of the three (erosion, share of land fertilized, and share of high-value crops) has the greatest impact and thus will depend on the characteristics of each farm.

Taken individually, the conditioner erosion (calculated with the USLE) is negatively related to marginal value products both of land and of labor. When the erosion rate increases from 1 to 8 tons/ha (average is 4.55 tons/ha) the marginal value product of labor decreases by 15 percent and the marginal value product of land by 30 percent.

The conditioners FERTSHARE (percentage of land fertilized by chemical and/or organic fertilizers) and share of high-value crops (percentage of value of bananas and coffee in gross value of output) have a positive impact on productivities both of land and of labor. The marginal value product increases by 2 percent for labor and by 15 percent for land when the percentage of land fertilized goes from 40 to 90 percent of total cultivable land (the average is 67.34 percent).

The overall effect of changes in land quality (proxied by erosion and land fertilized) will depend on which of the two (erosion or fertilization) has the greatest influence on productivity. This effect will vary over farms.

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[8] In Table 4, however, some of these variables do not have the expected sign as a result of the presence of interaction terms (with land and labor).

The "share of high-value crops" has a positive effect on both productivities. It increases the marginal product of labor by 27 percent and the marginal product of land by 57 percent when the share of bananas and coffee in total value of output moves from 15 to 54 percent (the average is 34 percent). The decrease of the marginal value product of land due to erosion can be as low as 24 percent for farmers with a high percentage of area fertilized and a high percentage of land dedicated to the production of high value crops. These farmers have the greatest incentives to invest in erosion control to protect investments in soil fertility. When there are both a low level of land fertilized and a low share of high value crops the loss from erosion can go as high as 50 percent (Table 8.b).

The percentage of area fertilized (chemical and organic fertilization) has a small effect on labor productivity. However, it improves land productivity by as much as 44 percent when there is a high level of erosion and a low share of high value crops (Table 8.c). These farmers have the greatest incentives to invest in fertilizers (chemical fertilizers and organic matter).

By producing more high value crops (bananas and coffee), farmers can improve their cash income from agricultural activities significantly. With a low erosion level and a high share of land fertilized, the increase in productivity due to difference in investment in high-value crops holding other factors constant can be as high as 92 percent for land and 49 percent for labor (Table 8.d). The least increase in productivity (39 percent for land and 29 percent for labor) is recorded for farmers with highly eroded land and using few inputs (manure, mulch and other fertilizers).

The marginal value product of land increases by 21 percent, when on-farm soil conservation investment increases from 345 to 673 meters/ha (the average is 477 meters/ha) holding all other factors (farm size, erosion, share of land fertilized, and share of high value crops) constant. The increase is almost insignificant for labor (Table 8.a). Table 8.e shows that the farms that benefit most are those with high erosion and both low shares of area fertilized and high value crops (a 42 percent increase). Those that benefit the least are those with low erosion rates and high share of high value crops (around 15 percent for any size of area fertilized).

Table 8.f shows the effect of land quality (proxied by the combined effect of erosion, percentage of land fertilized, and length of soil conservation investments) on the relationship between farm size and productivity. The highest decrease in productivity between smaller and larger farms is observed with farms with a high erosion level, a low percentage of land fertilized and little anti-erosion capital. The productivity decreases by 44 percent between smaller and larger farms while the decrease is only 36 percent (Table 9.a) without the effect of land quality. The lowest decrease in productivity is 26 percent (compared to 36 percent without the effect of land quality) on farms with low erosion and with both high percentage of land fertilized and high length of soil conservation investments. Thus, land quality strongly affects the observed inverse relationship between farm size and land productivity by exacerbating it when the quality of land is poor (high erosion, low share of land fertilized and little anti-erosion capital) and by offseting it when the quality of land is good (low erosion, high share of land fertilized and big anti-erosion capital). For labor productivity, the rate of change with varying land quality is around one third.

Table 8.f also shows that the crop mix of output strongly affects the relationship between farm size and productivity. Labor productivity increases by 31 percent and 42

percent from smaller to larger farms respectively with a high share of high-value crops and a low share of high-value crops. Conversely, the decrease in land productivity between smaller and larger farms is 28 percent on farms with a high share of high value crops and 43 percent on farms with a low share of high value crops compared with 36 percent with the change in high-value crops is hold constant. The decrease in productivity is the difference between smaller and larger farms. Hence, land productivity on larger farms is lower than that on smaller farms for a given category.

Land quality and crop mix are thus important determinants of farm productivity. By controlling the level of erosion and by improving his land (with manure and/or mulch), a farmer can successfully increase his production and the overall productivity of the farm. The above results point out that land quality affects significantly the oft observed inverse relationship between farm size and productivity. A poor quality of land will exacerbate the observed relationship while a good quality of land will soften the observed realtionship.

The crop composition of output also affects the observed relationship between farm size and productivity. By investing more in high value crops small farms get higher marginal value products than large farms and this exacerbates the observed relationship.

In sum, the effect of land quality and crop mix of output should be controlled for in studies of the determinant of farm productivity.

Chapter VI : CONCLUSIONS AND IMPLICATIONS

This thesis analyzes the determinants of farm productivity for smallholders in Rwanda and the farm size-farm productivity relationship in the context of changing land quality and varying crop composition of output. Determinants of farm productivity can be classified in three categories:

(1) variable inputs: are land and labor. Land is the resource in short supply. Labor is constructed from family size and composition and data on labor transactions. We are mostly interested in land results.

(2) land quality: is proxied by erosion, share of land fertilized, length of soil conservation investments and to a lesser extent other factors like number of parcels, number of years of cultivation, distance residence-parcel, land tenure and agro-climatic zones. These factors affect jointly land quality and the resulting effect depends on factors that have the greatest effect.

(3) crop composition of output: is the share of high value crops, bananas and coffee, in gross value of output. Small and very large farms allocate a higher proportion of their land to the production of coffee and bananas.

The model used, with data from a survey conducted in Rwanda, incorporates the effect of land quality and of crop composition. Their effects on the observed farm size-productivity relationship were assessed.

Our results show that, first, smaller farms have better land productivity than larger ones. The marginal value product of land decreases as the size of the farm increases while the marginal value product of labor moves in the opposite direction (increase with an increase of the size of the farm). In other words, small farms face high shadow prices of land (ratio of marginal value product of land to factor price higher than unity) while on the other hand they are confronted with relatively low opportunity costs of labor (marginal value product of labor is a fraction of the wage rate). This inequality of marginal value products and the price of factors of production is a sign that farmers are constrained in their access to some factors of production. The marginal value products of land and labor are the furthest from unity for smaller farms, implying factor use inefficiency. Smaller farms are both constrained in their access to land and access to labor market opportunities. By contrast our findings point out that the value product and the price of factors of production for larger farms show less divergence. Larger farms are allocatively more efficient than smaller ones.

Second, the observed relationship between farm size and productivity is exacerbated by poor land quality and softened by good land quality. Land quality is declining due to a decrease in area and length of time devoted to fallow combined with an intense cultivation of steep slopes. However, this reduction is not homogeneously distributed among all groups of farm. In general, smaller farms has better land quality than larger farms because smaller farms invest more in land improvements (fertilization, soil conservation structures). A farm with land subject to erosion will have its productivity one third lower than that of a farm with land not eroded and the loss in productivity will jump at nearly one half if in addition the farm has a low share of land fertilized and a low length of soil conservation investments. This loss is compensated for if the farm invests in fertilization and soil conservation structures though. Use of fertilizers improves land productivity by 15 percent while soil conservation investments improves it by 20 percent. Farmers with the greatest incentives to invest in soil conservation are those with a high percentage of fertilized area and a high share of high value crops. On the other hand, among farmers already investing in fertilization and soil conservation those who will benefit the most are those with a high level of erosion and a low level of other conditioners. Thus, land quality affects the observed inverse relationship between farm size and land productivity. For example, farms with highly degraded land (high erosion, low fertilization and low investment in soil conservation) will see their marginal value product fall by nearly 50 percent from smaller farms to larger ones.

Third, the production of high value crops strongly increases land productivity. A farm that allocates a substantial amount of its land to high-value crops (bananas and coffee) will also have higher productivities (a mix of physical and value effects). The increase in marginal value product will be nearly 100 percent if the farm has a low erosion level and a high percentage of fertilized land. For farms with a low share of high value crops the increase in productivity from small to large farms will be more than 40 percent for labor while land productivity will decrease by more than 40 percent. On the other hand, when the share of high value crops is high, the change in productivity will be only around 30 percent for both labor and land. The better farms (low erosion, and high fertilization, soil conservation, and high share of high value crops) will have less difference among them while the worst farms (high erosion, and low fertilization, soil conservation and share of high value crops) will show the greatest variability among them. Thus, our model provides some alternative explanations of what causes and what exacerbates the inverse relationship between farm size and productivity.

For theory, the study highlights the importance of factors that are usually not accounted for by most studies on the determinant of farm productivity and on the inverse relationship between farm size and productivity (in this case land quality and crop composition of output). It thus stresses the importance of omitted variables or specification errors on the overall relationship.

For policy, the study highlights the presence of market imperfections. It is hard to draw policies from the study which would not be biased by these market imperfections. Thus it is necessary to ensure the well functioning of rural markets so that the necessary reallocation of factors of production arise as a result of competitive forces (for example by abolishing the law that hamper the free transfer of land). The intensification by adding more labor has reached a limit in Rwandan agriculture. The marginal value product of labor is far below the market wage. Thus, the new intensification strategy should be directed toward non-traditional means of production (new technology) and market information (credit market, research, etc.) and in the process to give more attention to smaller farms as they demonstrate higher potentials in the use of those inputs (also Carter and Wiebe, 1990). The use of organic matter (with mulch from perennial, manure from animals and green manure from windbreaks) and fertilizer/lime have high payoffs and need to be greatly increased. Access to these inputs, especially purchased ones, must be made much easier to farmers. Investments in soil conservation are a necessary condition to improved productivity and must be encouraged through agricultural extension as they increase land productivity significantly. Also high value crops increase greatly farm productivity. Thus, farmers should be incited to invest more in these crops which are even an excellent source of cash income needed to purchase highly priced inputs. However, more than the above, increase in productivity will be greatly dependent to farmers confidence after these years of war and political instability.

APPENDICES

APPENDIX A: SENSITIVITY OF MARGINAL VALUE PRODUCTS OF LAND AND LABOR

Table 7 : Estimates of Marginal Value Products of Land and Labor (Soil Conservation Investments Included)[abc]

Variables	MVP of Land	MVP of Labor
Constant	14436.25*** (2185.52)	17.64 (14.43)
LAND	- 8825.79*** (984.81)	17.31*** (6.50)
$LAND^2$	778.81*** (134.25)	- 1.76** (0.89)
EROSION	- 982.87*** (123.50)	- 1.20 (0.82)
FERTSHARE	37.06* (19.57)	0.02 (0.13)
SHAREHVC	24206.04*** (2906.89)	32.62*** (19.19)
DEVICE	5.36*** (0.82)	0.001 (0.005)
NORTHWEST	21719.13*** (1736.34)	37.33*** (11.46)
Adjusted R^2	0.31	0.02
F statistics	74.24***	2.78***

Note: The dependent variables are respectively the marginal value product of land and the marginal value product of labor for column 1 and 2.

[a] Standard errors are in parentheses.

[b] *** *significant at 1%;* ** *significant at 5%;* * *significant at 10%.*

[c] *Definitions of variables are described as in Table 1 and 4.*

Table 8 : Impact of Land Quality and Crop Mix Effect

(a) Variation of One Conditioning Factor while Holding other Variables Constant[a]

Moving from ..	MVP of Labor	MVP of Land
.. Small to Large Farms	35 %	- 36 %
.. Low to High Erosion	- 15 %	- 30 %
.. Low to High Fertshare	2 %	15 %
.. Low to High Share of High Value Crops	27 %	57 %
.. Low to High Devices[b]	2 %	21 %

[a] *Farms:* *small ≈ 0.34 Ha; large ≈ 2.38 Ha; average = 1.2 Ha.*
Erosion: *low ≈ 1 T/Ha; high ≈ 8 T/Ha; average = 4.6 T/Ha.*
Fertshare: *low ≈ 40 %; high ≈ 90 %; average = 67.3 %.*
ShareHVC: *low ≈ 15 %; high ≈ 54 %; average = 34.0 %.*
Soil Cons: *low ≈ 345 m/Ha; high ≈ 673 m/Ha; average = 477.0 m/Ha.*
[b] *Devices:* *Soil conservation investments.*

(b) Impact of Change from Low to High EROSION for Various Farm Categories[a]

Moving from Low to High EROSION	MVP of Labor	MVP of Land
Low SHAREHVC Low FERTSHARE	- 21 %	- 51 %
Low SHAREHVC High FERTSHARE	- 22 %	- 45 %
High SHAREHVC Low FERTSHARE	- 14 %	- 29 %
High SHAREHVC High FERTSHARE	- 16 %	- 24 %

[a] *Description of variables is as in Table 9.a.*

(c) Impact of Change from Low to High FERTSHARE for Various Farm Categories[a]

Moving from Low to High FERTSHARE	MVP of Labor	MVP of Land
Low EROSION Low SHAREHVC	7 %	27 %
Low EROSION High SHAREHVC	4 %	11 %
High EROSION Low SHAREHVC	6 %	44 %
High EROSION High SHAREHVC	2 %	18 %

[a] *Description of variables is as in Table 9.a.*

(d) Impact of Change from Low to High SHAREHVC for Various Farm Categories[a]

Moving from Low to High SHAREHVC	MVP of Labor	MVP of Land
Low EROSION Low FERTSHARE	39 %	58 %
Low EROSION High FERTSHARE	49 %	92 %
High EROSION Low FERTSHARE	29 %	39 %
High EROSION High FERTSHARE	42 %	67 %

[a] *Description of variables is as in Table 9.a.*

(e) Impact of Change from Low to High Conservation Investment for Various Farm Categories[a]

Moving from Low to High Conservation Investment	MVP of Labor	MVP of Land
Low EROSION Low FERTSHARE Low SHAREHVC	1.5 %	25 %
High EROSION Low FERTSHARE Low SHAREHVC	1.9 %	42 %
Low EROSION High FERTSHARE Low SHAREHVC	1.5 %	22 %
High EROSION High FERTSHARE Low SHAREHVC	1.8 %	35 %
Low EROSION Low FERTSHARE High SHAREHVC	1.2 %	16 %
High EROSION Low FERTSHARE High SHAREHVC	1.4 %	21 %
Low EROSION High FERTSHARE High SHAREHVC	1.2 %	15 %
High EROSION High FERTSHARE High SHAREHVC	1.4 %	19 %

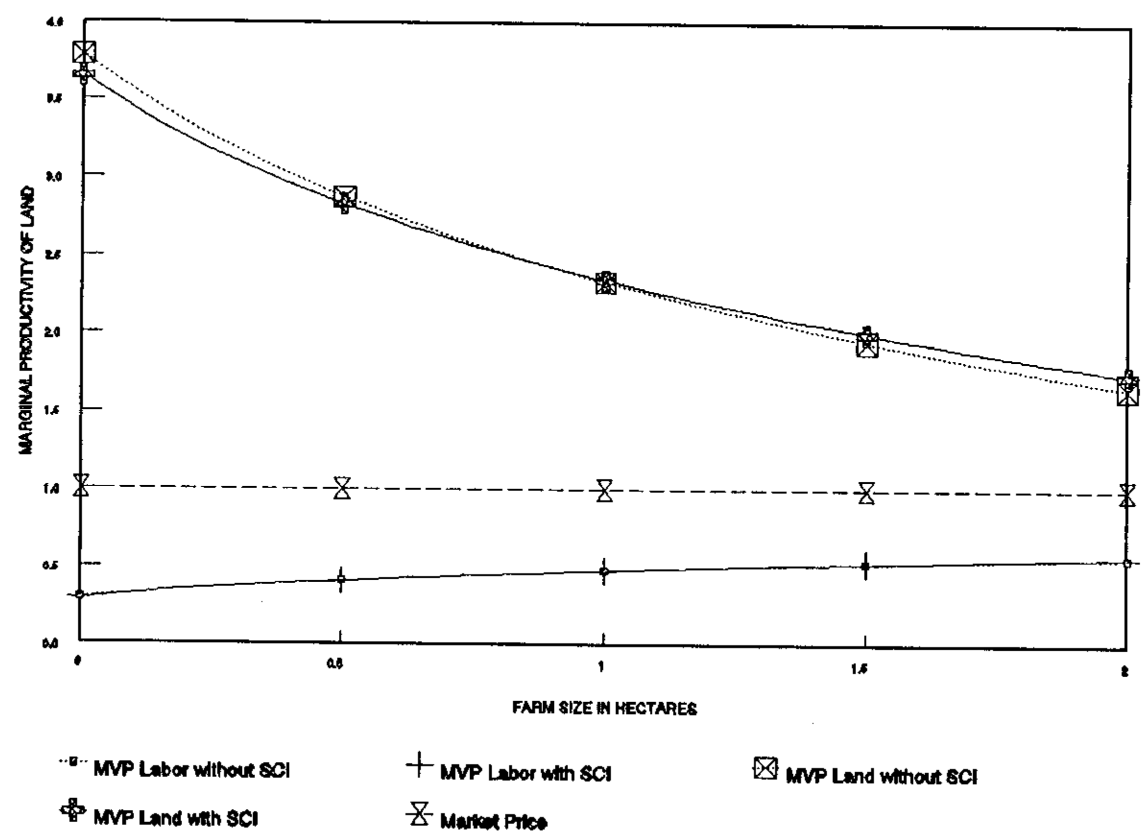
[a] *Description of variables is as in Table 9.a.*

(f) Impact of Change from Small to Large Farms Various Farm Categories[a]

Moving from Small to Large Farms	MVP of Labor	MVP of Land
Land Quality		
Low EROSION Low FERTSHARE Low DEVICES	33 %	- 32 %
High EROSION Low FERTSHARE Low DEVICES	40 %	- 44 %
Low EROSION High FERTSHARE Low DEVICES	32 %	- 30 %
High EROSION High FERTSHARE Low DEVICES	39 %	- 39 %
Low EROSION Low FERTSHARE High DEVICES	32 %	- 28 %
High EROSION Low FERTSHARE High DEVICES	39 %	- 36 %
Low EROSION High FERTSHARE High DEVICES	32 %	- 26 %
High EROSION High FERTSHARE High DEVICES	38 %	- 33 %
Crop Mix of Output		
Low SHAREHVC	42 %	- 43 %
High SHAREHVC	31 %	- 28 %

[a] *Description of variables is as in Table 9.a.*

Figure 2 : MARGINAL VALUE PRODUCT
OF LAND AND LABOR
(IMPACT OF SOIL CONSERVATION INVESTMENTS-SCI)



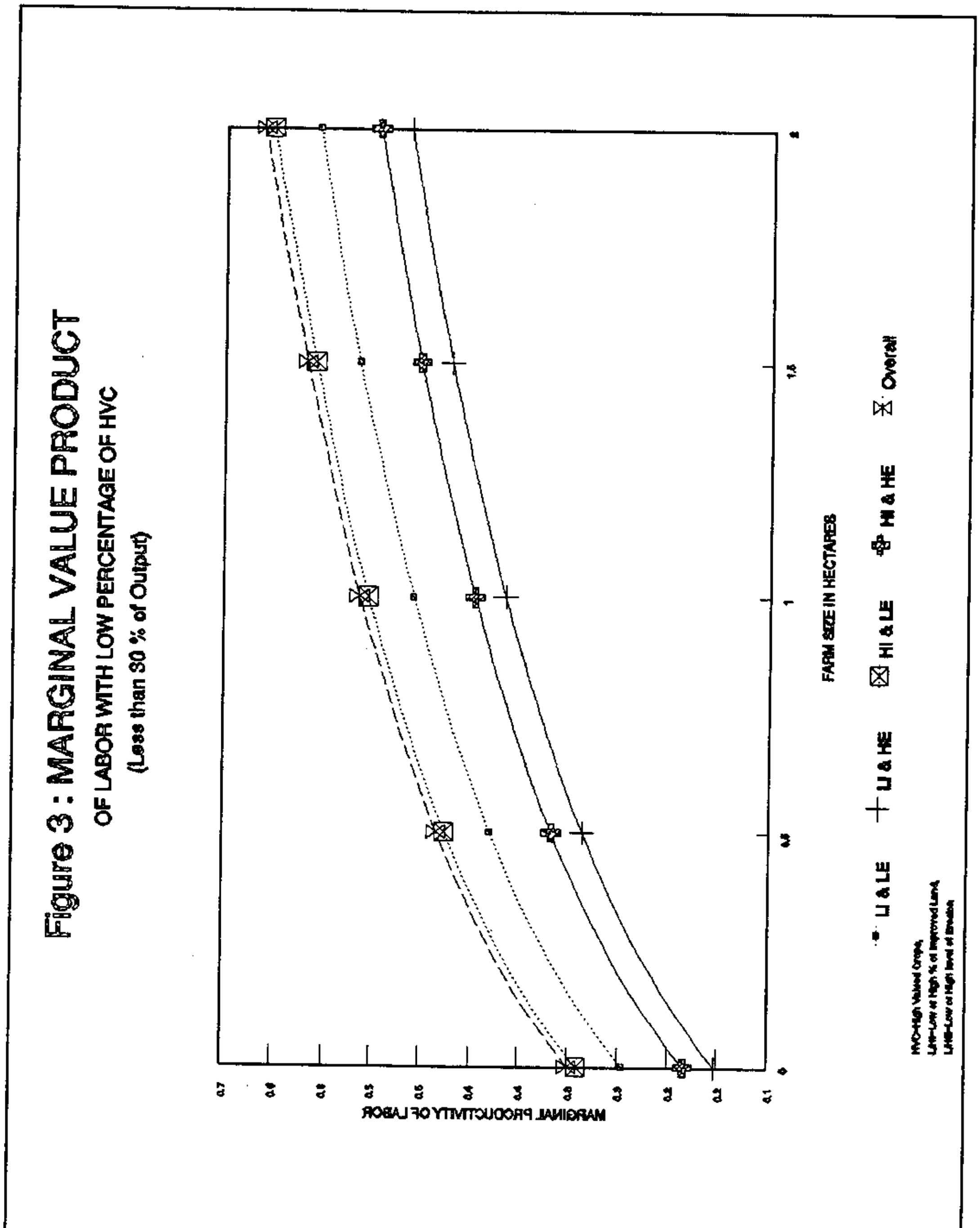


Figure 3 : MARGINAL VALUE PRODUCT
OF LABOR WITH LOW PERCENTAGE OF HVC
(Less than 30 % of Output)
MARGINAL PRODUCTIVITY OF LABOR
FARM SIZE IN HECTARES
LI & LE
LI & HE
HI & LE
HI & HE
Overall

Figure 4 : MARGINAL VALUE PRODUCT
OF LABOR WITH HIGH PERCENTAGE OF HVC
(More than 30 % of Output)

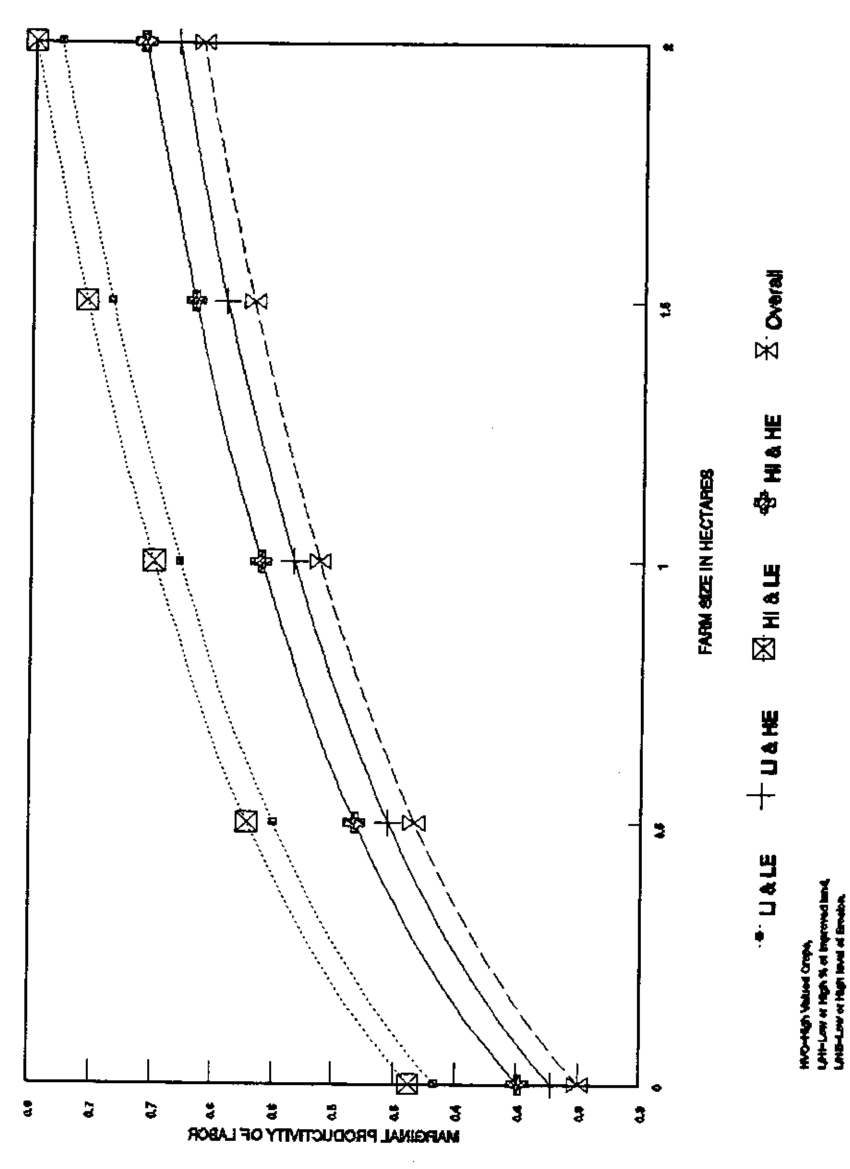
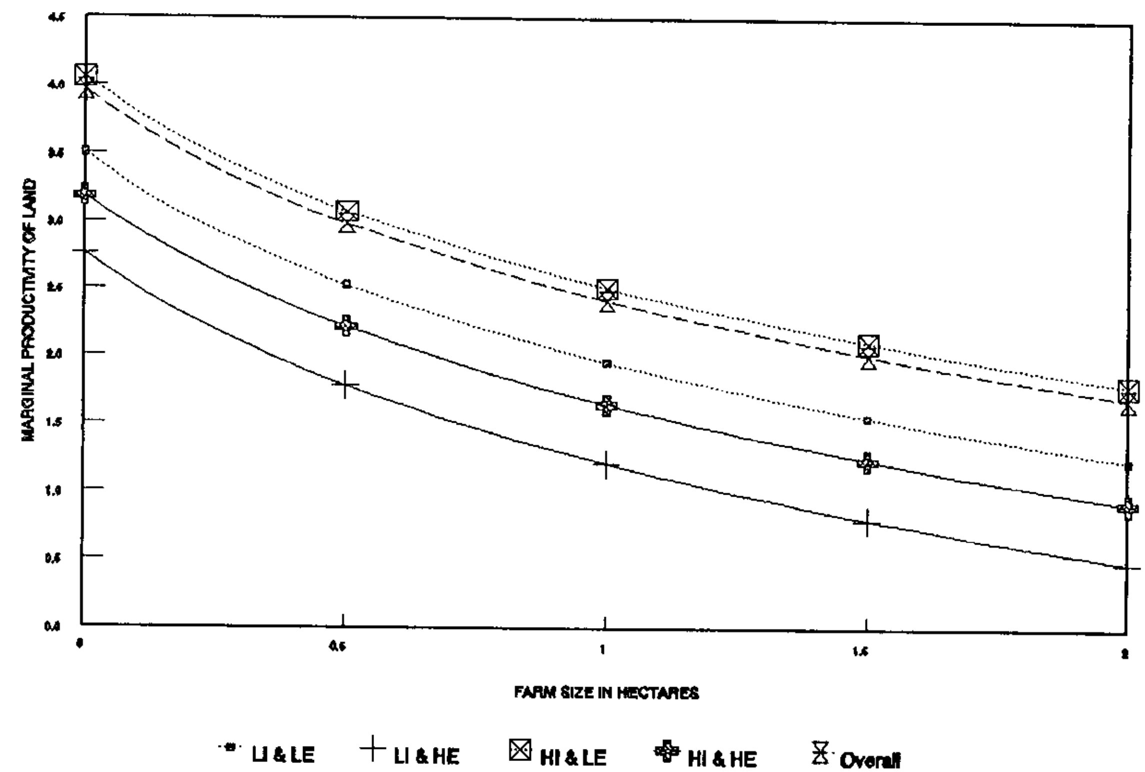


Figure 5 : MARGINAL VALUE PRODUCT

OF LAND WITH LOW PERCENTAGE OF HVC

(less than 30 % of Output)

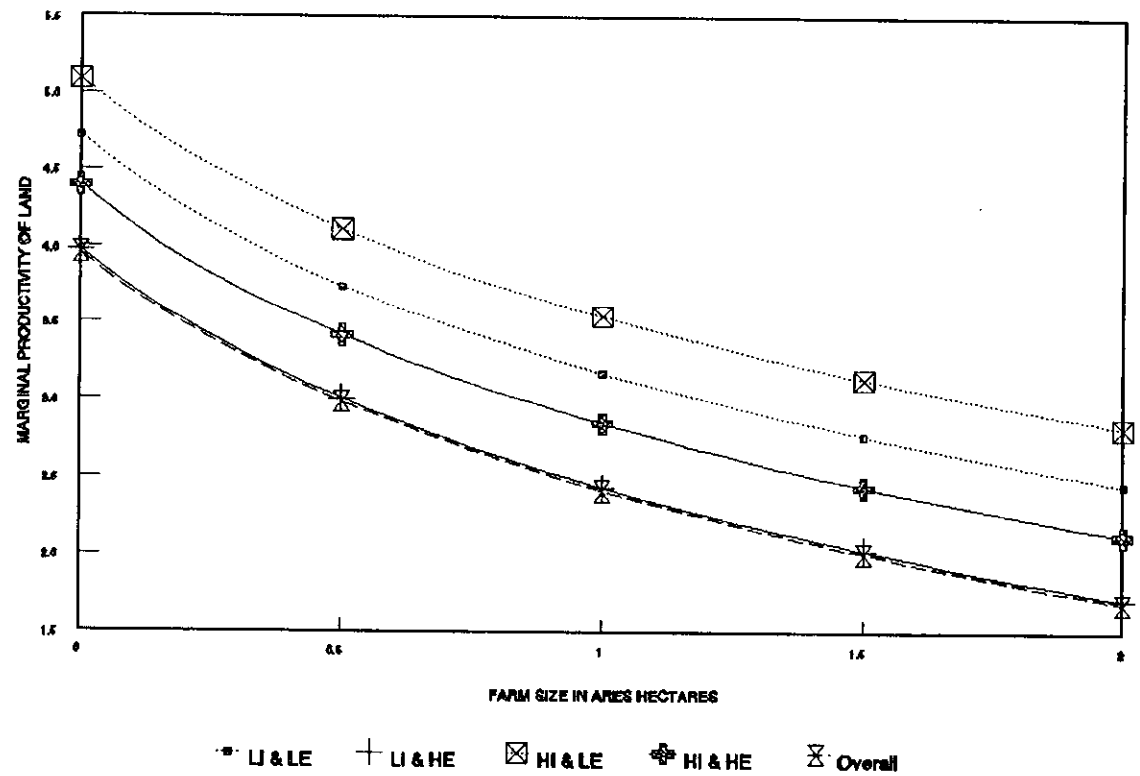


HVC-High Valued Crops,
L/HI-Low or High % of Improved land,
L/HE-Low or High level of Erosion.

Figure 6 : MARGINAL VALUE PRODUCT

OF LAND WITH HIGH % OF HVC

(More than 30 % of Output)



HVC-High Valued Crops,
L/HI-Low or High % of Improved land,
L/HE-Low or High level of Erosion.

APPENDIX B: ECONOMETRIC TESTS

1. Test of Exogeneity (Rivers & Vuong, 1988)

There are reasons to believe that some variables may depend on some characteristics of the household (especially the percentage of area fertilized and the share of high valued crops). For example, small farms may be more inclined to invest in lucrative crops or large farms may be having difficulty to improve all their land. If some of these variables are endogenous, estimating equation 10 without instrumenting it would lead to biased results. Thus, we tested and failed to reject the null hypothesis of exogeneity of the above variables, using specifications of the type:

$$\text{Conditioner} = f(X_i, Z_j, D_k)$$

where X_i contains labor and land characteristics, Z_j some of the other conditioners included in equation 10 and D_k the effect of some zone dummy variables (also included in equation 10). The least squares residuals were estimated and the results added as regressors in the original production function (10) above:

$$\ln Y = \beta_o + \Sigma_i \beta_i \ln X_i + \Sigma_j \beta_j Z_j + \Sigma_i \Sigma_i \beta_{ii} \ln X_i \ln X_i + \Sigma_i \Sigma_j \beta_{ij} \ln X_i Z_j + \beta_k D_k + \beta_l v_l$$

where v - least squares residuals. Under the null hypothesis that these factors are exogenous, β_ls are zero. This was tested using a standard t-test on β_ls, and the null hypothesis was retained.

2. Test for Parametric Restrictions (Greene, 1990)

In linear models restrictions are tested by showing that they are identical to the original model without restriction. However, in the non-linear case, the models (restricted and unrestricted) are only equivalent asymptotically. The hypothesis to be tested is:

$$H_0 : R(\beta) = q$$

This may be any kind of restrictions, linear or non-linear. The above hypothesis impose at least one functional relationship on the parameters and if there is more than one, they must be functionally independent. Let β be the unrestricted, non-linear least squares estimator, and β^* be the estimator obtained when the constraints of the hypothesis are imposed. The asymptotically valid F test or nonlinear analog to the familiar F statistic based on the fit of the regression (i.e., the sum of squared residuals or SSR) would be:

$$F_{n_1, n-n_2} = \frac{[SSR(\beta^*) - SSR(\beta)]/n_1}{SSR(\beta)/(n-n_2)}$$

where: F - F statistic; SSR - Sum of Squared residuals, n_1 -degrees of freedom of restricted model; n_2 - degrees of freedom of unrestricted model; and n - total degrees of freedom. However, in this non-linear setting, neither the numerator nor the denominator has exactly the necessary chi-squared distribution, so the F distribution is only approximate.

APPENDIX C: MAJOR ADJUSTMENTS AND ASSUMPTIONS MADE[9]

Hours of Work:

Survey data on labor use is difficult and expensive to collect. The DSA data set used in this work has no data on labor allocation, except for labor transactions (sales and purchases). Combining labor transaction data with demographic data gives us estimates of hours available to agriculture, other non-market activities, and leisure.

To derive estimates on agricultural labor productivity, we have had to make strong assumptions about how much rural Rwandans allocate time to agriculture. The following assumptions were made by Uwamariya et al. (1993):

- Agricultural working day in Rwanda is six hours, except for three prefectures. The working day is seven hours in Byumba, eight hours in Gisenyi, and nine hours in Ruhengeri.
- In Rwandan Agriculture, each week has five working days.
- No agricultural work is done in July, and in most of Rwanda farmers work half-time in January, February, June, and August. The exceptions are the prefectures of Byumba, where farmers work only one-third of the normal hours in August, and Kibungo, where they do no agricultural work in August.

Note that the assumptions we have used do not depend on farm size. In other words, we have made the strong assumption that the lack of land to work on neither makes farmers

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[9] This section is extracted from: Clay, D., F. Byiringiro, J. Kangasniemi, T. Reardon, B. Sibomana, and L. Uwamariya. "Promoting Food Security in Rwanda through Sustainable Agricultural Productivity: Meeting the Challenges of Population Pressure, Land Degradation, and Poverty." Staff Paper No. 95-08, Department of Agricultural Economics, Michigan State University 1995.

work less, nor makes them work more. In still other words, the assumption is that if farm size per available worker declines by one-half, per hectare labor use exactly doubles.

Labor:

The labor variable is the available labor for the household in man-day per hectare. It is calculated as follow:

Labor = Total family labor + Hired labor - Sold out labor

Labor had been first homogenized in Adult Equivalent (AE) with adult male and female (between 16 and 60) receiving a weight of 1 while children (between 6 and 15) and senior citizens (above 60) received a weight of 0.25.

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