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To cite this version:

Stéphane Korsaga. Land Tenure Security, Land-Related Investments and Agricultural Performance in Sub-Saharan Africa: Efficiency or Equity? A Microeconomic Analysis Applied to Burkina Faso's Case. 2023. halshs-03977756

HAL Id: halshs-03977756

https://shs.hal.science/halshs-03977756v1

Preprint submitted on 7 Feb 2023

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Document de travail du LEMNA N° 2023-01

Février 2023

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Stéphane Korsaga*†

2023

Abstract

In this article, we study the impact of both subjective and objective land tenure security on farming households' propensity to invest in land as well as the productivity of the soil. For that purpose, we resort to the World Bank LSMS-ISA data collected in 2014 at the national level of 10,800 households in Burkina Faso. The empirical application favors a simultaneous equations system made up of a multivariate Probit with random effects on the one hand, and a Cobb-Douglas-type production function on the other hand. From the application of the limited information maximum likelihood estimation and cmp methods using Stata 17.1, the results show that a secured individual field management and the membership in a socio-economic organization, considered together, have a positive and significant effect on yield per ha at 13.1% on average. But for the approved or objective land tenure security and a subjective one in terms of the location of crop fields, the total impact of both on the soil productivity is negative and significant at 18.6%. Accordingly, it would be advisable to stress, strengthen and increasingly promote the protection of individual exploitations specifically.

Keywords: Economics of Land Tenure, Tenure Security, Land-Related Investment, Agricultural Performance, Sustainable Agricultural Development, Burkina Faso.

JEL Classification : D1, K0, Q1

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†I would especially like to acknowledge Professor François-Charles WOLFF for his instructive support. However, I am fully accountable for any arguments developed here.

1 Introduction

In the course of the world recognition of agriculture multifunctionality in the process of development (Myrdal in Hayami and Ruttan, 1998; World Bank, 2008; IFAD, 2016; AfDB, 2016), the theory of induced institutional change (TIIC) argues that when transaction costs start becoming high in agricultural land management and exploitation, a better formal or informal security of land rights would lead farming households to invest based on their own assets in devices for soil improvement and protection (Platteau, 2000; Simbizi et al., 2014). The underlying context of the TIIC is a sharp and constant rise in population growth and the relative paucity of farmland.

A number of studies have been conducted to assess the facts with respect to the hypotheses set within the theoretical framework. The limits of the top-down approach to tenure security in terms of incentive to the productivity-based behaviors, particularly for Sub-Saharan African (SSA) nations (Bruce and Migot-Adholia, 1994; Deinlnger and Biswanger, 1999; Lawry et al., 2014), have created the need to deeply analyze the African experience concerning land rights insurance. In this process of assessing the facts, for the studies which have centered their interests on the economic importance of social norms and practices through the insuring of land rights, the scope is as theoretical as it is empirical. Theoretically, the concept of land tenure security has evolved from an orthodox perception towards a more flexible conceptualization (Bruce and Migot-Adholia, 1994; Sjaastad and Bromley, 1997; Toulmin, 2009; Van Gelder, 2010; Arnot et al., 2011) which has emphasized the African reality. In the early 1990s, several empirical works tried to shed light on the security of land rights provided by the local institutions in most African countries. However, as has been revealed by relevant empirical literature reviews

realized by Place (2009), Fenske (2011), Lawry et al. (2014), Tamini et al. (2018), the results are still mixed for these countries and the reasons put forward are both conceptual and methodological.

Some authors have used specific rights (Place and Hazell, 1993; Besley, 1995; Place and Otsuka, 2001) as proxies of tenure security, while others, on the contrary, have resorted to generic variables taking into account the concept of the bundle of rights (Pender et al., 2004; Deininger and Jin, 2006; Deininger and Ali, 2008; Deininger et al., 2008). Otherwise, most of the empirical studies are limited in terms of statistical inference. In fact, as observed by Deininger and Jin (2006) "(...) many of the conclusions in the literature are derived from small samples originating in limited geographical domains". For instance, this is the case for the study realized by Place and Otsuka (2001) based on a sample of 97 households compared to those implemented by Deininger et al. (2008) and Deininger and Ali (2008) all of them concerning Uganda. These latter works have used samples of 970 and 7,500 households respectively. Contrary to the first study, the latter authors have managed to highlight the effect of tenure security on the incentives for farmers to adopt the technologies for soil improvement and protection. In terms of the expected effects of land tenure security on agricultural performance, the same results were obtained from the studies carried out by Amsalu and De Graaff (2007) and Deininger and Jin (2006) all pertaining to Ethiopia, and with samples of 147 and 8,540 farming households respectively.

Another criticism is the econometric approach to the behavior of investment of the farming households and the limited functional forms used in the specification of agricultural productivity functions. This appraisal is in particular about the strong hypothesis of individual random effects at the expense of household fixed effects in the estimation and use of productivity functions of the kind of limited Cobb-Douglas functional form; this restrained form concerns the basic hypotheses about the constancy and the unitarian character of substitution elasticity, covering up more flexible forms.

With regard to these various reports on the growing degree of land tenure insecurity, there is an emerging need to conceptualize a more suitable tenure system, particularly the harmonization of de jure and de facto rules. It is most probably the purpose of the new theoretical conception of land tenure security by Simbizi et al. (2014), which overlaps the top-down and bottom-up approaches to the security of tenure. Regarding this process, one of the subjects which constantly arises in the scientific debates concerning the way of strengthening the economic effects of land tenure security, is the manner farmlands are managed (De Soto, 2000, p. 187-252; Lavigne Delville, 2006). However, a small number of empirical studies have been interested in this issue, which appears to be even more important in the context of the SSA's countries, and this is probably due to the unavailability of appropriate microeconomic data. Thus, for more optimal interventions by development agencies concerning the improvement of the results of productive agricultural activities, there is a question of considering whether land reform policy should empirically favor the efficiency goal rather than the equity one in the exploitation of farmlands.

The present study answers this question by examining the context of Burkina Faso. Burkina Faso is a country where the issue of land tenure security holds an important rank in the debates on the socioeconomic drives of economic development; the reason is that the insecurity of land rights is admitted to be a real bottleneck in the activities of agricultural production. To complete this study, we have resorted to the World Bank LSMS-ISA database derived from a representative sample at the national level of 10,800 households. This dataset presents some particularities.

The survey LSMS-ISA/Burkina Faso contains information on the modalities of land security in Burkina Faso in accordance with the theoretical development. It is specifically focused on the modes of current land security in this country and the different ways of farm management. It also contains information on the location of croplands with regard to the housing environment and the status of households from the viewpoint of their membership in socio-economic organizations. From a methodological perspective, a recursive system of simultaneous equations (SSE), which concerns investment decisions and agricultural productivity, is estimated on the one hand, and a Seemingly-Unrelated-Regression-type model consisting of the same SSE, on the other hand. The limited information estimation method (MIL) is used to regress the first system, and the cmp method from Roodman (2007) is used for the second system of equations. In general, it appears that the more households are protected in their land rights, the more they are incited to invest, and this tends to improve agricultural productivity. Specifically, crop fields safely managed in an individual way are empiri-

cally more efficient than those held in a collective manner.

The remainder of this paper is presented as follows. In sections two and three, we approach respectively the conceptual framework and the diachronic evolution of land tenure systems in Burkina Faso. Then, in the fourth section, we present a description of the data used in our empirical analyses. The estimation strategy and the econometric results follow in sections five and six respectively. Finally, we end this report with a conclusion in section seven.

2 Land Tenure security and agricultural productivity: conceptual framework and measurement issues

The conceptual framework (CF) of the study is derived from a large one we had developed during our doctoral study and named the *Augmented Evolutionary Theory of Land Rights* (AETLR) (Korsaga, 2022). CF is fundamentally based on the transaction cost theory. It also rests on the hypothesis that the evolution of land rights depends on the ecological, socioeconomic and demographic configuration of the human environment. According to this operational framework, when transaction costs start becoming high because of the paucity of soil due to a rapid population growth exacerbated by the agro-climatic, economic, and demographic changes, the insurance of agricultural producers' rights has a major incentive power on their investment and production behavior in two ways. In the first way, it is shown that access to a formal plan to strengthen the security of their land claims tends to incite the agricultural producers to invest more in basic devices for the improvement of soil quality. The effect of these devices is strengthened by the expenditure on complementary investments. This channel finally ends in an increase in the profits from agricultural production.

Another channel implied by the CF with the aim of agricultural productivity improvement refers to the financial market. Indeed, a high land tenure security tends to favor the emergence of the land market either by the delivery of a land-related document symbolizing access to the protection guaranteed by the state or by the incontestable insurance of the privileges provided by local authorities. The process of securing land rights creates an improvement in the market value of the land, which can be used then as a mortgage-related security in loan-based operations both with the formal and informal institutions of agricultural credit. It is shown that the emergence of the land market and the granting of agricultural credit mutually strengthen each other. The capital stemming from this loan is then used in the long, average and/or short-term investment expenditure, which in turn tends to strengthen the performance of the activities of the agricultural production. However, it is important to note that the relinquishment of the dichotomous approach to land safety has given rise to a sophisticated diachronic development of this concept.

Land tenure security is now considered a multidimensional notion, with the issuing of land title as a sign of "maximum safety"(Brasselle et al., 2002, p. 379). In fact, many components make up the concept created by Simbizi et al. (2014) based on the works of both North (1990) and De Soto (2000), which are clearly the premises to that. It is a question of knowing whether the farming households have individual or collective access to the crop fields (Lavigne Delville, 2006, p. 13-14) they exploit, or do they have overlapping rights: both individual and collective? In terms of implications, it is implicitly shown that the farming households which have individual access to either the objective or subjective secured lands they exploit are more productive than those having collective access to them. Indeed, the insurance of profit from their work in an exclusive way urges the households to invest more in the activities of production, particularly in the context of land safety.

This clarification about the approach to tenure security is little investigated in the empirical literature from the viewpoint of its impact on the productivity-related behavior of the farming households at the crop-field level. In this way, as De Soto (2000) has mentioned, it is worth grasping the psychological and social processes acting in a society, specifically the *bottom*, if we strongly desire to develop a harmonious institutional environment (p. 191) capable of spurring the performance of the activities of agricultural production.

3 The economic evolution of the land tenure system in Burkina Faso

The history of land-related institutions in Burkina Faso can globally be divided into three sub-periods beginning from the time of its political independence to nowadays: 1960 – 1983, 1984, 1991-today[1]. However, only the part of this evolution, the starting point which is the year 1984, matters. In the context of growing and diversified land tenure insecurity, it is from that moment that the government has actually begun to pay attention to land tenure system as one of the factors significantly prone to affect the pace with which agricultural productivity evolves (Banque Mondiale et al., 2014).

The main characteristics of the land system in Burkina Faso are its law pluralism with a customary system on the one hand and, on the other hand, the statutory law which originally came from the colonial period, but has evolved since then. The first characteristic coordinates the relationships between people from the viewpoint of the use of arable lands based on measures from the customary law. The second characteristic ensures land governance by focusing on the rules established by the laws, decrees, and orders and thus aiming, according to Banque Mondiale et al. (2014), at economic, financial or monetary targets.

However, markedly affected by the famines in the 1970s and the early 1980s, the new government of Burkina Faso decided in 1984 to completely abrogate the authority of the customary institutions in the management of land-related relationships, blaming the productive ineffectiveness of these institutions (Banque Mondiale et al., 2014, p. 29). Therefore, this emerging system of land rights had a productivity perspective. However, it is worth specifying that under this political system, private individual and collective ownerships of land were canceled to benefit the State, which became the unique legitimate and legal owner. Only the usufruct was given to the workers of farmlands through the delivery of titles of enjoyment. This configuration of the economic-cum-juridical landscape lasted only a few years because a new agrarian and land reform (RAF) was put into place in 1991 with the advent of the fourth republic and the expansion all over the world of the liberal capitalist ideology.

By the same token, in this productivity-related perspective, the amendment of the RAF, which took place in 1991, restored the concepts of private individual and collective ownerships thanks implicitly to the rise of neoliberalism. It is, however, necessary to note that the land of the *domaine foncier national*[2] (DF) remained the property of the State, but with a possibility for third parties to uniquely possess the land-based resources possibly associated with a set of servitudes or easements. The private physical or moral entities which were concerned with this issue had from then on the possibility of acquiring relative titles of enjoyment and private property formalized by the 1996's RAF, with both documents having the same legal value.

This arrangement of the institutional and economic-cum-juridical environment is the one which prevails, nowadays, with a few exceptions. Indeed, after having made a report that the legal and institutional frameworks were ineffective and inefficient (CNSFMR, 2005, p. 3), the parliament, acting on the government proposal, passed a new law n°034/2009 concerning the rural land tenure system. This has an unusual feature in that it has institutionalized the customary land tenure (Art. 8) as a source of the statutory law, the idea behind it being the harmonization of legality and legitimacy (Assemblée Nationale, 2009). Moreover, it states in article 5 that the lands of the *domaine foncier rural*[3] (DFR) are the legacy of the nation, and not only the property of the State. Therefore, the lands of the DFR can be divided into three main categories (Art. 5): the DFR of the State, the DFR of local authorities with a measure of autonomy and the DFR of private individuals. This law reckons in article 34 that the private property of land can be individual or collective, thus modeling the reality that prevails over the land. As a result, the feeling of safety of the individuals' land-related claims can originate from different and/or interdependent sources, contrary to the statutory provisions in law n°034/96/ADP that stipulate "the State is the only source of the rights held by private individuals"(CNSFMR, 2005, p. 41).

[1] The starting year in this subdivision is related to the African Union principle that "... They (all people) shall have the unquestionable and inalienable right to self-determination. They shall freely determine their political status and shall pursue their economic and social development according to the policy they have freely chosen"

[2] The *domaine foncier national* consists of all the real estate (land or building) privately or publicly owned by the State, local authorities, or private individuals within the limits of Burkina Faso's territory (Assemblé Nationale, 2012)

[3] The *domaine foncier rural* refers to all the rural lands owned by the State, local authorities, or private individuals (Assemblée Nationale, 2009, p. 4)

Another reform enacted in 2012, the law n°034/2012 concerning agrarian and land rights structures reorganization in Burkina Faso, aimed to be complementary to the law n°034/2009 (Assemblé Nationale, 2012). Consequently, this additional enactment has come to confirm the important productive function of a legal and institutional guarantee of the land-based privileges of the farming households. The last two laws dealing with agrarian matters, although not completely applied in practice (Banque Mondiale et al., 2014, p. 32), have succeeded in carrying out a bottom-up strategy (World Bank, 2001) of land governance which Burkina Faso's government intended to implement from that moment (2012). These new legal and institutional landscapes eventually aim at a strategic legitimization and legalization of land-based relationships and acts. And as Holmes argues (in De Soto, 2000, p. 187), "the life of the law is not made of logic, it is made of experience", implicitly evoking the importance of *ex-ante* analyses prior to development policies, and hence an increasing need to perform a microeconomic examination of the existing agro-juridical-cum-institutional landscape.

This study is all the more necessary as, according to our investigation, applied scientific works are more a matter of economic sociology and anthropology. Furthermore, it seems that no dissertation in Economics has dealt with the subject in the context of Burkina Faso so far. Moreover, some studies of empirical applications conducted within the frame of this country (Matlon cited in Bruce and Migot-Adholia, 1994; Ouedraogó et al., 1996; Brasselle et al., 2002; Linkow, 2016) with samples of relatively low size, have not generally ended in the results predicted by economic theories until now.

With regard to the above review and current new developments in theoretical frameworks, it is desirable that empirical estimations are repeated, particularly as the legal and institutional orders were changed by the adoption and promulgation of the laws n°034/2009 and n°034/2012. It is a question of putting a particular emphasis on the way in which land is managed, especially individual, collective and mixed modes, which appear as determinant in the variation of land-tenure-security intensity.

4 Data and statistical description

4.1 LSMS-ISA survey in Burkina Faso's case

Our analysis is related to a database built by the *Institut National de la Statistique et de la Démographie du Burkina faso* (INSD) in collaboration with the World Bank through the program LSMS-ISA[4]. This databank is derived from a representative sample survey realized in 2014 at the national level of $10,800$ households from which $7,536$ are farmers and from which $5,941$ are from the rural areas.

LSMS-ISA, implemented in more than eighteen countries, is an international non-governmental program, the activities of which began in the early 1980s. The ultimate goal of this institutional organization is to provide driver support in the conception and implementation of development policies based on reliable and thorough statistics (Grosh and Glewwe, 1995). It appears that the main contributor to this institution is the World Bank, which is prone to be heavily involved in land matters in developing countries in general and in SSA in particular. Indeed, the World Bank has significantly contributed to the support and endorsement of the "Voluntary Guidelines on the Responsible Governance of Land Tenure, Fisheries and Forest in the Context of National Food Security". Moreover, it appears that the World Bank and its partners have also developed the "Land Governance Assessment Framework"(LGAF), the objective of which is to assess the status of land governance at the country level. Finally, the World Bank Group has supported twenty-four development projects on land administration as well. These supports are considered likely to be the largest number of interventions concerning the governance of land tenure of any international development agency [5].

Burkina Faso is one of the eight countries in SSA that benefit from this program. It has contributed to the development and implementation of the "Enquête Multisectorielle Continue"(EMC) at the national level[6]. The

[4]LSMS-ISA: Living Standards Measurement Study - Integrated Surveys on Agriculture

[5]http://www.worldbank.org/en/news/press-release/2013/07/22/how-africa-can-transform-land-tenure-revolutionize-agriculture-end-poverty

[6]EMC is a household-panel survey

EMC, a harmonized tool for data collection, was largely realized by the agencies of the National Statistic System (NSS) (INSD, 2013), including the INSD, and involved a sample of 10,800 households in 2013/2014. The households were randomly chosen using the results of the general census of population and housing environment (RGPH) in 2006, in all the forty-five provinces making up Burkina Faso. Consequently, 900 enumeration zones (ZD) were considered. In each ZD, 12 households were selected, and hence the above-mentioned total size. After processing the data, we carried out a secondary sample of 4,314 farming households and 4,105 crop fields. These figures are all related to the fields particularly close to dwellings, and so are the descriptive statistics.

The statistics are considered in two dimensions: the crop field and household levels. They deal with information about the characteristics of the farming households, the croplands, and in particular the modes of land rights insurance. It is also about the modalities of land management and the location of the crop fields, as well as the topography of the piece of land, the typology of soil and the quantities of the farming goods produced.

4.2 The characteristics of the households and crop fields

From the viewpoint of the characteristics of agricultural households, three types of farmers are considered: they are respectively those of an individual land management; the ones involved in collective land management; and the remaining doing mixed land management. Table 2 presents a description of the households' demographic and socio-economic characteristics. This is done from the point of view of the modalities of land management. The statistics related to the farming households, which have an exclusive collective management of their croplands, are on average quite close to those of the three groups altogether. As to the question of knowing whether there are enough variations between those groups, Table 2 (columns 6 and 7) shows that the three types of farmers are generally statistically different from one another.

Setting aside off-farm activities, farm employment is the largest primary source of household head income at 27.67%. Moreover, the categories of households have not been statistically distinguished from one another on average from the viewpoint of socio-economic characteristics. This report may suggest that the effect of these groups on the global agricultural efficiency is significantly differentiated statistically. So there appears in general a potential heterogeneity of the farming households to be discussed in the econometric estimations downstream.

With regard to the characteristics of the crop fields, table 3 highlights their attributes according to the modes of land management and the degree of protection of the farmlands. The insurance of a field in terms of land rights is mainly ensured by the local institutions and contains two modalities: the ownership of land with land authorities' agreement and the ownership without their specific support. These two modalities, in addition to the method of land management and the geographical location of the fields, determine the effective characterization of the concept of land tenure security in Burkina Faso's case. This is all the more useful because it gets closer to the theoretical conceptualization elaborated by Simbizi et al. (2014) and to the insurance strategy of the land laws that Burkina Faso's government intends to set up. The characteristics of the croplands are particularly informative on the state of the practices of plowing, the systems of cultivation, the mode of land acquisition and the quality of soil. The relief of the crop fields as well as the nature of the land-related investments undertaken by the farmers are also evoked.

For each of the two categories of farmers, it is possible to observe that the fields benefiting from approval for exploitation and control are greater in absolute and relative values than those which do not possess it: 78.2%; 79.7% and 72.69% respectively (columns 3, 6, and 10) (see Table 3). Not only does this implicitly express a gradually increasing will of the households to resort to any protection (either legal, traditional, or coming from the household's members themselves) for their land privileges, but also a land tenure insecurity which is growing because of the pressure on the farmlands and coming from various rural land-based actors. Moreover, Table 3 partially indicates the proportions of the fields in terms of their attributes according to the various characteristic components of land tenure security. Whether the fields associated with an ownership with agreement are generally more numerous than those for which the access and exploitation received no approval, it is important to note that this configuration is sometimes reversed when it comes to the statistics in terms of proportion for each characteristic of soil.

Furthermore, it is worth observing that in the case of compost, the proportion of the fields that receives it is greater for the Ownership With Agreement than for the Ownership Without Agreement, whatever the method of land management and the location of land. This result may express the fact that the farmers are more inclined to invest in the farmlands where they have a larger room for maneuver. But this finding does not occur for the two other types of investment which in practice appear as complementary to the soil-related effects of compost. This description remains even if we take into account the location of the crop fields which presents two modalities worth knowing. There are lands not far from dwellings (we have already dealt with) and others which are far away in the bush. A difference in the proportions according to both modalities of objective land tenure security shows that there is enough statistical variation in the data.

Interestingly, another way of highlighting the variation in the data is to look at the distribution of the crop fields in terms of the types of main crops and the degree of the use of labor force according to the components of land tenure security. This is also another way to measure the extent to which the farmers are concerned with the question of the insurance of land-related privileges. As can be observed in table 4, there are more fields which have received local recognition on behalf of the land authorities whatever the type of household considered. A priori, all the proportions seem to appear in favor of the category of the fields not having received the authorities' approval in the case of "Cash Crop". But for the other characteristics, such as "Grain Crops" and "Days.Men...", this difference clearly appears in favor of the lands associated with the approved land-access rights[7]. Consequently, it may be possible to state that farmers would be inclined to invest and produce on the fields where their rights seem guaranteed. This intuition is the same for the lands located in the bush (not developed here).

With regard to the findings obtained by means of the statistical description of the data, it generally emerges that the various soils from the viewpoint of the components of land tenure security present a certain statistical heterogeneity. A complementary econometric analysis to the statistical description appears to be necessary with the aim of quantifying the theoretical nexus between land tenure security and the performance of the farming activities, given the general conditions of the agricultural production environment.

5 The specification and estimation strategies

5.1 Land-related investment decisions model

At this stage, many considerations are taken into account. One of the questions which comes up quite often in the literature on this issue is the nature of the security of land rights, whether it is exogenous or endogenous. This is a question of knowing whether the farmers influence the insurance of the land rights they have received or whether this can be considered predetermined. In this respect, according to Besley (1995), land tenure security can be considered a function of the acquisition mode of the crop fields, the possession of land documents, visible investments realized upstream, etc. Considering the first one of these factors, it is necessary to note that inheritance is the most frequent mode of land access as a whole or land rights acquisition. In Burkina Faso, 75.6% of the crop fields are inherited (LSMS-ISA, 2014). Yet as Hayes et al. (1997) have underlined for Gambia, land security depends more on the mode of acquisition of the fields or the land rights via legacy which in turn is a function of factors outside the control of household heads in some respects. According to Deininger and Ali (2008) in the case of Uganda, it is even more likely that the inherited crop fields were awarded very long ago to the predecessors of the current farmers (p. 9). As a result, the farmers in question have little chance of having obtained them because of their specific behaviour to some extent. By virtue of this argumentation and the limited content of our databank, the generic variable of land tenure security is considered exogenous.

Now at this point of the process of modeling is the specification of the functional form of the investment behavior according to the explanatory variables which include the components of land rights safety. For that purpose, the cognitive framework (Lavigne Delville, 2006, p. 1) frequently used in the empirical literature as a benchmark model concerns the one developed by Feder (1988, cited in Place, 2009, p. 1327). So with regard to our study, two types of investment can be underlined: middle-term devices (organic fertilizers) and

[7] see Table 3), for the different definitions of Days.Men

the short-term ones (inorganic or chemical fertilizers). "Commonly used organic fertilizers include animal manure, household wastes, plant materials, and compost (retained in the present study) made from combining the previous variants. In addition to providing nutrients, organic fertilizers contribute to the soil quality by improving the structure, chemistry, and biological activity level of the soil"(Morris et al., 2007, p. 21). Accordingly, the effects of organic fertilizers can generally last more than one farming cycle, because they have to undergo a process of more or less low decomposition.

"Commonly used inorganic fertilizers include straight fertilizers containing a single nutrient - nitrogen (N), phosphoros (P) or potassium (K) - and compound or mixed fertilizers containing more than one of these so-called macro-nutrients... They (inorganic fertilizers) release nutrients quickly because they do not have to experience decomposition"(Morris et al., 2007, p. 21-22). This means that they are generally spread over the ground seasonally, hence the short-term denomination applied to them.

In reference to the framework of Feder (1988), the middle-term investments influence the decision of households in their choice concerning the short-term. However, for the relationship between the short-term investments mentioned here, it emerges in the agronomic literature that the use of the phytosanitary products is impacted by mineral or chemical fertilizers (Rahman, 2003). Given the dichotomous character of these variables, the recursive specification in qualitative answers is usually used as the model of analysis for the decisions related to the land-based investments. This is the specification that allows us to determine the probability P_h of the agricultural households (h) to apply these types of agricultural investments.

To determine this probability, we define two latent unobserved or continuous variables IM^*_{hf} and IC^*_{hf} which generate the corresponding investment behavior observed respectively of middle and short term IM_{hf} and IC_{hf}. So the general model of investment decisions related to crop field p by farming household h is as follows:

$$IM_{hf} = 1 \text{ iff } IM^*_{hf} > 0 \; ; \; 0 \; otherwise \tag{1}$$

$$IC_{hf} = 1 \text{ iff } IC^*_{hf} > 0 \; ; \; 0 \; otherwise \tag{2}$$

where

$$IM^*_{hf} = LS_{hf}\beta + F_{hf}\delta + HD_h\gamma + G\varphi + \alpha_h + \varepsilon_{hf} \tag{3}$$

$$IC^*_{hf} = IM_{hf}\beta' + F_{hf}\delta' + HD_h\gamma' + G\varphi' + \alpha'_h + \mu_{hf} \tag{4}$$

The explanatory variables of the investment behaviors are contained in the matrices defined as follows: LS_{hp} the matrix of the proxies of land tenure security the household h feels with regard to the field f; the demographic and economic characteristics of the household h by means of the matrix HD_h; the field characteristics expressed by the matrix F_{hf}; α and α' represent the unobserved characteristics of the farming households for the equations (3) and (4) respectively; the other variables (structural) are put together in the matrix G. The remaining components of the model are the parameters: β, β', δ, δ', γ, γ', φ and φ', and the error terms of the equations are ε_{hp} and μ_{hp} respectively.

Thus, we have got a multivariate model, the nature of which depends on the distribution of the error term : normal or logistic. As it generally appears in the literature, we favor a normal distribution, and hence a multivariate Probit model with random effects. Two methods of estimation are used: the limited information estimation model (MIL) on the one hand and the estimation method with complete information (MIC) (Greene et al., 2011) on the other hand. The results from the two approaches will be presented shortly with a focus on those related to the first one.

5.2 The specification of agricultural productivity

Knowing that the model of analysis of the impact of tenure security on agricultural performance is a structural system of interconnected equations, the specification of the functional form of agricultural productivity jointly comes after the formalization of the investment behaviour.

The agricultural productivity is generally defined as the total monetary value of the agricultural production aggregated by hectare of cultivated land, with reference to the indicators used in the literature. Concerning the basic CF from Feder (1988), tenure secu-

rity has an impact on the agricultural productivity via its effect upon the household propensity to use land-related investments. From the viewpoint of a structural model, the investment variables are then introduced as adjusted ones in the functional form of the agricultural productivity. This estimation technique is related to the MIL. But for the MIC, the simultaneous equations system (SES) is estimated using the conditional mixed-process estimator procedure (cmp) (Roodman, 2007). In the economic literature, the econometric model usually used in searching for the determinants of the agricultural productivity are the Cobb-Douglas-type functions (CDTF). But as is mentioned in the literature on fundamental research, there is a functional form of productivity more flexible, which is the translogarithmique shape or the translog model of productivity (Greene et al., 2011) built from Berndt and Christensen (1973). However, due to the limited content of our database, we focus on the CDTF. Accordingly, the technology of production is specified as follows.

$$\begin{aligned} lny_{hf} = (b+\alpha_h) &+ \sum_{f_1=1}^{m} \delta_{f_1} lnF_{hf_1} + \sum_{k_1=1}^{\nu} \gamma_{k_1} lnHD_{h_{k_1}} \\ &+ \sum_{f_2=m+1}^{r} \delta_{f_2} F_{hf_2} + \sum_{k_2=\nu+1}^{n} \gamma_{k_2} HD_{h_{k_2}} \\ &+ \tau I_{hf} + \varphi G + \mu_{hf} \end{aligned}$$

y_{hf} for agricultural productivity. For the sake of clarity, we separate the quantitative explanatory variables from the qualitative ones. So, F_{hf_1} represents the quantitative characteristics of the crop fields for household h at the field level f_1. For $HD_{h_{k_2}}$, it only consists of the household h_{k_2}'s quantitative demographic and economic characteristics. Their complementary qualitative ones are F_{hf_2} and $HD_{h_{k_2}}$: they are either indicator values, or variables that are eventually and theoretically not substitutable between themselves (Zhengfei et al., 2006, p. 208; Theodoridis and Anwar, 2011, p. 97) in terms of interaction. τ, δ_{f_1}, γ_{k_1}, δ_{f_2}, γ_{k_2} and φ are the coefficients to be estimated. b, α_h et μ_{hf} represent respectively the constant, the specific individual household effects and the error term. I_{hf} represents the explanatory endogenous land-related investment variables. The estimation technique of this model lies within the global framework of the method of estimation of a SES: the MIC as explained above.

5.3 The specification of the variables used in the econometric model

The objective of this sub-section is to define the nature of the dependent and exogenous variables corresponding to the above-mentioned matrices, and additionally coming into play in the modeling of the relationship between land security, investment activities and agricultural productivity.

The choice of the explanatory variables is based on a three-step procedure. For each dependent variable, a prior task is to refer to the economic literature. An inventory of all the independent variables that could reflect a given category of explanatory phenomenon is realized. Then, a pair-wise linear correlation coefficient system is calculated to look at the degree of correlation between a category of explanatory variables and the dependent variables they are supposed to explain. Finally, for a given category of explanatory phenomenon related to a given dependent variable, the explanatory variable that has the highest correlation coefficient with the explained variable is preferred to the other explanatory variables in the same category. This three-step procedure is applied to the investment variables as well as to the variable of the agricultural productivity. Consequently, all the variables, either dependent or independent retained for the empirical stage, are presented in table 1 as follows.

Table 1: Description of the variables used in the regression models

Variables	Expected signs	Variables description
Dependent variables		
Compost	Nil	1 if compost is used and 0 otherwise.
Chemical or mineral fertilizer	Nil	1 if mineral fertilizer is used and 0 otherwise.
Phytosanitary products	Nil	1 if phytosanitary products are used and 0 otherwise.
Farming productivity	Nil	Agricultural productivity (continuous variable FCFA/Kg).
Explanatory variables		
Tenure security proxies		
Objective tenure security	+	1 for approved ownership and 0 otherwise.
Individual land management	+	1 for individually managed field and 0 otherwise (Subjective security).
Cropfield location	+/-	1 if cropfield are located near dwellings and 0 otherwise.
Socioeconomic organization membership	+/-	1 if household head is a socioeconomic organization member (Subjective security).
Cropfield characteristics		
Land size	+/-	Hectare (ha).
Clayey	+/-	1 if cropfield is of clay and 0 otherwise.
Sandy	+/-	1 if cropfield is of sand and 0 otherwise.
Plain	+/-	1 if cropfield is on plain and 0 otherwise.
Plateau	+/-	1 if cropfield is on plateau and 0 otherwise.
Grain crops	+/-	1 if grain field and 0 otherwise.
Cash crops	+	1 if cashcrop field and 0 otherwise.
Insecurity	+/-	1 if household is located in the insecure land tenure zone.
Household characteristics		
Age of household head	+	Measured in years (Continuous variable).
Household adult members	+	Family labour force equivalent-adult (Continuous variable).
Days.Men for plowing	+	Number of working days for men and women for plowing (Continuous variable).

Table 1: Continuation

Days.Men for maintenance	+	Number of working days for men and women for the field maintenance (Continuous variable).
Days.Men for harvesting	+	Number of working days for men and women for harvesting (Continuous variable).
Household Head Education	+	1 if household head can read and 0 otherwise.
Wealthiness	+	1 if household is declared rich and 0 otherwise.
Number of cropfields owned	+/-	Cropfield owned by a household
Household location to the nearest market	+/-	Distance between the household and the nearest market
Household location to the nearest road	+/-	Distance between between the household and the nearest road.
Dependence ratio	-	The proportion of non-working persons being looked after by ahousehold.
Muslim	+	1 if household head is a Muslim and 0 otherwise.

Source: Constructed by the author using LSMS-ISA database for Burkina Faso's case.

At this stage of our argumentation, the question worth asking concerns the identifiable character of the structural equations of the analysis model. To that purpose, though the condition of rank is one of the criteria for guiding the decision, it turns out that the condition of order (Bourbonnais, 2015) is most used in the literature. So the application of the latter to the equations system of the land-related investments and the agricultural productivity, results in the over-identified equations by construction, thus authorizing the implementation of the above-mentioned empirical estimation methods.

6 The interpretation of the econometric results

6.1 The effect of land tenure security on the investment decisions

The results in terms of marginal effects of the estimation of a recursive system of Probit models with random effects, which models the investment decisions with regard to the use of organic and chemical fertilizers and of phytosanitary products, are presented in table 5. As mentioned earlier, not only do we present the figures from the implementation of the MIL, but also those of the MIC in terms of the gap between them.

In column 1 in table 5, the variable Objective-land-tenure-security associated with the crop fields, the exploitation and control of which have received traditional local authorities' approval, presents a positive and significant sign at the threshold of 1%. This result implicitly expresses the fact that farmers, whoever they may be, are all the more inclined to produce and to use some compost (+13 percentage points) as they are ensured to completely reap the benefits of their investment efforts[8]. Insofar as this mode of local insurance, which is land possession, authorizes complete transfers (alienation) and limited (loans or gift) land rights, it is easy to observe that the same results, in terms of significance, have been reached by a number of research projects. It is, in particular, those of Gavian and Fafchamps (1996) for Niger; Hayes et al. (1997) for Gambia (but of negative sign); Deininger and Ali (2008) for Uganda.

For the other sources of subjective control power (column 2), the results are in general positive as well as significant except for the membership-in-a-social-organization and individual-land-management. Consequently, the farming households seem more inclined to spread some compost on the fields over which they have an informal close surveillance. The more the crop fields are close to the dwellings, the more the households are incited to use some compost independently of the status of the farmlands (+33 percentage points). However, the croplands owned by the households of individual-land-management are less inclined to receive some compost (−22 percentage points). But the fact of being a member of an institutional social organization significantly reduces the investment decision of farmers by 23 percentage points on average. On the other hand, the fact of controlling this dimension increases the impact of Objective-tenure-security on the consent to use some compost by the households. This result is not surprising at all in that the donations of inputs the farmers often receive, could have actually influenced their final decision to invest. This finding does not take into account the potential sources of land tenure insecurity.

After having checked the variables expressing the factors specific to the main zones of land tenure insecurity, column 6 gives us an idea of the relationship between the variables of tenure security and the investment intentions of farmers. The effect of the mode of insurance decreases slightly for both the objective proxy of safety and the crop field geographical location. In addition, it remains positive and statistically significant for the coefficients associated with these variables. The probability of investing associated with the objective variable decreases by 2 percentage points. Whatever the level of land insecurity, the farmers who have permanent control over their lands may always be inclined, to the same degree, to invest in the usage of compost on their crop fields. The fact of benefiting from a subjective insurance increases the propensity of the households of individual-land-management to invest by 2 percentage points (the combined effects of secure individual land management, the location of the crop fields and the membership in a socio-economic organization). For this type of land-related investment, the empirical results are in accordance with the predic-

[8]The figures we are presenting here result from the MIL. By contrast, those obtained via the MIC are a bit different: +18 percentage points for the objective-tenure-security; −6 percentage points for individual-land-management; −16 percentage points for membership-in-a-socioeconomic-organization, and +32 percentage points for the crop-fields-location. The resulting total effect from the implementation of the MIC is then +28 percentage points

tions made in the theoretical framework. This latter observation also appears generally in the estimation of the equation expressing the decision of the households to make use of chemical fertilizers.

According to column 4 in table 5, the insurance of land rights guaranteed by the land authorities, as well as the de facto or subjective land tenure security, both have a considerable impact on the tendency of the farming households to use mineral fertilizers. The more households are safe having relative control over all the benefits stemming from their investment effort, the more they are incited to use mineral fertilizers (+0.784 percentage points)[9]. This effect of insurance is transmitted through the compost use, which has apparently a complementary relationship with the chemical fertilizers. The characteristics of the crop fields and of the farming households present to some extent the predictions of the theoretical framework, with the control of the potential risks of land insecurity. The fact of adding the proxy of land insecurity (column 7) does not considerably alter the figures in terms of scope and significance in the previous interpretation. The adjusted probability of the application of compost keeps a positive and significant value at the threshold of 1%. These small differentiated results call for a more thorough study of the land-insecurity zones, as this gap results from the addition of the variable which represents them, and also appears in the specification of the decision of the households to apply phytosanitary products.

Column 5 in table 5 shows the results of the estimation of the equation expressing the propensity of the households to apply the phytosanitary products. As it is possible to observe in column 5, the explanatory variables *Compost Predict* and *Chemical Predict* have their coefficients statistically and significantly different from zero[10]. This means that the subjective and objective tenure security indirectly influence the propensity of the households to use the phytosanitary products through the use of compost and mineral fertilizers (−0.515 percentage points). But in terms of direct effects, the more the households are inclined to use some compost, the less they have a tendency to use the phytosanitary products (PPS) by 2.3 percentage points on average. Subsequently, these two inputs are substitutes. These findings may be explained by the properties of compost. Indeed, the application of compost, according to the standards and the required practices, has the quality of strengthening the plant which gives it the means to fight against diseases and the appearance of weeds. Yet the reason for the use of PPS is to fight against these harmful pests, and hence there is a reduction in the use of this product. But the croplands which receive some mineral fertilizers are more inclined to be covered by PPS (+9.6 percentage points). Consequently, with regard to the farming households, the PPS and the chemical fertilizers seem to be complementary. These results do not change significantly in terms of sign after the addition of the variable representing both the agro-climatic conditions to some extent and the possible land tenure insecurity, as indicated in column 8 in table 5.

As table 5 indicates, the feeling of having a guarantee of their land privileges constitutes an important factor in the household decisions concerning land-related investments, either directly or indirectly. These findings result from the application of a method of econometric estimation with limited and complete information in the regression of a multivariate Probit model. As we have mentioned above, it is also possible to turn to the estimation of a conditional Logit, a functional form that takes into account the household's individual fixed effects. In addition to answering the criticism formulated in the literature with regard to the neglect of the household fixed effects, this specification allows us to test the robustness of the results obtained. From the sign viewpoint of the coefficients associated with the variables of interest, the results are generally identical to those obtained in the previous estimations. However, the significance of the parameters is different from those predicted by the theory (not presented here). This is probably due to one of the properties of the conditional Logit, namely the deletion of a big part of the data during the estimation procedure. Therefore, we keep the figures that resulted from the estimation of the Probit model system with random effects.

[9] All indirect effects are derived here via the implementation of the Chain rule (https://fr-academic.com/dic.nsf/frwiki/1633676 and Mas-Colell et al., 1995, p. 927), as well as for the upcoming figures. See page 22 of this report

[10] "Compost Predict" and "Chemical Predict" are the predicted probabilities resulted from the estimation of the Probit models concerning the investment decisions

6.2 The impact of tenure security on agricultural productivity

The figures we are dealing with in this section come from the implementation of the MIC, which results in better estimators in terms of significance. They are presented in Table 6.

The determinants of the productivity of soil, which is measured by the aggregated monetary value of yield per hectare (yield/ha), arise from the application of the cmp method[11]. As it is possible to observe in all the four columns, the different types of investment significantly influence the agricultural productivity, though contrary to the theoretical expectations to some extent in terms of sign. A plausible explanation of these results could be linked to the fact of failing to consider some important exogenous variables in each of the cases. Besides, as it is possible to observe, the estimation of the equation of the yield/ha with the three categories of investment variables (column 4) produces the signs expected to a lesser extent. Indeed, the coefficient associated with the mineral fertilizers proxy preserves its positive sign. However, it is possible to assert that the more the land privileges of the farmers are guaranteed (individual land management and the membership in a socio-economic organization), the more it leads to an increase in the agricultural productivity of 13.1%, through the use of compost and the phytosanitary products.

The signs of the other variables, and in particular, the characteristics of the households and the crop fields, are generally in accordance with the theoretical expectations. The family workforce represented by *lnJourHomRecolt* positively and significantly impacts the productivity of soil. An increase of 1% in the number of working-days per ha for harvesting entails an increase in the soil productivity by 0.20%. The more the soil is of clayey-type, the less this input favors the increase in the agricultural productivity by 21%. The relief of plain and plateau entails on average an increase in yield/ha respectively by 39%, and 22%. Additionally, the results show that the main cash crops, unlike the main grain crops, contribute more to the increase in the agricultural productivity by 8%. These results were also obtained by Deininger et al. (2008), but for other types of agricultural products. Similarly, it is possible to observe that the crop fields subject to both conservation techniques and mechanization significantly participate in the increase in the productivity of soil. Indeed, the farmlands which experience an association of different crops influence the increase in the productive efficiency of soil of 20%. Moreover, those crop fields which experience the use of *traction animals*, show an increase in the productivity of the soil of 6%. The foregoing results concerning the determinants of the agricultural productivity are obtained by postulating a Cobb-Douglas-type technology with its restrictive hypotheses of homogeneity and substitution elasticity equal to unity.

[11] Agricultural productivity, yield per hectare, and productivity of soil are synonymous.

7 Conclusion and policy implications

In the context of the relative weakness of agricultural productivity and the growing rise in land risks against which the farming households are confronted in Burkina Faso, few empirical studies have been realized so far in this country to guide the decision-making in terms of economic policy in this area of sustainable development. This study has mainly dealt with a microeconomic analysis of the nature of the relationship between land tenure security, land-related investments and the performance of agriculture in Burkina Faso. The latter has tried to answer the question of knowing if it is necessary to favor the objective of efficiency or equity in access and control of crop fields.

Inasmuch as land tenure security is considered resulting from the interaction of a set of factors, this study has defined two specific objectives. The first objective concerns the question of examining the effect of the components of land rights insurance of the farming households on their propensity to use various land-related investments. The second objective consists of examining the effect of land tenure security on the agricultural productivity through the household tendency to invest in three devices of improvement and maintenance, and protection of soil. In general, the econometric results appear to fit the theoretical expectations to some extent.

Land tenure security measured by proxies such as land possession, the individual management of crop fields and the membership in a socio-economic organization (which constitutes a source of economic power for the farming households) contributes to an increase in the agricultural productivity of 13.1%. On aver-

age, the farmers whose rights are perfectly enforceable against a third party are more incited to use compost and chemical fertilizers, but less so for the use of phytosanitary products (+29, +0.784 and −0.515 percentage points respectively). Moreover, the results have shown that greater tenure security incites the households to have an environment-friendly behavior compatible with the sustainable development goals. Indeed, it seems that the more land rights are institutionally guaranteed against any risk of contestation and violation, the more farmers show a willingness to reduce the spreading of the phytosanitary products. Consequently, favoring the efficiency objective in the access and exploitation of farmlands would help strengthen the effects of land tenure security on the performance of the agricultural production activities.

The empirical results obtained from our estimation procedures allow us to formulate some recommendations in terms of socio-economic development policy and perspectives for future research. First of all, it would be wise to stress, strengthen and increasingly promote the protection of individual farmers in particular. Secondly, it seems necessary to promote good governance in peasant socio-economic organizations. Accordingly, the fact of knowing there are social structures prone to defending their interests, particularly land-related ones, would constitute for the farmers a kind of strengthening of their subjective power concerning their land rights and incite them to invest in productive devices. Finally, for a better understanding of the role of tenure security on agricultural performance, an empirical study should be implemented on the effect of the harmonization of the systems of land-related standards; this study should take into account the differentiation among the native, non-native agricultural producers (i.e. immigrants) and the vulnerable groups (i.e. children, women), thus bringing information economically useful for the general well-being of the population *in fine*.

Table 2: Rural farming household characteristics related to the management mode of crop fields in Burkina Faso in 2014

Variables	**All Crop fields**	**Household collective management of crop field**	**Household individual management of crop field**	**Mixed management of crop field**	**Individual management vs. collective management**	**Mixed management vs. collective management**
Household demographic characteristics						
Household size (Mean)	9.097	9.056	9.184	9.71	-0.127	-0.655
Members younger than 15 years old (Mean)	4.923	4.895	4.99	5.28	-0.095	-0.392
Members $15-60$ years old (Mean)	3.989	3.967	4.059	4.043	-0.092	-0.076
Age of household head (Mean)	49.688	49.75	49.33	51.068	0.413	-1.315
Dependency ratio (Mean)	1.427	1.429	1.413	1.52	0.015	-0.096
Household head education level (%)						
Household head can read	19.15	19.27	18.98	16.25	0.003	0.03
Lack of formal education	89.84	90.17	88.68	90	0.0149	0.002
Primary education	7.33	7.01	8.33	8.75	-0.0131	-0.017
Secondary education	1.83	1.7	2.33	1.25	-0.0063	0.004
High school	0.05	0.06	0	0	0.001	0.001
Socio-economic organization membership (%)	25.92	25.54	27.97	17.5	-0.024	0.08
Genre (%)	7.7	6.63	11.76	2.75	0.051***	-0.028
Household socio-economic characteristics						
Household head main job (%)						
Agriculture	78.51	79.87	74.25	73.75	0.056***	0.061
Household economic assets						
Wealthiness (%)	28.33	27.98	29.52	28.75	-0.015	-0.008
Number of crop fields (Mean)	3.44	3.22	4.34	2.012	-1.119***	1.212***
Household income level (Mean)	383 092.2	370 398.5	423 280.8	426 156.3	-52.88***	-55.757
Household Agricultural income level (Mean)	97 880.12	106 554.6	59 774.21	188 307.4	46 780.4***	-81752***

Table 2: Continuation

Crop field area (ha) (Mean)						
<0.5 ha	19.27	15.49	33.85	2.5	-0.183***	0.129***
0.5 ha – 1.0 ha	29.89	27.94	38.29	11.25	-0.103***	0.166***
1.0 ha – 2.0 ha	31.79	34.7	21.64	32.5	0.13***	0.021
2.0 ha – 3.0 ha	11.23	12.96	4.44	20	0.085***	-0.07*
<5.0 ha	7.82	8.9	1.78	33.75	0.071***	-0.248***
Cultural assets (%)						
Muslim	56.52	56.5	56.71	55	-0.002	0.0149
Christianism	21.92	21.19	24.64	20	-0.034**	0.011
Animism	16.54	17.2	13.76	18.75	0.035**	-0.014
Observation (Field)	**4,105**	**3,124**	**901**	**80**		

Source: Constructed by the author using LSMS-ISA 2014 data concerning Burkina Faso.

Table 3: Crop field characteristics by land management and land tenure security modalities in Burkina Faso in 2014

Variables	All crop fields				Collective land management			
	Total	**Ownership with agreement**	**Ownership without agreement**	**Difference**	**Total**	**Ownership with agreement**	**Ownership without agreement**	**Difference**
Crop field characteristics								
Land size (Mean)	1.09	1.11	1,04	-0.076***	1.18	1.19	1.15	-0.041
Animal traction (%)	54.37	42.32	61.74	0.094***	56.75	55.18	62.93	0.077***
Mode of farming (%)								
Pure crops	74.18	73.34	77.2	0.038**	72.06	71.24	75.24	0.039**
Associated crops	25.6	26.38	22.82	0.036**	27.72	28.47	24.76	-0.037**
Mode of acquisition of land (%)								
Inheritance	75.59	77.92	67.23	-0.106***	81.5	82.85	76.18	-0.066***
Gift	11.64	10.78	14.77	0.039***	11.43	10.64	14.51	0.038***
Marriage	8.55	7.2	13.42	0.062***	3.1	2.73	4.57	0.018**
The quality of soil (%)								
Sandy	54.69	55.81	50.67	-0.051***	54.26	55.54	49.21	-0.063
Clayey	27.43	25.82	33.22	0.074***	26.82	25.06	33.75	0.086
Lateritic	16.59	17.2	14.43	-0.027**	17.67	18.19	15.62	-0.025
Topology (%)								
Plain	68.79	71.66	58.5	-0.131***	67.67	70.8	55.36	-0.154***
Plateau	24	22.5	29.58	0.069***	24.97	23.13	32.18	0.090***
Low ground	4.92	4.17	7.61	0.034***	4.83	4.22	7.26	0.03***
Slope	1.71	1.28	3.24	0.019***	1.89	1.41	3.79	0.023***
Land-related investments (%)								
Compost	51.77	54.03	43.62	-0.104***	53.07	55.66	42.9	-0.127***
Chemical fertilizer	24.34	23.82	26,17	0.023	26.47	25.98	28,39	0.024
Phytosanitary products	18.1	16.6	23.49	0.068***	19.72	18.15	25.87	0.077***
Number of observations (Crop fields)	**4105**	**3211**	**894**		**3124**	**2490**	**634**	

Table 3: Vertical continuation

Variables	Individual land management				Individual land management vs. Collective land management
	Total	Ownership with agreement	Ownership without agreement	Difference	Difference
Crop field characteristics					
Land size (Mean)	0.688	0.71	0.631	-0.079*	0.481***
Animal traction (%)	46.61	42.6	57.32	0.147***	0.125***
Mode of farming (%)					
Pure crops	82.57	82.6	82.52	-0.0007	-0.113***
Associated crops	17.31	17.25	17.48	0.002	0.112***
Mode of acquisition of land (%)					
Inheritance	54.94	58.93	44.31	-0.146***	0.239***
Gift	13.1	11.91	16.26	0.043*	-0.012
Marriage	28.08	24.73	36.99	0.122***	-0.22***
The quality of soil (%)					
Sandy	56.71	57.86	53.66	-0.042	0.023
Clayey	29.52	28.09	33.33	0.052	-0.03
Lateritic	12.76	13.44	10.98	-0.024	0.047***
Topology (%)					
Plain	72.92	75.73	65.45	-0.102***	-0.049***
Plateau	20.2	19.24	22.76	0.035	0.038**
Low ground	5.33	3.97	8.94	0.049***	0.002
Slope	1.22	0.92	2.03	0.011	0.005
Land-related investments (%)					
Compost	46.06	46.72	44.31	-0.024	0.089***
Chemical fertilizer	17.54	16.02	19.92	0.032	0.093***
Phytosanitary products	12.54	10.99	16.67	0.056**	0.071***
Number of observations (Crop fields)	**901**	**655**	**246**		

Source: Constructed by the author using LSMS-ISA 2014 data concerning Burkina Faso.

Table 4: Distribution of land tenure security by crop characteristics and family farming labour in Burkina Faso in 2014

Variables	**All crop fields**				**Collective management of crop fields**			
	Total	**Ownership with agreement**	**Ownership without agreement**	**Difference**	**Total**	**Ownership with agreement**	**Ownership without agreement**	**Difference**
Main crops and soil productivity								
Grain crop (%)	67.41	68.86	62.19	-0.066***	74.84	75.22	73.34	-0.018
Cash crop (%)	21.1	19.99	25.06	0.05***	15.52	15.22	16.72	0.014
Soil productivity (Mean)	95 067.65	93154.91	101937.7	8782.75***	97 355.92	95185.09	105881.8	10696.67***
Farming laborforce intensity (Mean)								
Days.Men per hectare for plowing[12]	8.358	8.757	6.927	-1.83***	7.937	8.3	6.49	-1.81***
Days.Men per hectare for crop field maintenance	16.628	17.814	12.371	-5.443***	15.219	16.16	11.51	-4.64***
Days.Men per hectare for harvesting	2.487	2.678	1.8	-0.877***	2.682	2.86	1.98	-0.878***
Observations (Champs)	**4 105**	**3 211**	**894**		**3 124**	**2 490**	**634**	

[12]"Days.Men" is a unit of measure of work duration carried out by a family workforce. The concept "Men" encompasses men and women.

Table 4: Vertical continuation

Variables		**Individual management of crop fields**			**Individual management vs Collective management**
	Total	**Ownership with agreement**	**Ownership without agreement**	**Difference**	**Difference**
Main crops and soil productivity					
Grain crop (%)	45.95	49.62	36.18	-0.134***	0.256***
Cash crop (%)	41.73	39.39	47.97	0.085**	-0.241***
Soil productivity (Mean)	87195.08	85100.45	92775.21	7674.76	10 084.64***
Farming laborforce intensity (Mean)					
Days.Men per hectare for plowing	10.277	11	8.345	-2.657***	-2.697***
Days.Men per hectare for crop field maintenance	22.3	24.99	15.127	-9.867***	-8.833***
Days.Men per hectare for harvesting	1.92	2.11	1.4	-0.708***	0.746***
Observations (Champs)	**901**	**655**	**246**		

Source: Constructed by the author using LSMS-ISA 2014 data concerning Burkina Faso.

Theorem 7.1 *(The Chain Rule (C.R))*
Let E and F be two normed vector spaces, and G a separate topological vector space. Let U be an open set of E, V an open set of F, f a function of V in G, and x a point of U. If f is differentiable at the point x and g is differentiable at the point $f(x)$, then $g \circ f(a)$ is differentiable at the point x, and:

$$D_a(g \circ f) = (D_{f(a)}g) \circ D_a f \tag{5}$$

In particular if $E = R^n$, $F = R^m$ and $G = R^p$, the jacobian matrix of the partial derivatives of $g \circ f$ at the point x is that of g at the point $f(a)$ times that of f at the point x, which can be written as follows:

$$\begin{aligned} f(x) = (f_1(x), \ldots, f_m(x),\ g(y) = (g_1(y), \ldots, g_m(y)) \\ et\ (g \circ f)(x) = h(x) = (h_1(x), \ldots, h_p(x)) \\ \frac{\partial h_i(x)}{\partial x_j}(a) = \sum_{k=1}^{m} \frac{\partial g_i}{\partial y_k}(f(a)) \frac{\partial f_k}{\partial x_j}(a) \end{aligned} \tag{6}$$

C.R.1. The Chain Rule applied to the case study of Burkina Faso

The application of the Chain Rule theorem to the simultaneous equations system allows us to compute the productivity-effect of land tenure security as follows. For the sake of simplicity, we have removed the subscripts of the variables[13].

C.R.1.2 Productivity-effect of objective land tenure security

$$\begin{aligned} \left(\frac{\partial Rend}{\partial ModeSecur}\right) \times \frac{1}{e^{\bar{X}}} = & \frac{\partial Rend}{Compost} \times \frac{\partial Compost}{\partial ModeSecur} \\ & + \frac{\partial Rend}{\partial EngChim} \times \frac{\partial EngChim}{\partial Compost} \\ & + \frac{\partial Rend}{\partial Phyto} \times \frac{\partial Phyto}{\partial Compost} \\ & \times \frac{\partial Compost}{\partial ModeSecur} + \frac{\partial Rend}{\partial Phyto} \\ & \times \frac{\partial Phyto}{\partial EngChim} \times \frac{\partial EngChim}{\partial Compost} \\ & \times \frac{\partial Compost}{\partial ModeSecur} \end{aligned} \tag{7}$$

[13] *Rend* stands for agricultural productivity.

C.R.1.2 Productivity-effect of individual management of cropfields

$$\begin{aligned} \left(\frac{\partial Rend}{\partial GesInd}\right) \times \frac{1}{e^{\bar{X}}} = & \frac{\partial Rend}{\partial Compost} \times \frac{\partial Compost}{\partial GesInd} \\ & + \frac{\partial Rend}{\partial EngChim} \times \frac{\partial EngChim}{\partial Compost} \times \frac{\partial Compost}{\partial GesInd} \\ & + \frac{\partial Rend}{\partial Phyto} \times \frac{\partial Phyto}{\partial Compost} \times \frac{\partial Compost}{\partial GesInd} \\ & + \frac{\partial Rend}{\partial Phyto} \times \frac{\partial Phyto}{\partial EngChim} \times \frac{\partial EngChim}{\partial Compost} \\ & \times \frac{\partial Compost}{\partial GesInd} \end{aligned} \tag{8}$$

C.R.1.3 Productivity-effect of the location of crop fields close to dwellings

$$\begin{aligned} \left(\frac{\partial Rend}{\partial Case}\right) \times \frac{1}{e^{\bar{X}}} = & \frac{\partial Rend}{\partial Compost} \times \frac{\partial Compost}{\partial Case} \\ & + \frac{\partial Rend}{\partial EngChim} \times \frac{\partial EngChim}{\partial Compost} \times \frac{\partial Compost}{\partial Case} \\ & + \frac{\partial Rend}{\partial Phyto} \times \frac{\partial Phyto}{\partial Compost} \times \frac{\partial Compost}{\partial Case} \\ & + \frac{\partial Rend}{\partial Phyto} \times \frac{\partial Phyto}{\partial EngChim} \times \frac{\partial EngChim}{\partial Compost} \\ & \times \frac{\partial Compost}{\partial Case} \end{aligned} \tag{9}$$

C.R.1.4 Productivity-effect of a socio-economic organization membership

$$\begin{aligned} \left(\frac{\partial Rend}{\partial Assoc}\right) \times \frac{1}{e^{\bar{X}}} = & \frac{\partial Rend}{\partial Compost} \times \frac{\partial Compost}{\partial Assoc} \\ & + \frac{\partial Rend}{\partial EngChim} \times \frac{\partial EngChim}{\partial Compost} \times \frac{\partial Compost}{\partial Assoc} \\ & + \frac{\partial Rend}{\partial Phyto} \times \frac{\partial Phyto}{\partial Compost} \times \frac{\partial Compost}{\partial Assoc} \\ & + \frac{\partial Rend}{\partial Phyto} \times \frac{\partial Phyto}{\partial EngChim} \times \frac{\partial EngChim}{\partial Compost} \\ & \times \frac{\partial Compost}{\partial Assoc} \end{aligned} \tag{10}$$

Where

$$\begin{aligned} \overline{X} = & \alpha_{4h} + \tau_1 \overline{Compost}_{hf} + \tau_2 \overline{EngChim}_{hf} + \tau_3 \overline{PhytoSan}_{hf} \\ & + \delta_1 \overline{Log(LandSize)}_{hf} + \delta_2 \overline{[Log(LandSize)]^2}_{hf} \\ & + \delta_3 \overline{Log(JourHomRecolt)}_{hf} + \delta_4 \overline{Clayey} + \delta_5 \overline{Sandy}_{hf} \\ & + \delta_6 \overline{Plain}_{hf} + \delta_7 \overline{Plateau}_{hf} + \delta_8 \overline{MixedCropping}_{hf} \\ & + \delta_9 \overline{CashCrop}_{hf} + \delta_{10} \overline{TractionAnimal}_{hf} \end{aligned}$$

and

$$Compost = CompostPredict;$$
$$PhytoSan = PhytoSanPredict;$$
$$EngChim = EngChimPredict$$

The global indirect productivity-effect of the above-defined proxies of land tenure security is given by the total differential formula as follows:

$$\begin{aligned} d(Rend) = & \frac{\partial Rend}{\partial ModSecur} \times dModSecur \\ & + \frac{\partial Rend}{\partial GesInd} \times dGesInd \\ & + \frac{\partial Rend}{\partial Case} \times dCase \\ & + \frac{\partial Rend}{\partial Assoc} \times dAssoc \end{aligned} \tag{11}$$

Since $d(ModSecur) = d(GesInd) = d(Case) = d(Assoc) = (1 - 0) = 1$, then the total differential of the productivity of soil with regard to land tenure security can be written as follows:

$$d(Rend) = \frac{\partial Rend}{\partial ModSecur} + \frac{\partial Rend}{\partial GesInd} + \frac{\partial Rend}{\partial Case} + \frac{\partial Rend}{\partial Assoc} \tag{12}$$

The above procedure can also be used to compute the other effects of land tenure security in terms of absolute value or proportion.

Table 5: The determinants of the household propensity to resort to the different types of land-related investments in Burkina Faso in 2014.

Variables	**Limited security proxies and absence of risk variables**	**Augmented security proxies and absence of risks variables of tenure insecurity**			**All variables**		
	Compost	**Compost**	**Chemical fertilizer**	**Phytosanitary product**	**Compost**	**Chemical fertilizer**	**Phytosanitary product**
Chemical fertilizer Predict				0.096^{***} (3.15)			0.091^{***} (3.05)
Compost Predict			0.067^{***} (2.14)	-0.023^{***} (2.78)		0.069^{***} (2.17)	-0.019^{***} (2.42)
Objective land tenure security	0.13^{***} (6.75)	0.11^{***} (4.22)			0.09^{***} (3.65)		
Individual land management		-0.23^{***} (10.41)			-0.22^{***} (10.66)		
Crop field location		0.34^{***} (18.22)			0.33^{***} (18.44)		
Socio-economic organization membership		-0.23^{***} (3.29)			-0.09^{**} (3.38)		
Clayey	-0.12^{***} (5.39)	-0.13^{***} (5.08)	0.035^{**} (2.00)	-0.0027 (0.74)	-0.128^{***} (5.06)	0.035^{**} (2.01)	-0.002 (0.66)
Sandy	0.02 (0.90)	0.07 (0.26)	-0.03^{*} (1.89)	-0.014^{***} (3.07)	0.006 (0.23)	-0.03^{*} (1.89)	-0.014^{***} (3.08)
Plain	0.14^{***} (5.63)	0.09^{***} (3.33)	-0.10^{***} (5.55)	-0.004 (0.84)	0.088^{***} (3.26)	-0.10^{***} (5.55)	-0.005 (0.93)
Plateau	0.055^{**} (2.04)	0.019 (0.65)	-0.043^{***} (2.71)	0.011^{*} (1.85)	0.026 (0.90)	-0.044^{***} (2.68)	0.009^{*} (1.70)
Land size	0.26^{***} (10.88)	0.28^{***} (10.43)	0.112^{***} (18.91)	0.011^{***} (2.68)	0.28^{***} (10.16)	0.11^{***} (18.73)	0.011^{***} (2.69)
Squared Land Size	-0.04^{***} (8.26)	-0.044^{***} (7.45)	$---$	$---$	-0.042^{***} (7.12)	$---$	$---$

Table 5: Continuation

Household Head Age	0.009^{***}	0.012^{***}	-0.002	-0.0002	0.012^{***}	-0.002	-0.0003
	(2.60)	(2.89)	(0.78)	(0.33)	(2.88)	(0.79)	(0.39)
Squared Household head Age	$-1e-4^{**}$	$-1e-4^{**}$	$7.41e-06$	$-3.2e-06$	$-1e-4^{**}$	$7.52e-06$	$2.81e-06$
	(2.07)	(2.52)	(0.30)	(0.33)	(2.53)	(0.31)	(0.42)
Days.Men for plowing	0.002	0.005^{***}	$---$	$---$	0.005^{***}	$---$	$---$
	(1.11)	(2.77)			(2.73)		
Days.Men for maintenance	0.001	0.002^{*}	-0.003^{***}	$---$	0.002^{*}	-0.003^{***}	$---$
	(1.31)	(1.72)	(4.60)		(1.66)	(4.59)	
Household head education level	0.004	0.025^{*}	0.038^{**}	0.003	0.026	0.038^{**}	0.003
	(0.14)	(0.86)	(2.07)	(0.57)	(0.90)	(2.06)	(0.56)
Number of crop fields owned	-0.028^{***}	-0.02^{***}	-0.008	-0.002^{*}	-0.02^{***}	-0.008^{*}	-0.002^{*}
	(4.21)	(2.64)	(1.82)	(1.91)	(2.73)	(1.80)	(1.86)
Wealthiness	0.085^{***}	0.105^{***}	0.066^{***}	0.012^{*}	$0.11.^{***}$	0.066^{***}	0.011^{*}
	(3.67)	(3.90)	(3.38)	(1.85)	(4.04)	(3.85)	(1.81)
Muslim	0.085^{***}	0.11^{***}	0.06^{***}	-0.01^{*}	0.11^{***}	0.06^{***}	-0.01^{*}
	(3.67)	(3.90)	(4.04)	(1.92)	(4.04)	(4.03)	(1.91)
Dependency ratio	-0.006	-0.01	-0.005	-0.002	-0.011	-0.005	-0.002
	(0.56)	(0.64)	(0.59)	(0.74)	(0.77)	(0.58)	(0.64)
Household distant to the nearest market	0.001^{*}	0.001	-0.001^{***}	$2e-4^{***}$	$4e-4$	-0.0014^{***}	$2e-4^{*}$
	(1.80)	(1.14)	(4.14)	(1.58)	(0.78)	(3.17)	(1.67)
Household distant to the nearest road	0.001^{***}	0.002^{***}	$-5e-4^{*}$	$-3e-4^{***}$	0.002^{***}	$-5e-4^{*}$	$-3e-4^{***}$
	(3.31)	(3.18)	(1.71)	(3.44)	(2.90)	(1.70)	(3.39)
Household adult members				-0.004^{***}	$---$	$---$	-0.0037^{***}
				(3.39)			(3.31)
Insecurity					-0.17^{***}	0.009	0.019
					(4.60)	(0.728)	(1.53)
Number of observations	10,607	10,607	10,607	10,607	10,607	10,607	10,607
Wald Chi2	498.33^{***}	664.07^{***}	714.74^{***}	664.65^{***}	669.33^{***}	714.36^{***}	666.87^{***}

Source: Generated by the author using LSMS-ISA 2014 data for Burkina Faso's case.

Note: Absolute value of z-statistics are in brackets. The significance levels are $p < 0.01(^{***})$, $p < 0.05(^{**})$, $p < 0.1(^{*})$

Table 6: **The determinants of soil productivity in Burkina Faso in 2014.**

Variables	**Compost**	**Chemical fertilizer**	**Phytosanitary product**	**All variables**
	Coefficient	**Coefficient**	**Coefficient**	**Coefficient**
Compost Predict	-0.14^{*}			-1.08^{***}
	(1.73)			(8.28)
Chemical Fertilizer Predict		0.72^{***}		2.47^{***}
		(10.66)		(7.76)
Phytosanitary Products Predict			-1.01^{***}	-1.51^{***}
			(9.34)	(4.34)
Clayey	-0.49^{***}	-0.08^{**}	-0.05	-0.21^{**}
	(5.09)	(2.23)	(1.05)	(2.07)
Sandy	0.028	0.012	-0.43^{***}	-0.17
	(0.38)	(0.34)	(6.98)	(1.30)
Plain	0.24^{**}	0.052	-0.35^{***}	0.39^{***}
	(2.38)	(1.22)	(5.70)	(3.00)
Plateau	-0.23^{**}	-0.058	-0.08	0.22^{*}
	(2.43)	(1.38)	(1.35)	(1.70)
Log(Land Size)	0.18^{***}	-0.041^{***}	0.23^{***}	-0.34^{***}
	(4.34)	(14.81)	(5.5)	(4.31)
$(\text{Log(LandSize)})^2$	0.015^{***}	0.07^{***}	0.028^{***}	0.07^{***}
	(2.58)	(10.61)	(4.63)	(10.89)
Log(Days.Men for Harvesting)	0.2^{***}	0.24^{***}	0.24^{***}	0.20^{***}
	(11.84)	(15.34)	(15.66)	(12.02)
Mixed cropping	0.16^{***}	0.2^{***}	0.18^{***}	0.2^{***}
	(7.08)	(9.26)	(8.24)	(8.94)
Cash crop	0.07^{***}	0.04^{*}	0.014	0.08^{***}
	(2.78)	(1.75)	(0.62)	(3.30)
Traction Animal	0.11^{***}	0.08^{***}	0.10^{***}	0.06^{***}
	(5.53)	(3.96)	(5.17)	(3.28)
Constant	10.52^{***}	11.29^{***}	10.36^{***}	10.8^{***}
	(90.77)	(206.54)	(112.87)	(58.29)
Number of observations	$10,607$	$10,607$	$10,607$	$10,607$
LR Chi2 (26)	1258.08^{***}			
LR Chi2 (22)		1555.27^{***}		
LR Chi2 (23)			2044.84^{***}	
LR Chi2 (43)				3329.47^{***}

Source: Generated by the author using LSMS-ISA 2014 data for Burkina Faso case

Note: Absolute value of t-statistics are in brackets. The significance levels are $p < 0.01(^{***})$, $p < 0.05(^{**})$, $p < 0.1(^{*})$

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