DISCUSSION PAPER / 2008.09

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Abstract

The Rwandan government has recently adopted new agricultural and land policies that strive to increase productivity in the agricultural sector though land consolidation and concentration, and through the promotion of regional crop specialisation and monocropping. This paper, however, identifies the strong inverse relationship between farm size and land productivity under the current land management system; also when taking into account farm fragmentation, crop diversifiation, frequency of multicropping and household size. In addition, it concludes that increased farm fragmentation, higher frequency of multicropping, and more crop diversification do not necessarily have a significant negative impact upon productivity, on the contrary. The paper reflects upon the implications of Rwanda's agrarian and land policies.

Résumé

Le gouvernement rwandais a récemment adopté une nouvelle politique agricole et foncière visant à accroître la productivité dans le secteur agricole au moyen d'une consolidation et d'une concentration des terres et par la promotion de la culture de spécialités régionales et de la monoculture. Cet article, cependant, établit un fort lien inverse entre l'étendue de la ferme et la productivité des terres sous le système actuel de gestion foncière; c'est aussi le cas quand on tient compte de la fragmentation de la ferme, de la diversification des cultures, de la fréquence de multicultures et de la grandeur du ménage. En outre, l'article conclut qu'une fragmentation croissante de la ferme, une fréquence plus élevée des multicultures et une plus grande diversification des cultures n'ont pas nécessairement un impact négatif significatif sur la productivité, bien au contraire. L'article réfléchit aux implications de ces résultats sur la politique agraire et foncière au Rwanda.

1. Introduction

Rwanda's civil war in the early nineties is rightfully pictured as an ethno-political conflict, ending sadly in a tragic genocide that killed approximately 800.000 people. However, next to political and ethnic problems, Rwanda's pre-war society was also marked by a 'grievance factor', triggered off by increasing ecological resource scarcity. In a country with over 80% of its people relying upon agriculture, high population growth worsened the pressure on natural resources and increased land competition. This evolution profoundly affected the livelihoods of rural farmers and endangered the survival chances for the weakest among them. Already in the early eighties, scholars referred to Rwanda as a potential Malthusian case (e.g. see Marysse, 1982). After the war and genocide, many others raised the Malthusian argument to explain popular participation in the genocide (for an overview, see Uvin, 1998).

In the current post-1994 context, access to and productivity of land remain highly sensitive topics. Average landholdings in Rwanda are only 0,71 hectares per household (2000), considerably less in comparison to land availability during the mid-eighties when households, on average, had 1,20 hectares. In addition, inequality in the distribution of land has strongly increased over this period (Jayne et al., 2003). Conflicts over land are frequent, both within and between households, families, and lineages.

The Rwandan government has recently adopted new agricultural and land policies that strive to increase productivity in the agricultural sector through land consolidation and concentration, and through the promotion of regional crop specialisation and monocropping. The land law was adopted in 2005[1] and aims to enhance the security of tenure and reduce conflicts by registering land holdings. It subscribes to the overall goal of increasing agricultural productivity and land efficiency, while attempting to avoid environmental degradation. One of the underlying assumptions of the law is that fragmented land use has a counterproductive impact upon these objectives. Article 20 prohibits the division of land parcels of one hectare or less (no ceiling on landholdings was included in the final approved law). Land consolidation[2] is presented as one of the main objectives of the land law (GoR, 2005). It is hoped that this consolidation will increase land concentration and provide economies-of-scale in two ways: first, the consolidation movement should lead to more concentrated farms (instead of a farm scattered over many land plots); and second, the consolidation movement should increase land concentration amongst a smaller number of modern and more efficient farmers (Ansoms, 2008, 2009).

The Rwandan Agricultural Policy, and Strategic Plan for Agricultural Transformation (SPAT, see GoR, 2004A) aim to transform the primary sector into a growth engine through agricultural modernisation, intensification, professionalisation and enterprise development. The SPAT strategy focuses upon the development of commodity chains with export potential, or on crops with great importance for internal markets where the policy makers see a major role for the private sector. Regional crop specialisation and the promotion of monocropping are seen as important triggers for the marketisation of agricultural production, and the modernisation of the sector as

[1] Its full name is the Organic Law determining the use and management of land in Rwanda (N°08/2005 of 14/07/2005, GoR 2005).

[2] Land consolidation is defined as, "a procedure of putting together small plots of land in order to manage the land and use it in an efficient uniform manner so that the land may give more productivity." (Organic Law N° 08/2005 of 14/07/2005, article 2).

a whole. Coherent policy plans to implement these 'triggers' are not yet developed. Nonetheless, Ansoms (2009) enumerates several examples where local peasants in particular regions have been obliged by local authorities to concentrate on certain crops, and even to destroy crops that were not planted 'in row' with the monocropping technique.

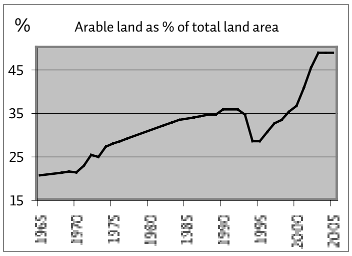
This paper tests whether the underlying assumptions of the new agricultural and land policies are justified: do land consolidation and land concentration, less crop diversification and less multicropping have a positive impact upon productivity figures? Affirmative answers to these questions alone would not justify the immediate implementation of consolidation, specialisation, and monocropping policies. Policy makers must also consider the distributional effects these initiatives would have upon local rural livelihoods. On the other hand, negative answers to the various aspects of these questions should not necessarily lead to the immediate rejection of consolidation, specialisation and monocropping-promotion. This would only highlight the necessity for further research into the institutional constraints that prevent farmers from adopting certain risk-prone options that could increase the marketable surplus of their production. An answer to the principal research questions of this paper is, therefore, only a first step in the policy debate that should follow.

The paper first presents the natural resource constraint that typifies the Rwandan countryside. It then shows that there is an inverse relationship between farm size and land productivity (even when farm fragmentation, crop diversification, frequency of multicropping and variations in different regions' soil quality are taken into account). Based on this analysis, the paper finally reflects upon the implications for Rwanda's rural policies.

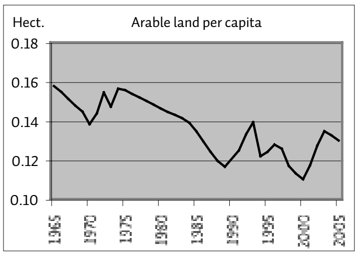
2. Rwanda caught in a Malthusian trap?

Rwanda has long been a densely populated country, confronted much earlier with severe land-scarcity than the rest of the relatively land-abundant African continent. Its strategy to cope with the problem was typically one of land expansion. Since the early sixties, the proportion of arable land has even further increased, except for an important decline in 1994-1995 (Graph 1A). Nevertheless, this trend could not keep pace with Rwanda's impressive population growth (Graph 1C). As a result of this gap, per capita arable land availability declined during the seventies and eighties (Graph 1B).

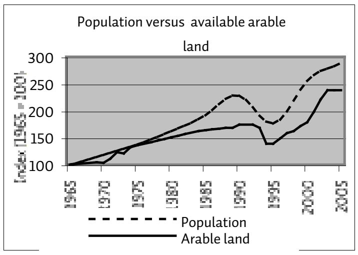
Graph 1A



Graph 1B

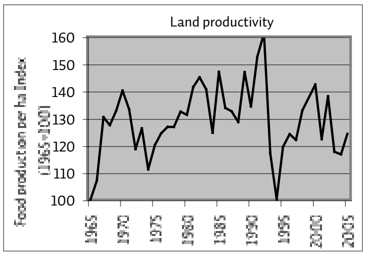


Graph 1C



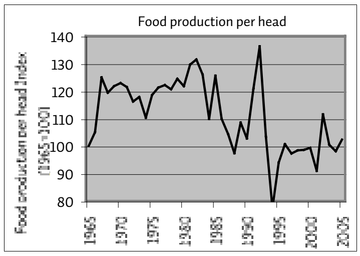
Source: World Bank, 2008.

Graph 2A



Graph 2B

Graph 2C



Source: World Bank, 2008.

As land resources became scarcer, land expansion went hand in hand with intensification strategies to increase land productivity. However, complex technological innovation was often unavailable, too costly, or not suitable for the typical subsistence-based production system. Therefore, intensification was mostly obtained through traditional methods; for example, by reducing fallow periods, by increasing the number of cultivation cycles per year and by exploiting steeper parts of hills with more demanding crops. This strategy increased the burden on available arable land with obvious harmful effects on its ecological state and potential. By the early nineties, land productivity growth collapsed (Graph 2A), reaching the limits of what seemed to be an ecological boundary. Stagnation in productivity rates, combined with limited options for expansion and increasing population growth, resulted in declining food production per capita (Graph 2C). At the same time, there were almost no available options for the Rwandan labour surplus to be absorbed by other sectors. This resulted in underemployment, which is reflected in the stagnating and declining labour productivity figures within the agricultural sector in the second half of the eighties (Graph 2B). It was exactly this worrying combination that led André and Platteau (1998) to the conclusion that Rwanda was, 'caught in a Malthusian trap'[1].

[1] According to Malthusian theory in its original version, the societal cycle leads unavoidably to a point where "mankind's biological reproduction capacity" structurally exceeds its "physical production capacity" (Ehrlich and Lui, 1997:207). Such tension eventually results in the outburst of "misery and vice", which takes the form of large-scale diseases or violence. This temporarily resolves problems of population pressure and thus of resource scarcity. Nevertheless, as the post-outburst context is characterized by the same institutional setting, society is implicitly 'doomed' to continuously fall into the same trap. Uvin distinguishes among two types of Malthusian arguments. The "hard" Malthusian argument sees violence and conflict as the unavoidable result of rising population pressure and resource scarcity. The "soft Malthusianists" argue that "ecological resource scarcity did play a role in the processes that led to the 1994 violence, [but] this role was not fixed and cannot be understood without considering political processes" (Uvin, 2003:83).

Post-war trends in agricultural intensification continue to be worrying. Land productivity has increased somewhat after 1994; although it remains problematic extremely volatile (Graph 2A). Labour productivity figures for the post-war years are also troublesome. They reflect how large numbers of rural peasants are still entrapped in agricultural survival activities (Graph 2B). Even more worrisome is the evolution of food production per head: the post-war recovery is very limited.

Surprisingly, the post-war potential for expansion seemed to be promising. The declining trend in per capita arable land availability was reversed in the first years of the new millennium (Graph 1B). Given that population growth continued at a considerable pace (Graph 1C), this can only be explained by an acceleration in the transformation of non-arable land into arable land (further expansion) over the post-war period (Graph 1A). However, from 2003 onwards, the expansion strategy is reaching its finite spatial limitations (see graphs 1A and 1B).

Next to the availability and intensity of land use, there is also the issue of land distribution. The long-term trend is far from encouraging, as shown in the next table. In 2000, average land available per household was about three quarters of the available arable land in 1990. Moreover, land ownership in Rwanda has shifted from the poor to the rich. According to Jayne et al. (2003), average landholdings have declined strongly for all economic quartiles between 1990 and 2000, except for the richest.

Table 1: Land availability and land distribution (long-run) (1)

	Av. land access per hh	Household per capita land access					Inequality		
		Quart 1	Quart 2	Quart 3	Quart 4	Av.	Gini 1	Gini 2	Gini 3
1984	1,20	0,07	0,15	0,26	0,62	0,28	-	-	-
1990	0,94	0,05	0,10	0,16	0,39	0,17	0,43	0,43	0,41
2000	0,71	0,02	0,06	0,13	0,43	0,16	0,52	0,54	0,54

Source: Jayne et al. 2003:262.
Remarks: Quart stands for quartile. Gini 1 is defined in terms of land per household, gini 2 in terms of land per capita, and gini 3 in terms of land per adult.

The question as to whether Rwanda has finally been able to escape the Malthusian trap of ever increasing resource scarcity remains unresolved. Expansion was only a temporary solution to the resource constraint in the post-1994 period, and it entailed the increasing exploitation of unsuitable lands to the point of total resource depletion. Successfully coping with land scarcity is, therefore, entirely conditional upon the ability of the rural sector to go beyond the current ecological and productivity boundaries of the natural resource base. Intensification depends upon the availability of land, production-improving techniques, incentives and the abilities of local farmers to make use of them. These abilities may differ for various types of farmers. The main issue is, therefore, the selection of national rural/agricultural policy objectives; including which particular type(s) or group(s) of farmers should be targeted to make the agricultural sector more productive. An important preliminary question to answer then is which type(s) of farmers and farming systems maximize land productivity in the current context.

3. Debates on the inverse farm size – productivity relationship

There is considerable empirical evidence that links land consolidation and concentration to improved productivity (For some recent literature, see Hung et al., 2007 for Vietnam; Lerman and Cimpoies, 2006 for Moldova). Wu et al. (2005) advance three potential sources for productivity improvements through land consolidation. First, concentration of plots could facilitate improved land quality management through irrigation and use of machinery. Secondly, concentration could reduce certain secondary cultivation costs (e.g. labour time, fencing costs, transportation, supervision, etc.). Finally, land concentration might also lead to changes in crop choice allowed by land improvements.

However, there is also an extensive literature that illustrates an inverse relationship between farm size and land productivity. The debate began with the work of Amartya Sen (1962) on India. The influential research of Berry and Cline (1979) and Cornia (1985) also pointed to a strong inverse relationship. Dyer (2004), however, found significant flaws in the approach of Berry & Cline, and pointed to the importance of disaggregating data. In their recent work, Johnston and Le Roux (2007) gave a short overview of disaggregated studies and found a diverse pattern of results, "… with some finding a clear inverse relationship, others a positive relationship and still others describing a convex or concave relationship." (Johnston and Le Roux, 2007, 357).

In addition, if an inverse relationship is identified, one should be careful to not automatically interpret this as a mere reflection of small-scale farmers' higher efficiency. On the side of the larger farmers, it may be that they have enough alternatives to earn their livelihoods, which decreases their incentive to fully exploit the potential of their land. They may hold it for other than productive purposes. They may also consider land as a 'relatively abundant resource'; even in a land-scarce environment, given they face a lower implicit price for land compared to other production factors (Ellis, 1990). Turning to the side of the smaller farmers, peasants may be obliged to overexploit the land at their disposal. Akram-Lodhi mentions that the greater productivity of small-scale farmers may be a 'survival mechanism of the poor' rather than a 'mechanism of potentially poverty-eliminating accumulation' (Akram-Lodhi, 2007, 560). Examples of these survival mechanisms have been elaborated by other authors. Binswanger and Rosenzweig (1986), for example, point to the possibility that imperfections on the labour market may prevent labour-selling households from allocating their labour force in the most optimal way, resulting in overemployment on the own farm that leads to an inverse relationship. Barrett (1996) adds that food price risks may incite small-scale peasant households to deliberately opt for employing their labour force in an excessive way, "beyond even their shadow valuation of labor" (Barrett, 1996). Assunção and Ghatak (2003) however, point to the possibility that the inverse relationship might be the result of self-selection among the peasants, where efficient small-scale peasants have higher opportunity costs to engage in wage labour. All these theories provide household-specific explanations, either pointing to opportunities, either to constraints to which these households are confronted, to provide explanations for the inverse land size – productivity relationship.

Another issue is whether the inverse relationship will hold in a modernising agricultural sector. A study focussing on the Indian case indicates that, "the inverse relationship between yields and farm size, although valid for a traditional agriculture, cannot be assumed to exist in an agriculture experiencing technical change" – certainly when the transformation is of the Green Revolution type (Deolalikar, 1981: 275). Based on data for the Thar Desert in India, Ram et al. (1999) find that the inverse relationship weakened with the increased availability of size-neutral biotechnology and differences in management input. Bhalla and Roy (1988), on the other hand, do confirm a weakened inverse relationship comparing Indian data for 1970 and 1976. But they reject the hypothesis that this was the result of technological change induced by the green revolution. Another study by Carter (1984), however, finds that even with post-Green Revolution data for India a strong inverse relationship continues to exist. The author concludes that, "these results suggest that small-scale agriculture warrants attention as a base for agriculture development in a land scarce economy" (Carter, 1984: 144).

The farm size – productivity relationship has again become relevant in current debates on agrarian reforms. There are two competing models. The first model promotes market-led agrarian reforms (MLAR) - based on the willing-seller, willing-buyer principle of land without maximum ceilings. This should result in a self-selection process of the most productive producers; and, accordingly, productivity and agricultural efficiency should increase (for the main arguments of the MLAR literature, see Deininger, 1999; Deininger and Binswanger 1999; Deininger and Feder 1998 and Deininger, 2003). Deininger and May (2000) accentuate that this growth-oriented strategy may, at the same time, lead to greater equity; given the inverse relationship between farm size and productivity.

Others (e.g. Borras, 2003) point out that agricultural reforms occur in a space where various social actors have unequal bargaining and negotiation positions due to the asymmetry of social class power. As a result, the small-scale farmers – regardless of whether they are the most productive – may be institutionally constrained in consolidating their position in a market-led land reform. The model which presents itself as an alternative to market-led reforms is promulgated by La Vía Campesina (for an overview of the movement's evolution, see Desmarais, 2002). This model argues for agricultural reforms in which small-scale producers play a central role; through peasant empowerment and food sovereignty. Roset et al. (2006) refer to the inverse relationship between farm size and land productivity as the main argument for smallholder farming systems as a basis for agrarian reform.

Turning to the case of Rwanda, rural policy documents and governmental policy makers do not consider small-scale subsistence agriculture as a viable option for rural development. The Strategic Plan for Agricultural Transformation identifies, as a main challenge, the "transformation of subsistence agriculture into commercial agriculture with all its involvements in terms of institutional, social changes of behaviour and distribution of roles and responsibilities between different stakeholders" (GoR, 2004A, 33). The land policy takes it further, "... the Rwandan family farm unit is no longer viable. ... The re-organization of the available space and technological innovations are necessary in order to ensure food security for a steadily and rapidly increasing population" (GoR, 2004B,16). Some of the foreseen innovations include: farm concentration, regional specialisation in certain crop types, and the abandonment of multicropping (i.e. combining different crops on the same plot of land) in favour of monocropping; in order to benefit from the 'economies of scale.' Most importantly, the policy envisages re-organising the agricultural sector by consolidating land and shifting to larger farm units.

At this point, it is doubtful, however, whether large-scale Rwandan farmers are indeed more productive. Byiringiro and Reardon (1996) use pre-conflict data to conclude that smaller farmers have higher average and marginal land productivity than larger farmers, and that their farmlands are not more eroded despite more intensive cultivation methods. Also, in the post-war context, larger farmers are not necessarily the most productive land users, as we show in the next part of the paper.

4. The case of Rwanda

We use socio-economic quantitative data gathered by the Food Security Research Project (FSRP) combined with data from the Household Living Conditions Survey (EICV)[1]. Conditional upon the dependent variable considered (see later), the sample includes a total of 1312 / 1357 households from 125 cellules[2] distributed over 12 different agro-ecological zones in Rwanda[3].

Productivity can be measured in different ways: results in terms of labour productivity are essentially different from efficiency in terms of land productivity. Considering labour productivity, Byiringiro and Reardon found that the market wage was higher than the marginal value product of labour on smaller farms. They conclude that "this implies a 'bottling up' of labor on smaller farms, and constraints to access to labor market opportunities, and perhaps barriers to entry into small business" (Byiringiro and Reardon, 1996: 135). In this chapter however, we focus on land productivity, given that this is the scarce factor for Rwandan peasant households.

Still, there are different ways to measure output per hectare. Productivity per unit of land may be expressed in yield (ton per hectare); however, this measure makes it difficult to compare productivity for different crops / combinations of crops. Productivity of land may also be expressed in monetary (in frw – Rwandan francs) or in caloric value.[4] The correlation between the two seems logical but it is not obvious. Peasants may, for example, choose to produce cash crops such as coffee or tea. The cultivation and sale of these crops may have a considerable impact upon the monetary value of overall production, but the output's caloric value is very low. On the other hand, food crops such as sweet potatoes may have a low market value but can be an important component of the food diet because of their high caloric value.

Graph 3 illustrates the relationship between farm size and output per land unit. The raw data shows that there is a large variance in the productivity rates of the land-poorest households. Nonetheless, the inverse trend in the relationship is clear, regardless of which productivity measure is used.

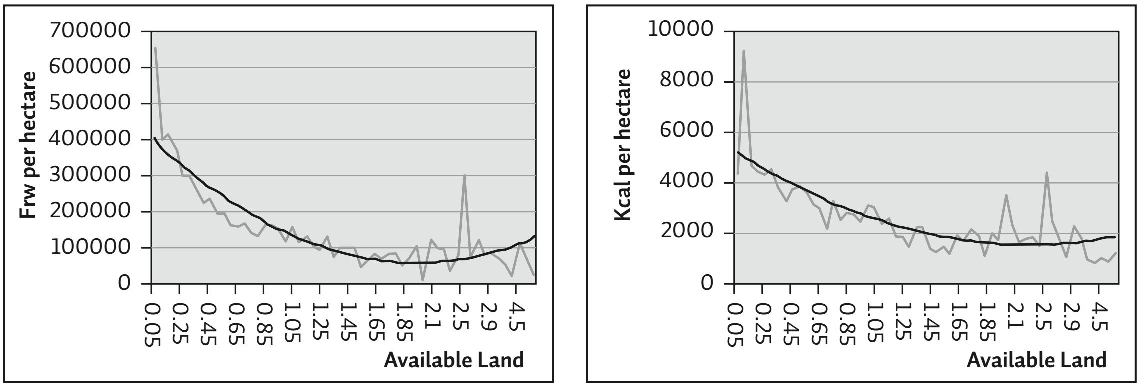
[1] The Food Security Research Project is a joint initiative of Michigan State University, the Rwandan Ministry of Agriculture and USAID. The FSRP sample is a sub-sample of the nationally representative Household Living Conditions Survey (EICV) that was undertaken by the Rwandan government (2001). In general, the FSRP sample retained the same households as included in the EICV sample, and replaced those non-available with households from the EICV's reserve list. The FSRP panel survey focused on land use and agricultural production for 6 seasons between 2000 and 2002. Compared to the EICV data regarding land and livestock ownership, the FSRP data is more reliable for variables; given the effort put into correct data measurement and follow-up. However, the data on the monetary value of agricultural production per household is only available in the EICV dataset. We combine the EICV dataset with the 2001 FSRP dataset in order to have compatible data.

[2] Rwandan households are typically scattered over the hills. Before the administrative reforms of 2005, the cellule was the administrative division that corresponded with one or a few hills.

[3] The EICV dataset was gathered data between July 2000 and June 2001. The FSRP data was gathered during 3 years (between 2000 and 2002), each time for both season A (September – January) and season B (March – August). This means that the FRSP 2001 data cover both season A (September 2000 – January 2001) and season B (March 2001 – August 2001), a period that is more or less compatible with the collection period of the EICV dataset.

[4] In this paper, calculations for added value of production per hectare are based on the combined EICV-FSRP dataset (2001). Calculations for caloric value of production per hectare are based on FSRP (2001) and FAO (2007) datasets.

Graph 3: Farm size – productivity relationship



Source: Calculations for median added value of production per hectare are based on the combined EICV-FSRP dataset (2001). Calculations for median caloric value of production per hectare are based on FSRP (2001) and FAO (2007) datasets.

4.1 OLS (Ordinary Least Squares) models

The farm size-productivity relationship may also be studied using regression analysis. Typically (see Bhalla and Roy 1988; Carter, 1984 and Deolalikar, 1981), the relationship is represented by the model:

$$\ln Y = \beta_0 + \beta_1 \ln H + e$$

where Y is the output per hectare and H represents the farm size in hectares. The log transformation highly improves the variation in productivity that is explained by the model (R^2). It allows one to interpret the coefficient as an elasticity, representing the percentage change in the dependent variable when the independent variable increases by one percent. A significant negative β_1 coefficient would indicate a negative elasticity between farm size and productivity, which would provide support for the inverse relationship. Table 2 indicates a strong negative correlation between farm size and productivity – regardless of which productivity measure is used.

Table 2: Farm size – productivity relationship: OLS regression with one explanatory variable[1]

OLS Regression 1 (N=1312) (productivity as independent variable measured in monetary value)			**OLS Regression 2 (N=1357) (productivity as independent variable measured in caloric value)**		
β_0	β_1	R^2	β_0	β_1	R^2
0,011 (0,002) ***	-0,539 (0,002) ***	0,190	0,001 (0,001)	-0,407 (0,001) ***	0,180

Unstandardised coefficients. Figures in parentheses are estimated standard errors
**** significant at the 0.001 level.*

Bhalla and Roy (1988) have adapted the original model by adding several coefficients accounting for soil quality (i.e. land type, land colour and land depth). Indeed, farm size may be correlated with soil quality. Ellis (1990) mentions that large farms may have less fertile land than

[1] The sample sizes are different for both regressions, and made compatible to the sample sizes of the analyses presented further in the paper. The variables are centred with respect to their means. This is also done in subsequent analyses (the rationale for this is explained later).

small farms and provides two possible explanations. First, the more fertile regions with a higher soil quality tend to have a higher population density and more fragmentation. Another thesis is that small-scale peasants are obliged to fully exploit the productive potential of all their land, while larger farmers only concentrate on their best land which brings down their 'average' productivity (taking into account their entire property). Therefore, the observed inverse relationship may result from a correlation between farm size and soil quality. Bhalla and Roy (1988), and Lamb (2003) both found for the Indian case that indeed, part of the inverse relationship can be accounted for by the soil quality factor.

To account for this factor in the analysis, we include a soil quality index, developed at the Laboratory of Soil Science, Ghent University, for the 125 selected cellules included in the EICV-FSRP datasets, based on the soil profile database and soil map of Rwanda at a scale of 1:50.000 (Imerzoukene and Van Ranst 2001). This soil quality[1] index was calculated by multiplying the scores (values between 0 and 100) attributed to five soil characteristics: soil texture (A), soil depth (B), topsoil sum of basic cations (C), pH (D), and organic carbon content (E). As such, it evaluates the physical and chemical soil fertility and gives an expression of the soil quality for crop production[2]. In our analysis, we consider the weighted average index for the dominant soil series at the cellule level. A formal definition of the soil quality index is given by[3]:

$$Index = \frac{A}{100} \times \frac{B}{100} \times \frac{C}{100} \times \frac{D}{100} \times \frac{E}{100}.$$

In their analysis on the inverse relationship, Bhalla and Roy (1988) further include a coefficient for land fragmentation. They identify this variable as a potentially important additional aspect of soil quality and, in any case, a variable that reveals important information. In an environment where peasants are often driven into distress sales of land, the worse land plots are assumed to get sold first. Therefore, a greater level of fragmentation is likely to be correlated with lower soil quality and would thus have a negative impact upon productivity rates. Blarel et al. (1992), however, point to the fact that in pre-war Rwanda, land fragmentation was advantageous for farmers' risk management and productivity. De Lame (2005) presents farm fragmentation as a typical characteristic of the Rwandan farming system: "Some fields, almost always including the banana grove, surround the house. Others are scattered and pieced out following divisions aimed at making sure that each heir possesses each type of field on the land inherited from the father or on purchased or given land." (De Lame, 2005, 128) We include farm fragmentation as a separate coefficient, measured by the number of plots over which the farm is divided.[4]

[1] The cellules, taking part in the socio-economic study, were indicated on hardcopy maps of the sectors within each Rwandan province. This map of studied sectors was digitised and overlaid with the soil map sheets at a scale of 1:50,000 giving information on the soil series present within each of the studied cellules. The physical and chemical properties of each of these soil series were extracted from the related soil profile database.

[2] The weighted average soil quality index has certain limitations. First, the soil profile database is based on information gathered over the eighties and early nineties while combined with the EICV - FSRP data of 2001. Over this period, it is likely that further land degradation has taken place in different degrees for different areas. This factor can not be accounted for in this analysis. Second, as the exact location of the household fields is not known, the soil quality needed to be reported at an aggregate (cellule) level. The variability in soil quality reported within each of the cellules may however be quite high. For example: the soil quality of fields located in the valleys can be higher than the soil quality of fields on steep slopes. Both elements may possibly bias the analysis.

[3] When calculating a soil quality index, one may opt for additive versus multiplicative methods. In this case we opted for a multiplicative method as, in comparison with addidive methods, it does a better job in revealing important limitations in only one or a few aspects of soil quality that may – despite good scores for all the other factors – have an important impact on overall productivity.

[4] The Pearson correlation between land fragmentation and land quality is significant and positive, but very small (0,037).

Table 3 Summary statistics

	Mean	Median	St. Dev.	Minimum	Maximum
Monetary value of production for season 2001A and 2001B (Rwf)	272.804	172.836	389.131	0	9.061.270
Caloric value of production for season 2001A and 2001B (Kcal per year)	4.327	3.098	4.731	70	79.197
Farm size (hectares)	0,82	0,57	0,86	0,02	8,46
Farm fragmentation (average number of blocs considering season 2001A and 2001B)	3,15	3,00	1,97	1,00	15,00
Crop diversification (sum of number of crops in season 2001A and 2001B)	12,40	12,00	4,27	3,00	28,00
Multicropping (percentage of cultivated land surface covered with multicropping technique)	53,47	53,12	25,27	0,00	100,00
Adult equivalent (number of adult equivalents in the household)	4,52	4,23	2,02	0,70	13,95
Soil quality (calculation explained above)	0,36	0,35	0,11	0,13	0,80
Population density (people per km²)	386,06	357,00	206,63	26,00	1.486,00
Distance to market (km)	4,18	3,00	4,53	0,00	32,00

Note: The calculation of summary statistics is based upon the sample size of 1357 households for all variables measured at the household level. The calculation of summary statistics for cellule-level variables is based upon the sample of 125 cellules.

Further, we consider two variables that are of specific importance to the Rwandan case with regards to farmers' risk management. First, we consider the number of crops cultivated on the farm (sum of number of crops in season A – September to February - and season B – March to August). Agricultural policies often encourage crop specialisation to realise economies of scale and to orient the agricultural sector more towards the cash market. However, the rationale for concentrating on one market crop may be irrelevant for subsistence farmers and/or for farmers with limited bargaining power in the local markets. Moreover, diversification of crop types may be an effective method for subsistence farmers to spread and thus reduce risk (i.e. weather risks, crop disease, etc.) when land is very scarce. In the same way, farmers may choose to cultivate different crops on the same piece of land. This technique (i.e. 'multicropping') is frequently used in Rwanda, and may also be useful –aside from its risk-mitigating character – in increasing agricultural output when the combined crops are complementary. We incorporate this into the regression analysis by adding a variable that accounts for the share of farm size used for multicropping (taking into account land use in seasons A and B).

We further add two variables that are related to population size, both on the farm and in the larger environment. One variable accounts for the population density in the district in which the household is located. It seems logical that households in more densely populated areas are bound to use their available land more intensively, which would have an automatic effect upon their productivity. This effect may also occur on a more disaggregate level. Households with a lot of household members may be obliged to intensify their agricultural activities on their available land. We therefore include a variable that measures the number of adult 'equivalents' present in the household. Finally, we include a variable that accounts for the distance from the cellule to the nearest market. This aspect could be important as an incentive/disincentive for households to produce a marketable surplus.

Including these variables complicates our regression model, but provides a solution as to whether the inverse relationship between farm size and land productivity holds after taking account of farm fragmentation, crop diversification, share of the farm size used for multicropping, household size and regional population density, variations in soil quality, and the distance to the nearest market. The new regression model can be specified as follows:

$$\ln Y = \beta_0 + \beta_1' \ln H + \beta_2 F + \beta_3 C + \beta_4 M + \beta_5 A + \beta_6 \ln H * A$$
$$+ \beta_7 L + \beta_8 P + \beta_9 D + \beta_{10} \ln H * L + \beta_{11} \ln H * P + \beta_{12} \ln H * D + \beta_{13} F * L + e \quad (1)$$

where Y is the output per hectare, H represents the area of the cultivated land (farm size), F represents the number of plots over which the total cultivated land is fragmented (farm fragmentation), C stands for the number of crops cultivated on the farm (sum of season A and B), M stands for the share of the farm size used for multicropping (based on land use in season A and B), and A stands for the adult equivalents present in the household. These variables are all measured at the household level. We further include three contextual variables. The variable L represents the soil quality index at cellule level. The variable P represents the population density (per square kilometre) of the district in which the household is located. Finally, D stands for the distance (in time) from the cellule to the nearest market. These variables are all measured at the aggregated level of the cellule in which the farmer's household resides. An OLS analysis, however, treats these variables as if they were household-level characteristics. We further include several interaction terms. The interaction terms lnH*A, lnH*L, lnH*P and lnH*D account for the possible variations in the relationship between farm size and productivity dependent upon household size, soil quality, population density, and distance to the market. The interaction term F*L accounts for the possible variation in the relationship between farm fragmentation and productivity; dependent upon soil quality. These interaction terms seem justified based upon the literature cited above. All variables are centred with respect to their means to minimize the risk of multicollinearity (see Bickel 2007:195).[1] The rationale for the log transformation of farm size remains the same as for the bivariate model. For the other variables, transformations are avoided as they would have little impact upon R^2. The coefficients of those variables represent the percentage change in productivity when the independent variable increases with one unit (e.g. one extra plot of land, one extra crop, one extra percentage of land cultivated with multicropping, etc.).

The extended model (see Table 4, model 1) also confirms a strong inverse relationship between farm size and productivity when other variables are considered. A one percent increase in farm size relates to a 0,6% decrease in productivity in monetary value, and a 0,5% decrease in productivity in caloric terms. Also, the coefficient of fragmentation is significant. The positive sign of the coefficient confirms Blarel et al.'s thesis that, in the current context, farm fragmentation has a positive impact upon productivity. Further, the crop diversification and the multicropping variables are both significant and positive for productivity, regardless of which output measure is used. The significance of all three variables – farm fragmentation, crop diversification, and the

[1] Bickel (2007) pleads for the grand-mean centring of all variables in order to avoid that correlations between random intercepts and random slopes insert a bias in the random regression coefficient estimates. Calculation of the grand-mean is based upon all cases included in the EICV– FSRP 2001 dataset. In the regression, some of these cases are not incorporated due to missing data for one of the variables.

incidence of multicropping - indicates that in the current context farmers' risk management techniques seem to pay off in terms of productivity, although their effects are small. The family size (adult equivalent) variable is positive and significant, whereas the farm size/family size interaction term is negative and significant. This indicates that an increase in adult equivalents reinforces the inverse relationship between farm size and productivity. Soil quality seems to have a strong and significant positive impact upon productivity rates. The significant (positive) farm size/soil quality interaction term indicates that the inverse relationship between farm size and productivity is mitigated when soil quality improves. The negative farm fragmentation/soil quality interaction term implies that the productivity gains associated with more farm fragmentation diminish as cellules have higher soil quality. The interpretation of the other contextual and interaction terms is somewhat less straightforward as their impact upon productivity is very small.

This OLS model combines data from two different levels: data at the household level (i.e. productivity, farm size, farm fragmentation, crop diversification, frequency of multicropping, and household size measured in adult equivalent) and at the cellule level (i.e. soil quality, population density and distance from nearest market). By disaggregating the cellule-level data to the household level, we introduce the methodological problem of 'the miraculous multiplication of the number of units': the effective degrees of freedom for the hypothesis tests is smaller than the number of households.

To avoid this, one may choose to perform the analysis at the aggregated level; in this case, the cellule level. We use the cellule medians[1] for the variables measured at the household-level (indicated by C in the subscript). The aggregated regression model is defined as:

$$\ln Y_C = \beta 0 + \beta 1'\ln HC + \beta 2FC + \beta 3CC + \beta 4MC + \beta 5AC + \beta 6\ln HC * AC + \beta_7 L + \beta_8 P + \beta_9 D + \beta_{10}\ln H_C * L + \beta_{11}\ln H_C * P + \beta_{12}\ln H_C * D + \beta_{13} F_C * L + e \quad (2)$$

Also this regression model (see table 4, model 2) provides support for a strong inverse relationship between farm size and land productivity for the Rwandan case. The results of the aggregate regression are entirely comparable with the first model, except for the change in the sign of the farm size/family size interaction term.

Another way to preclude the problem of combining data from different levels is by excluding all higher-level variables from the analysis. The model then becomes:

$$\ln Y = \beta_0 + \beta_1{}'\ln H + \beta_2 F + \beta_3 C + \beta_4 M + \beta_5 A + \beta_6 \ln H * A + e \quad (3)$$

We see that, in fact, with this "slimmed" regression (see table 4, model 3) the unstandardised coefficients and the standard errors of the variables change very little in comparison to model 1. This seems to indicate that the inclusion or exclusion of the contextual variables in the regression model has very little impact upon the interpretation of the variables measured at household level.

Bhalla and Roy (1988) have further disaggregated their analysis to investigate whether the inverse relationship held for more homogeneous environments within India. They consider

[1] The sample is not representative at the cellule level. Given the limited number of cases per cellule, we prefer to use cellule medians instead of cellule means to avoid that outliers profoundly distort the analysis.

particular administrative regions (up to the district level) next to agro-ecological regions. The Rwandan EICV-FSRP database only allows us to disaggregate based on administrative criteria as our data are representative only up to the provincial level. Model 3 can, therefore, be estimated at the provincial level. The regression estimates (see Table 5) show that in all provinces, the inverse relationship firmly holds. It is strongest for those regressions with higher R squares. The coefficient of farm fragmentation is positive and significant in all provinces and for both productivity measures, which again confirms Blarel et al.'s conjecture in every Rwandan province. The impact of crop diversification upon productivity is less consistent when comparing different provinces. The coefficient is significant in most cases; however, the sign of the coefficient differs depending upon location and the productivity measure used. The multicropping variable is significant in most cases and clearly has a positive though rather limited impact upon productivity rates. Family size has a significant positive impact upon productivity. The sign of the farm size/family size interaction term is less consistent across provinces. Overall, the results at the disaggregated administrative level, to a large extent, correspond overall with the national trend.

Table 4: Farm size – productivity relationship – Various regressions

Productivity as independent variable Measured in monetary value[1]					
Variable	**Simulating multilevel analysis with OLS**	**OLS at aggregated cellule level**	**OLS [2]**	**Multilevel regression with 2 levels**	**Random coefficient regression with 2 levels**
	(1)	(2)	(3)	(4)	(5)
	N=1312	N=125	N=1312	N1=1312 N2=125	N1=1312 N2=125
Intercept	0,014 (0,002) ***	0,087 (0,003) ***	0,016 (0,002) ***	0,051 (0,051)	0,056 (0,051)
LnH (farm size)	-0,624 (0,003) ***	-0,443 (0,008) ***	-0,633 (0,002) ***	-0,625 (0,047) ***	-0,613 (0,047) ***
F (farm fragmentation)	0,070 (0,001) ***	0,052 (0,003) ***	0,072 (0,001) ***	0,108 (0,024) ***	0,108 (0,023) ***
C (crop diversification)	0,009 (0,000) ***	0,007 (0,001) ***	0,008 (0,000) ***	0,000 (0,001)	0,000 (0,000)
M (multicropping)	0,004 (0,000) ***	0,002 (0,000) ***	0,004 (0,000) ***	0,004 (0,000) ***	0,004 (0,000) ***
A (adult equivalent)	0,098 (0,001) ***	0,042 (0,003) ***	0,100 (0,001) ***	0,093 (0,001) ***	0,093 (0,001) ***
LnH*A	-0,016 (0,001) ***	0,113 (0,006) ***	-0,015 (0,001) ***	-0,036 (0,001) ***	-0,036 (0,001) ***
L (soil quality)	0,269 (0,015) ***	0,285 (0,025) ***	-	0,615 (0,444)	-
P (population density)	0,000 (0,000) ***	0,000 (0,000) ***	-	-0,000 (0,000)	-
D distance to market)	-0,009 (0,000) ***	-0,011 (0,001) ***	-	-0,019 (0,011)	-
lnH*L	0,105 (0,018) ***	0,252 (0,055) ***	-	-0,284 (0,416)	-
F*L	-0,148 (0,008) ***	-0,118 (0,022) ***	-	-0,015 (0,206)	-
LnH*P	0,000 (0,000) ***	0,000 (0,000) ***	-	-0,000 (0,000)	-
LnH*D	0,005 (0,000) ***	0,014 (0,002) ***	-	0,001 (0,009)	-
R^2 / $R1^2$	0,252	0,262	0,248	0,222	0,222

[1] The sample sizes are different for both regressions. Here, the productivity variable is based on data in the EICV survey, while the other variables at the household level are based on the FSRP sample. The sample size represents the overlap between both samples.

[2] White's test indicates that there is a heteroscedasticity problem with these data (heteroscedasticity is accepted with α=0,01). This may result in the underestimation of standard errors. After using White's algorithm that corrects OLS standard errors in the presence of heteroscedasticity (Pryce, 2002), we find that the variables' coefficients with the White procedure are comparable to those of the ordinary OLS regression. The coefficients of variables C and LnH*A become insignificant.

Unstandardised coefficients, figures in parenthesis are estimated standard errors,
** significant at 0.05 leve, ** significant at 0.01 level, *** significant at 0.001 level.*

Productivity as independent variable Measured in caloric value[1]					
Variable	Simulating multi-level analysis with OLS	OLS at aggregated cellule level	OLS[2]	Multilevel regression with 2 levels	Random coefficient regression with 2 levels
	(1)	(2)	(3)	(4)	(5)
	N=1357	N=125	N=1357	N1=1357 N2=125	N1=1357 N2=125
Intercept	0,007 (0,001) ***	0,026 (0,003) ***	0,005 (0,001) ***	0,076 (0,045)	0,078 (0,045)
LnH (farm size)	-0,518 (0,002) ***	-0,383 (0,007) ***	-0,512 (0,002) ***	-0,523 (0,034) ***	-0,521 (0,034) ***
F (farm fragmentation)	0,068 (0,001) ***	-0,047 (0,002) ***	0,068 (0,001) ***	0,109 (0,015) ***	0,109 (0,015) ***
C (crop diversification)	0,034 (0,000) ***	0,056 (0,001) ***	0,032 (,000) ***	0,016 (0,000) ***	0,016 (0,000) ***
M (multicropping)	0,006 (0,000) ***	0,005 (0,000) ***	0,006 (0,000) ***	0,005 (0,000) ***	0,005 (0,000) ***
A (adult equivalent)	0,051 (0,001) ***	0,047 (0,003) ***	0,051 (0,001) ***	0,040 (0,001) ***	0,040 (0,001) ***
LnH*A	-0,010 (0,001) ***	0,052 (0,005) ***	-0,009 (0,001) ***	-0,017 (0,001) ***	-0,017 (0,001) ***
L (soil quality)	0,463 (0,011) ***	0,549 (0,024) ***	-	0,558 (0,396)	-
P (population density)	0,000 (0,000) ***	0,000 (0,000) ***	-	-0,000 (0,000)	-
D distance to market)	-0,003 (0,000) ***	-0,007 (0,001) ***	-	-0,010 (0,010)	-
lnH*L	0,129 (0,013) ***	0,474 (0,051) ***	-	-0,427 (0,301)	-
F*L	-0,144 (0,006) ***	-0,125 (0,020) ***	-	-0,054 (0,128)	-
LnH*P	-0,000 (0,000) ***	0,000 (0,000)	-	-0,000 (0,000)	-
LnH*D	-0,007 (0,000) ***	0,011 (0,002) ***	-	-0,006 (0,007)	-
R^2 / $R1^2$	0,292	0,251	0,285	0,295	0,287

[1] The sample sizes are different for both regressions. Here, all variables at the household level are based on the FSRP sample. The sample size represents the data for which all information included in the regression (seasons A and B) is available.

[2] White's test indicates that there may be a problem of heteroscedasticity with these data (heteroscedasticity is rejected with $\alpha \leq 0{,}01$, accepted with $\alpha > 0{,}01$). After using White's algorithm that corrects OLS standard errors in the presence of heteroscedasticity (Pryce, 2002), we find that the variables' coefficients with the White procedure are comparable to those of the ordinary OLS regression. The coefficients of the variables LnH*A becomes insignificant.

Unstandardised coefficients, figures in parenthesis are estimated standard errors,
** significant at 0.05 level, ** significant at 0.01 level, *** significant at 0.001 level.*

Table 5: Farm size – productivity relationship – Model (3) at provincial level[1]

Productivity as independent variable
Measured in monetary value

Variable	BUT	BYU	CYA	GIK	GIS	GIT	KIB	KIB	KIG	RUH	UMU
	N=128	N=127	N=113	N=130	N=119	N=133	N=115	N=135	N=114	N=83	N=115
Intercept	-0,198 (0,005) ***	-0,094 (0,008) ***	-0,248 (0,011) ***	0,043 (0,007) ***	0,207 (0,006) ***	0,389 (0,009) ***	-0,012 (0,006) *	0,079 (0,007) ***	-0,153 (0,006) ***	-0,290 (0,007) ***	0,354 (0,012) ***
LnH	-0,266 (0,008) ***	-0,631 (0,008) ***	-0,478 (0,009) ***	-0,665 (0,010) ***	-0,728 (0,006) ***	-0,731 (0,009) ***	-0,683 (0,007) ***	-0,736 (0,009) ***	-0,715 (0,008) ***	-0,811 (0,009) ***	-0,293 (0,016) ***
F	0,017 (0,003) ***	0,037 (0,002) ***	0,111 (0,008) ***	0,100 (0,003) ***	0,037 (0,002) ***	0,124 (0,005) ***	0,084 (0,002) ***	0,070 (0,004) ***	0,063 (0,003) ***	0,231 (0,003) ***	0,095 (0,008) ***
C	-0,031 (0,002) ***	0,039 (0,001) ***	-0,054 (0,003) ***	-0,023 (0,002) ***	-0,019 (0,002) ***	0,003 (0,002)	0,015 (0,001) ***	0,040 (0,002) ***	0,062 (0,001) ***	0,036 (0,002) ***	-0,027 (0,003) ***
M	0,002 (0,000) ***	0,004 (0,000) ***	0,003 (0,000) ***	0,001 (0,000) *	0,001 (0,000) ***	0,002 (0,000) ***	0,013 (0,000) ***	-0,002 (0,000) ***	0,008 (0,000) ***	0,010 (0,000) ***	0,007 (0,000) ***
A	0,109 (0,003) ***	0,101 (0,002) ***	0,150 (0,003) ***	0,082 (0,003) ***	0,106 (0,002) ***	0,116 (0,003) ***	0,016 (0,002) ***	0,108 (0,003) ***	0,064 (0,003) ***	0,001 (0,003)	0,232 (0,005) ***
LnH*A	-0,016 (0,003) ***	-0,068 (0,003) ***	0,083 (0,003) ***	-0,014 (0,003) ***	-0,044 (0,002) ***	-0,043 (0,003) ***	-0,014 (0,002) ***	-0,034 (0,003) ***	0,054 (0,003) ***	-0,017 (0,003) ***	-0,070 (0,006) ***
R²	0,141	0,174	0,299	0,360	0,377	0,250	0,394	0,248	0,255	0,342	0,170

Productivity as independent variable
Measured in caloric value

Variable	BUT	BYU	CYA	GIK	GIS	GIT	KIB	KIB	KIG	RUH	UMU
	N=135	N=132	N=119	N=134	N=123	N=137	N=117	N=136	N=116	N=87	N=121
Intercept	-0,127 (0,003) ***	0,306 (0,005) ***	0,124 (0,008) ***	0,024 (0,006) ***	-0,210 (0,006) ***	0,261 (0,005) ***	0,035 (0,005) ***	0,104 (0,004) ***	-0,305 (0,005) ***	-0,448 (0,005) ***	0,492 (0,007) ***
LnH	-0,335 (0,005) ***	-0,543 (0,006) ***	-0,512 (0,007) ***	-0,521 (0,008) ***	-0,226 (0,006) ***	-0,528 (0,005) ***	-0,403 (0,006) ***	-0,661 (0,005) ***	-0,527 (0,007) ***	-0,446 (0,006) ***	-0,403 (0,009) ***
F	0,128 (0,002) ***	0,051 (0,001) ***	0,160 (0,006) ***	0,088 (0,002) ***	0,067 (0,002) ***	0,159 (0,003) ***	0,065 (0,002) ***	0,055 (0,003) ***	0,095 (0,003) ***	0,146 (0,002) ***	0,098 (0,005) ***
C	-0,016 (0,001) ***	0,031 (0,001) ***	-0,037 (0,002) ***	0,008 (0,002) ***	-0,046 (0,002) ***	0,027 (0,001) ***	0,050 (0,001) ***	0,018 (0,001) ***	0,037 (0,001) ***	-0,029 (0,001) ***	0,018 (0,002) ***
M	0,002 (0,000) ***	0,004 (0,000) ***	0,001 (0,000) ***	0,007 (0,000) ***	0,001 (0,000) ***	0,007 (0,000) ***	0,009 (0,000) ***	0,004 (0,000) ***	0,003 (0,000) ***	0,006 (0,000) ***	0,009 (0,000) ***
A	0,087 (0,002) ***	0,030 (0,002) ***	0,032 (0,002) ***	0,069 (0,003) ***	0,014 (0,002) ***	0,046 (0,002) ***	0,022 (0,002) ***	0,051 (0,002) ***	0,059 (0,002) ***	0,052 (0,002) ***	0,080 (0,003) ***
LnH*A	-0,034 (0,002) ***	0,012 (0,002) ***	0,016 (0,002) ***	-0,035 (0,003) ***	-0,041 (0,003) ***	0,049 (0,001) ***	0,014 (0,002) ***	-0,007 (0,002) ***	-0,035 (0,002) ***	-0,030 (0,002) ***	-0,096 (0,003) ***
R²	0,283	0,240	0,368	0,349	0,084	0,427	0,264	0,516	0,157	0,325	0,360

[1] The sample sizes are different for both regressions. For the first regression, the productivity variable is based on data in the EICV survey, while the other variables at the household level are based on the FSRP sample. The sample size represents the overlap between both samples. For the second regression, all variables at the household level are based on the FSRP sample. The sample size represents the data for which all information included in the regression is available.

3.2. Random coefficient and multilevel analysis

We already raised the problem of combining data from different levels; but in addition, lower-level independent variables measured at the household level – in their relation to the dependent variable - may be influenced by contextual factors that are specific to the cellule/ province/agricultural region in which the households are nested. Applying OLS to nested data results in deflated standard errors. This entails the risk of erroneously rejecting the null hypothesis (Type I error of finding statistical significance, when in fact there is none). Random coefficient or multilevel regression analyses - with REML[1] estimators as substitutes for OLS estimators - are then the appropriate tools with which to analyze these data.

Random coefficient regression allows addressing the joint problems of dependent observations and (within-group) correlated residuals due to nesting of observations. This technique permits the intercepts and slopes of coefficients of the lower level explanatory variables to vary across groups (data grouped in cellules/provinces). All random regression coefficients have a ***fixed component***, this is the summary average of a population intercept and slopes that vary from one cellule to another); in most empirical applications, their estimates differ little from the OLS estimates. However, the standard errors for random coefficient regressions are typically larger than the deflated values reported in the OLS regression, which reduces the risk of committing type I errors (i.e. finding false significances). The ***random components*** measure the extent to which the random intercept and slopes vary across cellules. The model also allows the estimation of the covariances between intercepts and slopes. These determine whether the random components vary together or not.[2] The random coefficient analysis may be transformed into a multilevel analysis by including contextual variables from a higher level (i.e. soil quality, population density, and distance to the market measured at the cellule level) to see whether they account for the variability in the random intercept of lower level variables, and by including cross-level interaction terms as additional explanatory variables to see whether they explain variability in the random slopes (Bickel, 2007).

For the purpose of this paper, a random coefficient regression model with two levels (households and cellules) seems most appropriate; given that the inclusion of a third level (either agricultural zone or administrative province) would lead to a problematic reduction of the effective sample size (there are only 12 agricultural zones and 11 provinces in which lower-level data are nested). In addition, contextual factors related to the cellule level are more relevant than those at a more aggregated level for our type of agriculture-related analysis.

When defining a random coefficient or multilevel model, the first question to answer is whether there are coefficients that should be permitted to vary across higher-level groups. To formulate an answer, we calculate the unconditional intra-class correlation coefficient[3] (ICC,

[1] REML stands for REstricted Maximum Likelihood. In contrast to the Maximum Likelihood procedure, this REML procedure takes into account the number of parameters to estimate the model, which is important in the case of smaller samples.

[2] With the "variance components" default option of SPSS for the covariance structure, the variances of the random coefficients are allowed to vary, but the model specifies that they do not vary together. As a result, the estimates of covariance parameters will not include any covariances. When choosing the "unstructured" option instead, no constraints upon relationships among random components are imposed: random intercepts and slopes may vary together. The option, however, requires more parameters to estimate, which decreases the degrees of freedom (Bickel 2007).

[3] The intra-class correlation coefficient is calculated by dividing between-group variability by the sum of between-group variabilities and within group variabilities. 'Unconditional' means that there are no explanatory variables in the equation when calculating this coefficient.

with no explanatory variables in the equation). For productivity in terms of monetary value, the ICC amounts to 0,246 whereas it equals 0,356 for productivity in terms of caloric value. This implies that, respectively, 24,6% and 35,6% of the variability in the productivity variable occurs between cellules, while 75,4% and 64,4% occurs within cellules. This nested-engendered intra-class correlation seems to be sufficiently large to justify random coefficients in the regression analysis.

The second question is which independent variables should be assigned fixed slopes and which have to be treated as random coefficients. Bickel (2007) points to the importance of substantive theoretical knowledge when making this decision. He highlights that the inclusion of too many random coefficients may make the model too complex and difficult to interpret. As we described above, there is extensive empirical evidence in the literature of the diversified experience of different regions with the farm size/productivity question. Therefore, we opt for specifying the effect of farm size as random. Additionally, the effect of farm fragmentation will be treated as random, as it may vary from region to region dependent upon soil quality (see Bhalla and Roy 1988).

The final question to answer is which contextual variables may account for the variation in the random intercept and slope of the random farm size and farm fragmentation coefficients. In this analysis, we opt to include three contextual variables that may be relevant for the farm size/productivity relationship, the same three variables as included in the OLS regression presented above: soil quality, population density and distance to the market.

For the purpose of this analysis, all variables have been grand-mean centered. This reduces the risk of problematic correlations between random components;**[1]** and it facilitates the interpretation of the intercept as the estimated value of the dependent variable when all independent variables are equal to their means (Bickel, 2007).

The estimated level-one model is given by:

$$\ln Y_{IJ} = \beta_{0J} + \beta_{1J}{}' \ln H + \beta_{2J} F + \beta_3 C + \beta_4 M + \beta_5 A + \beta_6 \ln H * A + e_{IJ}$$

where Y_{IJ} is productivity of household I in cellule J, β_{0J} is the intercept for cellule J with a fixed and random component; β_{1J} and β_{2J} are the random slopes of the explanatory variables accounting for land size (H) and farm fragmentation (F) - again with a fixed and a random component; and β_3, β_4, β_5 and β_6 are the fixed slopes of explanatory variables accounting for crop diversification (C), multicropping (M), familiy size (A) and the interaction term land size/family size interaction term.

The level-two models for the intercept and the slopes of the variables H and F are:

$$\beta_{0J} = \gamma_{00} + \gamma_{01} L + \gamma_{02} P + \gamma_{03} D + u_{0J}$$
$$\beta_{1J} = \gamma_{10} + \gamma_{11} L + \gamma_{12} P + \gamma_{13} D + u_{1J}$$
$$\beta_{2J} = \gamma_{20} + \gamma_{21} L + u_{2J}$$

where the random intercept (β_{0J}) and random slope of variable H (β_{1J}) are expressed as functions of three contextual level-two variables L, P and D. The random slope of the farm frag-

[1] "Covariances among random slopes and between random slopes and random intercepts have consequences that are comparable to multicollinearity. When relationships among these various factors are strong, they interfere with efficient estimation of random regression coefficients. Grand-mean centering of all independent variables is a useful corrective." (Bickel 2007: 137)

mentation variable (β_{2J}) is only expressed as a function of the contextual variable accounting for soil quality.

The complete multilevel model can be specified as follows:

$$\ln Y_{1J} = \gamma_{00} + \gamma_{10}'\ln H + \gamma_{20}F + \beta_3 C + \beta_4 M + \beta_5 A + \beta_6 \ln H * A + \gamma_{01}L + \gamma_{02}P + \gamma_{03}D + \gamma_{11}L * \ln H + \gamma_{21}L * F + \gamma_{12}P * \ln H + \gamma_{13}D * \ln H + (u_{0J} + u_{1J}\ln H + u_{2J}F + e_{1J}) \quad (4)$$

The full model combines the level-one and level-two models. γ_{00} is the common intercept across cellules; and γ_{01}, γ_{02}, and γ_{03}, are the effects of the cellule-level variables L, P and D on cellule-specific intercepts. γ_{10} and γ_{20} are the common slopes with household-level variables H and F across cellules; γ_{11}, γ_{12}, and γ_{13} are the effects of the group-level variables L, P, and D on the cellule-specific slope of H; and γ_{21} finally is the effect of the group-level variable L on the cellule-specific slope of F. β_3, β_4, β_5, and β_6 have been defined above.

Considering the estimated model (see Table 4, model 4), we find that the coefficients of the contextual variables and cross-level interaction terms are all insignificant. This suggests that the inclusion of contextual variables and cross-level interaction terms adds little to the explanatory power of the overall model. Indeed, the conditional intra-class correlation[1] (24.4% for productivity in monetary value, 38.8% for productivity in caloric value) is nearly the same or even higher than the unconditional intra-class coefficient calculated above. This indicates that the contextual factors and cross-level interaction terms do not explain the differences in intercept and slopes for the different cellules in the study.

Therefore, as an alternative to this complex multilevel model, we might as well consider the simpler random coefficient model. Such a model still allows coefficients to vary across groups (cellules), but does not try to explain this variability using contextual variables and cross-level interaction terms. The simplified model is:

Level-one model

$$\ln Y_{1J} = \beta_{0J} + \beta_{1J}'\ln H + \beta_{2J}F + \beta_3 C + \beta_4 M + \beta_5 A + \beta_6 \ln H * A + e_{1J}$$

Level-two model

$$\beta_{0J} = \gamma_{00} + u_{0J}$$
$$\beta_{1J} = \gamma_{10} + u_{1J}$$
$$\beta_{2J} = \gamma_{20} + u_{2J}$$

Random coefficient model

$$\ln Y = \gamma_{00} + \gamma_{10}'\ln H + \gamma_{20}F + \beta_3 C + \beta_4 M + \beta_5 \ln A + (u_{0J} + u_{1J}\ln H + u_{2J}F + e_{1J}) \quad (5)$$

[1] The conditional intra-class correlation coefficient is calculated in the same way as the unconditional coefficient, except for the fact that the contextual variables and cross-level interactions are included as explanatory variables. If the conditional intra-class correlation coefficient is considerably smaller than the unconditional coefficient, then the contextual factors explain a considerable part of the nesting-engendered intra-class correlation. This is not the case in our analysis.

Before getting to the interpretation of the model's estimation, let us compare the predictive value of model 4 and 5. This brings forward several elements in favor of model 5. Indeed, the summary measure R_1^2 - indicating the percentage with which the model reduces errors in predicting productivity when compared with the null unconditional model - is not much better for the multilevel regression (Table 4, model 4) than for the random coefficient model (Table 4, model 5). Also, when comparing the 'smaller-is-better' information criteria for both models, we find that the multilevel model does not provide a substantially better fit in comparison to the random coefficient model, on the contrary: the deviance statistic (difference in –2 log likelihood between the multilevel model and the random coefficient) is not significant[1]. All other information criteria (Akaike's, Hurvich and Tsai's, Bozdogan's and Schwarz's Bayesian criteria) that punish for using up additional degrees of freedom, and aim at reducing the number of irrelevant parameters, suggest that the simpler random coefficient model is to be preferred. Comparing the variance – covariance parameters of both models (see Table 6 and 7) leads to similar conclusions. The estimates in table 6 account for the residual variance in the random intercept and random slope of the random components after including the contextual variables, cfr. model 4. Table 7 gives the same information for model 5, which does not include contextual variables. The household-level variances and covariances – both in terms of magnitude and in terms of their significance - are barely influenced by the inclusion of the contextual variables and cross-level interaction terms as identified above.[2] The between-cellule variability is, therefore, likely to be caused by other contextual factors for which no data is available.

Let us have a closer look at the results of the random coefficient model which fits our data best (see table 4, model 5). The model tests whether the underlying assumptions of the new Rwandese agricultural and land policies are justified. Do land consolidation and land concentration, less crop diversification and less multicropping, in fact, have a positive impact upon productivity figures? Our analysis suggests that this is not the case, on the contrary.

Farm fragmentation and the frequency of multicropping have a significant positive impact upon productivity, although their coefficients are small. An additional plot adding to the number of plots over which the farm is distributed, results in a 0,1% increase in productivity (for both measures). The effect of a percentage increase in soil covered with multicropping is marginal: it raises productivity with 0,004 or 0,005% (dependent upon the productivity measure used). The relationship between productivity and crop diversification is not clear: there is a significant positive - though small - effect of crop diversification upon productivity expressed in caloric value, but not for productivity in monetary value. Increased family size is associated with significantly higher productivity, although, again, the effect is small. The farm size/family size interaction term is negative and significant. For the random components (see Table 7), we see that the variances are significant which signifies that intercept and slopes of farm size and farm fragmentation do vary

[1] To compare information criteria, the model has to be estimated with maximum likelihood ML instead of restricted maximum likelihood REML (Bickel, 2007: 94, 257). The –2 log likelihood of the multilevel model with 21 parameters (1 for the intercept, 13 for each of the slopes, and 7 for each of the random terms) is 798,428.1 for productivity in monetary value, and 565,474.2 for productivity in caloric value. The –2 log likelihood of the random coefficient model with 14 parameters (1 for the intercept, 6 for each of the slopes and 7 for each of the random terms) is 798,439.5 for productivity in monetary value, and 565,481.7 for productivity in caloric value. The deviance differences are equal to 11.4 and 7.5 respectively. They do not surpass the critical value of ?² (equal to 14.067 with alpha .05 and with 7 degrees of freedom - the difference in the number of parameters used). This means that the multilevel model does not provide a better fit.

[2] If the contextual variables and cross-level interaction terms would account for part of the cellule-to-cellule variability, then the variances and covariances should become smaller, preferably reaching a level that is no longer statistically significant. This is not the case in this analysis.

across cellules. Looking at the covariances, we find that the farm size/farm fragmentation covariance is significantly different from zero although small - implying that the slopes of those variables are somewhat correlated.

The most important finding of this random coefficient model, however, is that the strong inverse relationship between farm size and productivity holds. Whereas coefficients for all other variables are small, the effect of farm size upon productivity is not only significant and negative, but also quite considerable: if farm size doubles, then productivity in monetary terms decreases with 60%, and productivity in caloric terms contracts with 50%. The fact that this inverse farm size- productivity relationship stands out in each model that we calculated, points to its consistency.

Table 6: Estimates of covariance parameters for model (4)

Productivity as independent variable measured in monetary value				
Parameter	**Estimate**	**St. Error**	**Wald Z**	**Sign.**
Residual	,548	,001	421,555	,000
Random intercept variance	,314	,041	7,720	,000
Covariance between intercept and slope of H	,003	,027	,099	,921
Random slope variance of H	,276	,036	7,744	,000
Covariance between intercept and slope of F	,015	,013	1,134	,257
Covariance between slope of H and slope of F	-,061	,014	-4,475	,000
Random slope variance of F	.069	.009	7.769	.000

Productivity as independent variable measured in caloric value				
Parameter	**Estimate**	**St. Error**	**Wald Z**	**Sign.**
Residual	,270	,001	429,154	,000
Random intercept variance	,250	,032	7,764	,000
Covariance between intercept and slope of H	,015	,017	,878	,380
Random slope variance of H	,144	,019	7,734	,000
Covariance between intercept and slope of F	-,001	,007	-,188	,851
Covariance between slope of H and slope of F	-,014	,006	-2,471	,013
Random slope variance of F	,027	,003	7,774	,000

Table 7: Estimates of covariance parameters for model (5)

Productivity as independent variable measured in monetary value				
Parameter	**Estimate**	**St. Error**	**Wald Z**	**Sign.**
Residual	,549	,001	421,555	,000
Random intercept variance	,325	,042	7,812	,000
Covariance between intercept and slope of H	,003	,027	,122	,903
Random slope variance of H	,279	,036	7,822	,000
Covariance between intercept and slope of F	,016	,014	1,195	,232
Covariance between slope of H and slope of F	-,061	,014	-4,496	,000
Random slope variance of F	,068	,009	7,800	,000

Productivity as independent variable measured in caloric value				
Parameter	**Estimate**	**St. Error**	**Wald Z**	**Sign.**
Residual	,270	,001	429,154	,000
Random intercept variance	,252	,032	7,859	,000
Covariance between intercept and slope of H	,014	,017	,830	,407
Random slope variance of H	,145	,018	7,832	,000
Covariance between intercept and slope of F	-,003	,007	-,416	,677
Covariance between slope of H and slope of F	-,015	,006	-2,531	,011
Random slope variance of F	,026	,003	7,805	,000

5. Conclusion: Policy Discussions

This paper has proven a strong inverse size-productivity relationship for the rural context of post-1994 Rwanda. Interestingly, this relationship is not unknown to Rwandan policy makers. Indeed, it is even recognised in the Strategic Plan for Agricultural Transformation, "… small production units perform better per land unit than larger ones" (GoR 2004A:10). In addition, this paper found that other risk-coping mechanisms of small-scale farmers, such as farm fragmentation, and multicropping, seem to pay off in terms of productivity.

However, as mentioned earlier in this paper, one should avoid to interpret the higher productivity of small-scale farmers as a mere reflection of higher efficiency. It is likely that extreme land scarcity compels small-scale farmers to overexploit their lands in the absence of other income generating opportunities. In addition, land and labour market imperfections, next to the risk of food price fluctuations, may provide valid explanations for the inverse relationship. The findings of this paper should not, therefore, lead to the immediate rejection of consolidation, specialisation and monocropping-promotion to achieve increased productivity.

On the other hand, Rwandan policy makers assume too easily that the inverse relationship will reverse itself when larger farmers would begin to exploit the land to its full potential. Then, it is hoped, land consolidation and the promotion of larger-scale oriented techniques will lead to a very significant productivity gain. But as mentioned in the literature review earlier in this paper, this has not always been the case in other contexts.

In-depth information on the rationale of small-scale peasants to invest so heavily in cultivating their own plots is necessary. And in addition, the rationale of larger farmers and large-scale agricultural entrepreneurs should also thoroughly be looked at. At this point, the question as to what would happen to the inverse relationship under the agricultural transformation policies elaborated by Rwandan policy makers, remains unanswered. At the least, its very existence at this point profoundly calls into question the underlying assumptions on which the currently promoted agrarian reforms are based (land consolidation, regional specialisation, monocropping production technique).

Besides the productivity discussion, there is also the aspect of poverty reduction. Agricultural policies focussing upon larger farmers might have a negative impact upon the well-being of the majority of non-professional subsistence-oriented rural agents, if no or few employment opportunities can be guaranteed for this large group outside of the farm sector. We would rather plead for rural policies that empower and actively involve the large community of small-scale farmers in agricultural development strategies to achieve a more equitable distribution of agricultural growth and to pro-actively prevent households from falling into the vulnerability trap.

Key issues are the removal of the institutional constraints that prevent small-scale farmers from adopting new types of agriculture and/or diversify their income portfolio away from subsistence agriculture; the expansion of off-farm employment opportunities which would provide peasant households with alternative options for their labour force; the enhancement of the bargaining position of peasants versus larger farmers in food, land and credit markets. Finally, attention should be paid to the intra-household distribution of assets, decision making power, and the work load in income-generating and other household activities. Overall, the paper's suggestion to policy makers is to focus on the potential of the large mass of small-scale farmers. This is the optimal choice, when combining the need for increased agricultural output with the objective of poverty reduction.

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