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Effects of rainfall variability on agriculture in Burkina Faso: a gender-sensitive CGE analysis.

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Résumé

Cette analyse utilise un modèle d'Equilibre Général Calculable dynamique intégrant la dimension genre pour l'analyse des conséquences de la forte variabilité interannuelle des précipitations du Burkina Faso sur son agriculture et sur ses femmes agricultrices en particulier. Nous montrons d'abord qu'une pluviométrie « normale » se traduit par une forte variabilité des performances du secteur agricole et du bien-être des ménages ruraux. L'agriculture féminine y semble plus sensible et les inégalités de genre en termes de participation aux activités économiques ou domestiques s'en trouvent renforcées. Nous montrons aussi que ces effets différenciés sont négativement amplifiés lors des épisodes « exceptionnels » de sécheresse que subit régulièrement le pays. Nous montrons enfin comment des stratégies d'amélioration de la maitrise de l'eau ou de promotion de l'utilisation de semences plus résistantes permettraient d'atténuer les effets négatifs des chocs pluviométriques, et comment des mesures plus ciblées en faveur des femmes agricultrices pourraient permettre de réduire leur vulnérabilité.

Mots clés : Variabilité climatique, Agriculture, Femmes

Abstract

This analysis uses a gendered dynamic Computable General Equilibrium model to analyse the consequences of Burkina Faso's high rainfall variability on its agriculture and on female farmers in particular. We firstly show that "normal" rainfall results in highly variable performances of the agricultural sector and variability in the well-being of farm households. Female farmers appear to be more vulnerable and this reinforces gender inequalities in terms of their participation in economic and domestic activities. We also show that these gendered effects are further aggravated during "exceptional" drought episodes that the country regularly experiences. Lastly, we illustrate how strategies aimed at improving water management or encouraging the use of more resistant seeds could mitigate the negative effects of rainfall shocks, and how more targeted measures in favour of female farmers could help reduce their vulnerability.

Keywords: Climate variability, Agriculture, Women

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List of acronyms and abbreviations

CES	:	Constant Elasticity of Substitution
FCFA	:	Franc of the Financial Community of Africa
CREG	:	Regional Consortium for Research in Generational Economics
DGESS	:	General Directorate for Sector Studies and Statistics
CGE	:	Computable General Equilibrium
EHCVM	:	Harmonised Survey on Living Conditions of Households
ENBT	:	National Time-Budget Survey
FAO	:	Food and Agricultural Organisation
IPCC	:	Intergovernmental Panel on Climate Change
GIZ	:	German society for international cooperation
INSD	:	National Institute of Statistics and Demography
MAAH	:	Ministry of Agriculture and Water Management
SAM	:	Social Accounting Matrix
MEA	:	Ministry of Water and Sanitation
MERH	:	Ministry of the Environment and Fisheries Resources
SDG	:	Sustainable Development Goals
UN	:	United Nations
PDSI	:	Palmer Drought Severity Index
PEP	:	Partnership for Economic Policy
PNA	:	National Adaptation Plan
PNDES	:	National Economic and Social Development Plan
PNSR	:	National Rural Sector Programme
UNDP	:	United Nations Development Programme

1. Introduction

The agricultural sector generates 25% of the Gross Domestic Product and employs nearly 80% of the workforce in Burkina Faso, therefore occupying a central place in the economy (DGESS/MAAH, 2020). However, this sector, which is mainly made up of small family-run rainfed subsistence farms, is highly exposed to the irregular rainfall conditions experienced in the country. There are often “good” and “bad” harvests, sometimes with extremely difficult years during the severe droughts that occur unfrequently but recurrently in the country (International Disaster, 2020). In this context, Burkinabe farmers thus appear to be highly vulnerable. This is more specifically true for women, whose situation is particularly fragile in rural areas. As the exposure of Burkina Faso's agriculture to rainfall variability is likely to increase in the future with the consequences of climate change in this Sahel region (GIZ, 2020; IPCC, 2022), the Burkinabe authorities have therefore reconsidered their development policies by incorporating objectives to reduce gender inequalities and promote women's empowerment in order to reduce their vulnerability. These new concerns, which are in line with the UN's Sustainable Development Goals (SDGs) for the year 2030, and more specifically with SDGs 5 and 13, which respectively aim to "*Achieve gender equality and empower all women and girls*" and "*Take urgent action to combat climate change and its impacts*", are for instance now integrated in the National Economic and Social Development Programme (PNDES II, 2021-2025), the National Rural Sector Programme (PNSR III, 2021-2025) and the National Adaptation Plan to tackle the effects of climate change (PNA 2015-2020).

This study uses a Computable General Equilibrium (CGE) model with the objectives to analyse the consequences of erratic rainfall in Burkina Faso on the economy in general, and on female farmers in particular, and to assess the effectiveness of certain adaptation strategies that could help to minimise the associated risks of this high rainfall variability. It is in line with recent works addressing climate risks in this country (i.e. Gonzalez et al., 2011; Laeticia, 2012; McOmber, 2020; Sawadogo and Fofana, 2021). Nevertheless, beyond a simple specific case study of Burkina Faso, our contribution to the existing economic literature is twofold.

First, our analysis draws on the many CGE studies that seek to analyse the vulnerability of developing economies to agricultural climate shocks. Compared to econometric or partial equilibrium analyses, one of the main advantages of CGE modelling is that it allows us to assess the impact of a climate shock not only on agriculture, but also on the economy as a whole, by considering the multiple interactions of supply, demand, prices and income. However, in existing economic literature, the majority of CGE analyses have focused on the medium- to long-term consequences of climate change and, particularly, on the potential effects of the resulting decline in agricultural yields (Calzadilla et al., 2009; Bezabih, et al., 2010; Gebreegziabher et al., 2015; Montaud et al., 2017; Sawadogo and Fofana, 2021). Only

a few studies have focused on the consequences of increased climate variability in the short term or on the specific cases of extreme events (Cabral, 2012; Sassi and Cardaci, 2013; Vargas et al, 2018; Montaud et al., 2017, 2019; Escalante and Maisonnave, 2022). In this paper, we adopt the latter approach, focusing on the effects of inter-annual variations in rainfall as well as on the effects of severe droughts that regularly affect Burkina Faso.

Secondly, our analysis also addresses the issue of gender inequalities in developing economies and, more specifically, female vulnerability to climate shocks (see for example Eastin, 2018). Understanding how gender inequalities determine the extent to which women are vulnerable to these shocks or how these shocks in turn cause these inequalities is indeed an important matter. However, in order to be able to address this question, we need to integrate a gender dimension into our CGE model. Many attempts have been made in this respect since the early 2000s (Fontana et al., 2014; 2020). While some studies are limited to the gender disaggregation of production factors or households (e.g. Arndt and Tarp 2000; Thurlow, 2006; Arndt et al., 2006; Arndt et al., 2011; Latorre; 2016; Al-Haboby et al, 2019; World Bank, 2019), others, more ambitious, introduce a modelling of the domestic sphere of the economy (Fontana and Wood, 2000; Fontana, 2001, 2002; Fofana et al., 2003; Terra et al., 2008; Cockburn et al., 2008; Cicowiez, 2018; Arora and Rada, 2020; Cikowiez and Lofgren, 2021). In our study, we adopt the latter approach, by building a "gendered" CGE model including household domestic activities and endogenous labour supplies. To our knowledge, such a CGE model has never been used in the case of Burkina Faso, even though domestic activities, where women are largely over-represented, are particularly important in the country's rural areas. However, by contributing to the production of goods and services essential to the well-being of households and by mobilising economic resources such as labour, they potentially interact strongly with the overall functioning of the economy, particularly in the event of rainfall shocks.

In the first section, the specific background of the study is described. The second section presents in detail the main assumptions of our CGE model for Burkina Faso, and more particularly the ways we include gender dimensions in this model and take into account family farm workers. The third and fourth sections present respectively the results of the simulations of the effects of a "normal" interannual variability in rainfall in the country and of an "exceptional" variability associated with severe drought episodes. Finally, the fifth section presents the effectiveness of some strategies for coping with these climatic events.

2. Background

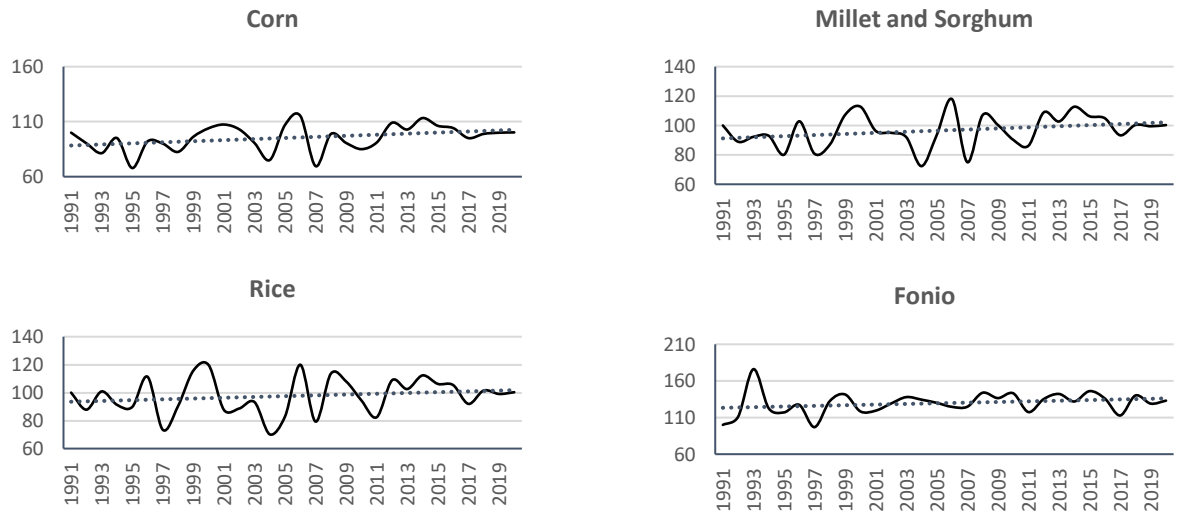
2.1. Burkinabe agriculture: a fragile sector vulnerable to rainfall variability

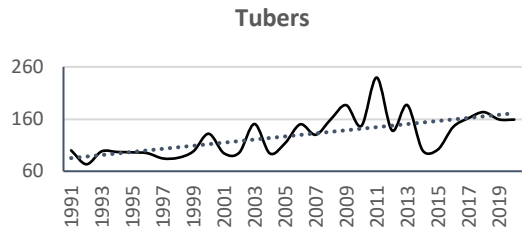
Mostly comprising small family subsistence farms of less than 5 ha (72% of all farms),

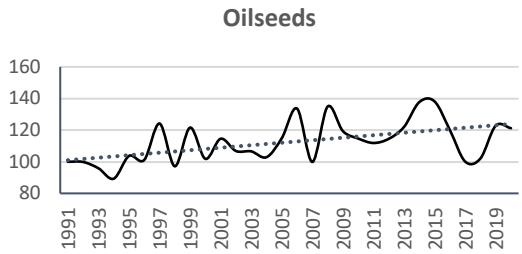
Burkina Faso's agricultural sector is a traditional one where production efficiency is particularly low (DGESS/MAAH 2020, 2021). Indeed, technical capital remains rudimentary (75% of farmers own a traction animal and less than 5% of cultivated areas are ploughed with a tractor). The land factor is also generally of poor quality. Due to the shortening of fallow periods associated with the country's high population growth, the country is experiencing a gradual decline in soil fertility that is not counterbalanced because of the low use of agricultural inputs. Furthermore, the level of human capital is also very low, with a poorly trained workforce and a low literacy rate (40%). In this context, the agricultural yields of Burkinabe agriculture are structurally low and are generally estimated to be around 40% of their full potential.

Moreover, because it is essentially rainfed and does not enjoy the benefit of sufficient perennial water resources, this agriculture is strongly determined by rainfall conditions (Ministry of Water and Sanitation, 2016; EHCVM, 2018; Ayphassorho et al, 2020). The most significant rainfall occurring during the wet season (May to October) is subject to large inter-annual variations that lead to high variations in crop yields (Graph 1), leading to a high degree of uncertainty around labour planning and incomes (Ouédraogo, 2012; Teno et al., 2018; Schleypen et al. 2019). Furthermore, in addition to this "normal" variability in rainfall, the agricultural sector in Burkina Faso is also subject to exceptional episodic droughts, with some years considered as being catastrophic. This was for example the case in 1973 and 1983. During these years, drought had a strong impact on the food security of the population (MERH, 2015; International Disaster, 2020).

Graph 1 - Yield trends for the main crops in Burkina Faso
(Base 100 in 1991)







Source: Authors, based on FAOSTAT-Data (2022)

2.2. Burkinabe agriculture: a sector where gender inequalities are significant

The level of gender inequality is particularly high in Burkina Faso. The country ranks 121st out of 144 in the Global Gender Gap Report (World Economic Forum, 2022) and 147th out of 162 countries in the Gender Inequality Index (UNDP, 2020). Nevertheless, these national figures conceal the specific situation of rural dwelling women. Women, who account for 51.6% of all agricultural workers (family or paid) and who ensure more than 75% of all subsistence production, experience an even more unfavourable situation (FAO, 2008; PNG, 2009; Gonzalez et al, 2011; Perez et al, 2015; SIGI, 2018; DGESS/MAAH, 2021).

One of the first examples of these inequalities is reflected in their restricted access to land ownership. Women account for less than 8% of landowners, with property rights being held by their spouses. Women thus have relatively limited economic decision-making power. For instance, only 14% of them have the possibility of selling their land and only 20% to use it as a guarantee in obtaining a loan. These figures are 32% and 40% respectively for male owners (SIGI, 2018). There are many reasons for these difficulties, some of which are difficult to identify precisely. Among these, the low literacy rate among female farmers (21%) and their difficulties in obtaining credit (56.5% of land is acquired through loans). But there are also more deeply rooted reasons, linked to values and traditional norms of customary laws that promote discriminatory practices against women (Vokouma, 2018; Henry, Toe and Ouedraogo, 2016). The symbolic importance of arable land, the special status accorded to women (who live in separate households from birth to marriage) or the widely shared idea that household investment decisions should be made exclusively by men, all have a negative impact on women. In this context, only 11% of the land is ultimately used by women on a permanent basis (MAAH, 2021).

A second manifestation of gender inequalities in rural areas lies in the conditions in which female farmers carry out their production activities. On the one hand, the average size of their farms is modest, around 0.4 ha compared to 2.5 ha for men (MAAH, 2021). On the other hand, although their participation in cash crop production increased during the period 2011-2020, from 15% to 28%, they remain predominantly engaged in subsistence farming, where they

cultivate land that is generally of lower quality and often located in areas that are poorly levelled and more exposed to climatic events. Their production technology is also mostly rudimentary. For instance, in 2019, almost two-thirds of the land cultivated by women was ploughed by yoke and less than 2% by motorised traction (DGESS/MAAH, 2021). Lastly, because of the small size of their farms, their limited access to expertise and their reliance on smaller social networks, they do not enjoy the same benefits as their male counterparts in terms of technical assistance from the state or regional or local agricultural organisations (AFDR et al., 2019). This assistance may include the use of inputs such as improved seeds, chemical fertilisers or pesticides. It may also include land development and preparation (e.g. zai, half-moons or stone barriers) which are increasingly essential to deal with the high level of soil erosion in the country, but which are labour-intensive and require financial resources to which women have limited access. Finally, it may also concern agricultural advisory services, which are mainly geared towards men. On the whole, these precarious conditions restrict their investment capacities and prevent them from securing their production and income, which averages 175,000 CFA francs per year compared to 451,770 CFA francs for men (INSD, 2018).

A final example of gender inequalities can be found in the way tasks are divided within agricultural households. Women are much more engaged than men in domestic work (e.g. preparation of meals, fetching water, childcare and education, etc.), which restricts the amount of time they can spend on other activities. According to the CREG (2019), they spend an average of 2.7 hours per day on this type of work, compared to 2.6 hours on income-generating activities. On the other hand, men spend 0.2 hours and 4.2 hours on these activities respectively. As an indirect effect, girls are withdrawn from school to help with domestic activities.

2.3. Burkinabe agriculture: a sector threatened by climate change

The structural challenges facing Burkina Faso's agricultural sector, together with its high exposure to rainfall variability, pose a significant risk to farmers, particularly the most vulnerable among them, women. The climatic conditions under which agricultural activities take place are increasingly affected by global climate change and indicate that future deterioration is likely (IPCC, 2014, 2022). Based on the RCP2.6 or RCP6.0 scenarios, the GIZ (2020) estimates, for example, that the average temperature in the country could rise by 1.9°C to 4.2°C by the year 2080 compared to pre-industrial levels. At the same time, the number of very hot days per year (where the maximum temperature exceeds 35°C) is also expected to increase significantly across the country. With regard to precipitation, the projections are more uncertain. While some climate models predict a tendency for average annual precipitation to decrease, others predict an increase. However, there seems to be a consensus that there will be greater inter-annual variability in rainfall, regardless of the RCP scenario considered.

Moreover, most studies predict an increase in the intensity and frequency of extreme droughts, which contribute to increased soil degradation, reduced availability of water for irrigation and consequently reduced crop yields.

3. "Gendered" CGE modelling framework

Our CGE model distinguishes five representative agents (Non-*Agricultural Households, Agricultural Households, Firms, Government and Rest of the World*), 36 production activities, of which 20 are agricultural, four types of labour factors (*Female and Male Salaried Labour, Female and Male Family Farm Labour*) and two types of capital (*Agricultural and Non-agricultural Capital*). It is mainly based on the $PEP_{1\text{-}t}$ model by Decaluwé et al. (2013). However, some modifications have been made to this original model. They mainly concern the integration of the gender dimension and the inclusion of family workers into the agricultural production process.

3.1. Key model features

The within-period specification of the model is based on fairly standard assumptions of Computable General Equilibrium modelling generally adopted for a developing economy. On the supply side, each producer is assumed to be a price-taker and maximises profit by combining, according to a CES (Constant Elasticity Substitution) function, the capital factor (here assumed to be fixed in each branch for each period) with the different types of labour provided by households. The characteristics of this production process, which includes notably a gender dimension, are discussed in more detail in section 3.2 for the agricultural activities. Part of the supply of products available in the economy comes from the rest of the world in an "Armington" specification reflecting the imperfect substitutability between domestic products and imports. On the income side, each private representative agent receives primary revenues from the factors of production on the basis of its initial endowments. It also receives transfer revenues from other agents and uses its total revenue to pay taxes, distribute transfer revenues, make consumption expenditures and save. On the demand side, intermediate consumption of products is specified through a Leontief-type function in the production processes of each branch. The final consumption of each household is based on a LES (Linear Expenditure System) function derived from a utility function maximisation programme under the constraint of its disposable income. The *Government's* final consumption is, for its part, assumed to be exogenous in nominal value and is distributed among the products according to a fixed key. Part of the demand expressed in the markets comes from the rest of the world in the form of exports. The division between the domestic and foreign markets is specified through a CET (Constant Elasticity Transformation) function that allows for imperfect substitutability between goods. Finally, the demand for investment goods is determined

according to a fixed allocation key between products based on the total nominal level of investment, which is itself determined endogenously in the model. On the market side, products and salaried labour are exchanged on their respective markets with endogenously determined prices and wages. In line with the Walrasian spirit of the model, it is the nominal exchange rate that has been chosen to play the role of the numeraire. The capital market is not explicitly modelled. The macroeconomic closure rule is in fact of the "Saving-Driven" type with a nominal level of investment determined by the degree of savings available in the economy, itself determined endogenously for each agent. On the other hand, it is exogenous for the *Rest of the World*, as it corresponds (in absolute value) to the current account balance assumed to be fixed. This choice makes it possible to avoid, in the wake of an exogenous shock, a variation in domestic savings being automatically compensated by an equivalent variation in external savings, and therefore without consequences for the level of investment. In this context, the General Equilibrium of the economy for each period is ultimately defined by the vector of prices and wages for which demand equals supply in all markets simultaneously.

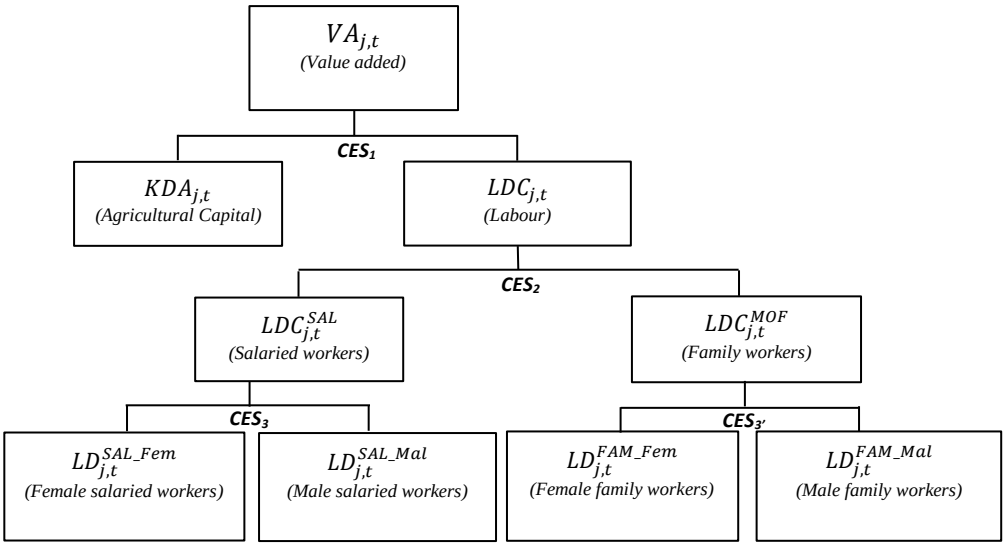
The between-period specifications of the model are recursive. The main specification concerns the accumulation of capital stock in each activity which reflects an exogenous depreciation rate and the new capital installed as determined for each period. The latter is defined endogenously during the previous period, through an investment function reflecting an allocation rule between activities, that is based on the ratio of the rental rate to the cost of that capital (see Decaluwé et al. 2013, p54, for more details).

3.2. Nature of the production process in agriculture

One of the main original features of our model concerns the way in which we regard the production processes of agricultural activities. Firstly, following the pioneering work of Arndt and Tarp (2000), each type of agricultural production is differentiated according to the gender of the farm head. Secondly, their production processes are represented through a three-level nested CES function structure (Figure 1).

At the first level, each activity *j* conventionally uses agricultural capital $(KDA_{j,t})$ and composite labour $(LDC_{j,t})$ to generate value added $(VA_{j,t})$. At the second level, it is assumed that the composite labour factor demand is split between salaried workers $(LDC_{j,t}^{SAL})$ and family workers$(LDC_{j,t}^{FAM})$. The specific case of the latter is discussed in more detail in section 3.4. On the third level, we introduce a second gender differentiation for family and salaried workers. The underlying assumption here is that, for each category, female labour $(LD_{j,t}^{SAL_Fem}, LD_{j,t}^{FAM_Fem})$ and male labour $(LD_{j,t}^{SAL_Mal}, LD_{j,t}^{FAM_Mal})$ are not homogeneous. The division between the two is based on their respective levels of remuneration and degrees of substitutability.

Figure 1 - Structure of the production processes of agricultural activities



3.3. Domestic activities and endogenous labour supplies

Another originality of our model lies in the introduction of domestic activities into the overall functioning of the economy. Following the pioneering work of Fontana and Wood (2000), this is an opportunity to introduce additional gender differentiations into the model and to endogenize the various labour supplies.

3.3.1. Trade-offs between market consumption, domestic consumption and leisure

The starting point of the approach is that each representative household *h* is assumed to arbitrate between three types of "goods": the "leisure" time of its individual active members ($LO_{h,t}^{SAL_Fem}, LO_{h,t}^{SAL_Mal}$, $LO_{h,t}^{FAM_Fem}$ *et* $LO_{h,t}^{FAM_Mal}$); goods produced in its domestic sphere ($CZ_{h,t}$); market goods produced by economic activities ($C_{h,i,t}$). According to standard consumer analysis, it is also assumed that the demand for each of these goods is defined by maximising the household's utility under the constraints of its full budget (see Fofana et al., 2003 for a similar approach). As is generally the case in CGE modelling, the form chosen for the utility function is a Stone and Geary one, which incorporates a minimum level of consumption for each of these goods. In the case of leisure, this may include, for example, essential personal activities (e.g. self-care). The full household budget ($FY_{h,t}$) consists of the various incomes (wage and non-wage) received in the economy ($YH_{h,t}$) plus the value of domestic production generated by the household ($PZ_{h,t}.Z_{h,t}$) and the "income" generated by leisure time. The value of the latter is determined by an opportunity cost, meaning the remuneration rates of the different active members of the household (w_t^l) on the labour market.

(1) $\text{MAX } U_{h,t} = \prod_l \left(LO_{h,t}^l - \overline{LOmin_h^l}\right)^{\beta l_h^l} . \left(CZ_{h,t} - \overline{CZmin_h}\right)^{\beta z_h} . \prod_i \left(C_{h,i,t} - \overline{Cmin_{h,i}}\right)^{\beta c_{h,i}}$

With: $\sum_l \beta l_h^l + \beta z_h + \sum_i \beta c_{h,i} = 1 \quad \forall h \quad (Engel\ law)$

Under constraint:

(2) $FY_{h,t} = YH_{h,t} + PZ_{h,t}.Z_{h,t} + \sum_l w_t^l.(LO_{h,t}^l + \overline{LOmin_h^l})$ $\forall h$

In consumer equilibrium, the first-order conditions of this maximisation program enable the determination of the household demand functions *h* for each type of good.

(3) $LO_{h,t}^l = \overline{LOmin_h^l} + \frac{\beta l_h^l.(CTH_{h,t} - \sum_i PC_{i,t}.\overline{Cmin_{h,i}})}{w_t^l.(1-\sum_l \beta l_h^l - \beta z_h)}$ $\forall h$

(4) $C_{h,i,t} = \overline{Cmin_{h,i}} + \frac{\beta c_{h,i}.(CTH_{h,t} - \sum_i PC_{i,t}.\overline{Cmin_{h,i}})}{PC_{i,t}.(1-\sum_l \beta l_h^l - \beta z_h)}$ $\forall h$

(5) $CZ_{h,t} = \overline{CZmin_h} + \frac{\beta z_h.(CTH_{h,t} - \sum_i PC_i.\overline{Cmin_{h,i}})}{PZ_{h,t}.(1-\sum_l \beta l_h^l - \beta z_h)}$ $\forall h$

With this modeling approach, the quantity of labour, which is now measured in hours, thus becomes endogenous in the model. Each *l*-type active member of a household *h* has indeed a certain amount of available time ($\overline{TIME_h^l}$) that he or she can allocate between leisure ($LO_{h,t}^l$), domestic production of goods ($LZ_{h,t}^l$) or paid employment in the non-domestic sphere of the economy ($LS_{h,t}^l$). It is assumed that the time spent on each of these three activities is mutually exclusive. By positing $\overline{MAXHOUR_h^l} = \overline{TIME_h^l} - \overline{LOmin_h^l}$, the maximum time that men or women allocate to the different activities after excluding the minimum leisure time they employ for their well-being, Equation (3) is transformed to finally specify the household labour supply *h* by category of workers *l* in the economy:

(6) $LS_{h,t}^l = \overline{MAXHOUR_h^l} - LZ_{h,t}^l - \frac{\beta l_h^l.(CTH_{h,t} - \sum_i PC_{i,t}.\overline{Cmin_{h,i}})}{w_t^l.(1-\sum_l \beta l_h^l - \beta z_h)}$ $\forall h \; et \; \forall l$

3.3.2. Supply and demand in the domestic sphere

The production process of domestic goods (Z_h) is assumed to mobilise only the different labour times of the household members (LZ_h^l), without intermediate consumption or capital factor. For simplicity's sake, we consider here that this production corresponds to a single good combining the various domestic activities (looking after children, making meals, fetching water, etc.). We also assume that female and male working hours are imperfect substitutes, combined in a CES function with an elasticity of substitution value that reflects the degree of rigidity of gender roles within the household.

(7) $Z_{h,t} = A_h^Z.\left[\beta_h^Z.LZ_{h,t}^{Mal\,-\rho_h^Z} + (1-\beta_h^Z).LZ_{h,t}^{Fem\,-\rho_h^Z}\right]^{-\frac{1}{\rho_h^Z}}$ $\forall h$

(8) $LZ_{h,t}^{mal} = \left[\frac{\beta_h^Z}{1-\beta_h^Z}.\frac{w_{h,t}^{Fem}}{w_{h,t}^{Mal}}\right]^{\sigma_h^Z}.LZ_{h,t}^{fem}$ $\forall h$

With:

(9) $LZ_{h,t}^{Mal} = LZ_{h,t}^{Mof_Mal} + LZ_{h,t}^{Sal_Mal}$ $\forall h$

(10) $LZ_{h,t}^{Fem} = LZ_{h,t}^{Mof_Mal} + LZ_{h,t}^{Sal_Mal} \quad \forall h$

(11) $w_{h,t}^{Mal} = \frac{w_t^{Mof_Mal}.LZ_{h,t}^{Mof_Mal} + w_t^{Sal_Mal}.LZ_{h,t}^{Sal_Mal}}{LZ_{h,t}^{Mof_Mal} + LZ_{h,t}^{Sal_Mal}} \quad \forall h$

(12) $w_{h,t}^{Fem} = \frac{w_t^{Mof_Fem}.LZ_{h,t}^{Mof_Fem} + w_t^{Sal_Fem}.LZ_{h,t}^{Sal_Fem}}{LZ_{h,t}^{Mof_Fem} + LZ_{h,t}^{Sal_Fem}} \quad \forall h$

It is moreover considered that this production is entirely self- consumed $(CZ_{h,t})$ by the household that produces it. Its value is determined here by its opportunity cost, i.e. the expected labour market remuneration rates in the non-domestic sphere of the economy by the various engaged active members of the household.

(13) $CZ_{h,t} = Z_{h,t} \quad \forall h$

(14) $PZ_{h,t}.Z_{h,t} = \sum_l w_t^l.LZ_{h,t}^l \quad \forall h$

3.4. Specific case of Family Farm Workers

The supply in each labour market segment corresponds to the sum of the supply expressed by the different households. Regarding salaried workers, it is conventionally assumed that the wage rate allows supply and demand to be balanced.

(15) $LSTot_t^l = \sum_h LS_{h,t}^l \quad \forall l$

(16) $LSTot_t^l = \sum_j LD_{j,t}^l \quad \forall l = SAL_Fem\ , SAL_Mal$

The remaining originality of our model compared to the $PEP_{1\text{-}t}$ model concerns the way in which we regard family farm workers. This type of labour is generally excluded from CGE modelling. Indeed, as it is generally considered as unpaid, it is technically not possible to take it into consideration as a non-priced production factor in the CES production functions, i.e. to assume that its marginal productivity is zero. However, with an average number of eight family workers per household, this labour force is largely dominant among the small-scale subsistence farms that typify the Burkinabe agricultural sector and thus represents nearly 84% of total employment (MAAH, 2021). Therefore, not taking these family workers into account leads to a significant underestimation of the labour force available for the agricultural sector.

We have therefore chosen to include it in our CGE modelling, although it is considered somewhat differently from the other salaried agricultural workers. This is because, on the one hand, this family labour force (which here concerns only agricultural households and the agricultural activities) is specific in nature. Women, for example, are over-represented, with almost 50% of the workforce used in this context. This is also the case for children, whose involvement in agricultural labour is a common practice in Burkina Faso, helping to socialise them and prepare them for the future (World Bank, 2006). According to the INSD (2011), 38% of children between the ages of 5 and 14 work in the country, mostly in agriculture (67.3%)

and on family farms (83.6%). On the other hand, the ways in which this labour force is used is also of a particular nature. Given that they are both family and work-related relationships, they are not only governed by the economic determinants that define the traditional framework of the employer-employee relationship, but also by socio-cultural determinants that are integrated into the system of rights and obligations that influence individual and collective behaviours (particularly solidarity) within the family and, more generally, within farming communities. Given this, one of the consequences of the use of family farm labour is, ultimately, a high level of underemployment and/or a low level of productivity, which is further accentuated by the seasonal nature of farm tasks (World Bank, 2006).

In order to formally integrate family labourers into the production function of an agricultural activity, we have first assumed that they receive remuneration in return for their effective participation in the creation of value added. We also considered, however, that this remuneration could not really be considered as a wage that could be determined on a family labour "market". To simplify, we have therefore set it at a very low rate (compared to the wages of other agricultural labourers), which we have derived from agricultural income data provided by the employment surveys. Secondly, given the fixed nature of this remuneration, we have specified a quantity adjustment mechanism to ensure the balance between supply and demand in the family labour "market". In standard CGE modelling, this adjustment by quantities is usually carried out through the introduction of an unemployment variable. However, this assumption of involuntarily unemployed family workers does not really make sense, and it seems to us more appropriate to consider a situation of underemployment and endogenous flexibility of the overall productivity of family labour (ψ_t).

(17) $LSTot_t^l = \psi_t . \sum_j LD_{j,t}^l \qquad \forall l = FAM_Fem\ , FAM_Mal$

In this context, it can thus be considered that family farm workers adjust their labour productivity collectively according to the needs of the branches and the informal collective solidarity rules that prevail in the rural areas of the country. During periods of low activity, and therefore of lower demand for labour, with the same total volume of hourly labour supply available, this implies some forms of mutual aid and sharing of agricultural tasks to prevent some family workers from becoming idle, thereby reducing the total productivity of labour. In contrast, during periods of high activity, productivity increases collectively, where previously, the potential of this workforce was under-utilised and productivity reserves were untapped.

3.5. Initialisation and calibration of the model

The empirical basis of the model is provided by the most up-to-date SAM available for Burkina Faso (UNDP, 2019), which includes a disaggregation of the agricultural labour factor according to gender and by whether it is family or wage labour, as well as a distinction made

for households according to their place of residence. Our main modification to adapt it to our specific needs was to disaggregate the agricultural activities according to the gender of the farm head. The disaggregation was carried out using data from the Harmonised Survey on Living Conditions of Households (EHCVM, 2018).

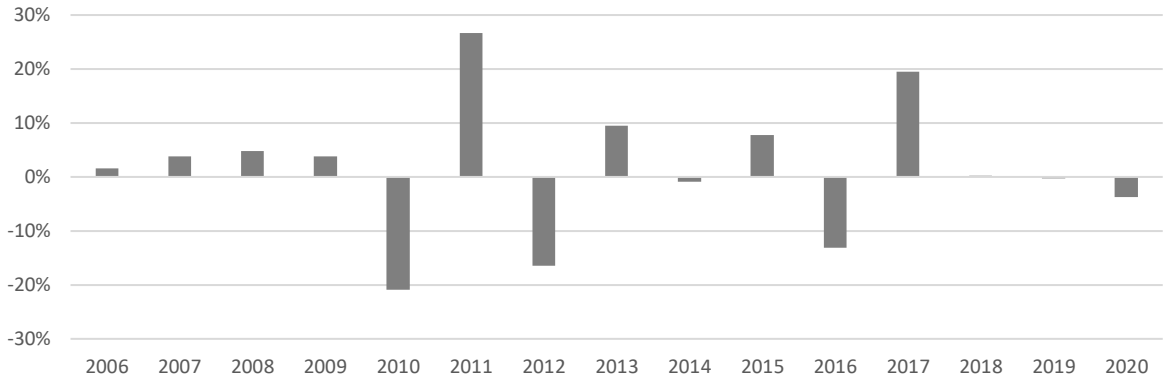
The vast majority of the values of the variables in the initial equilibrium as well as most of the parameters of the model concerning the non-domestic sphere of the economy can be derived from the data in this SAM. Where this was not possible we used the values used in other CGE models for Burkina Faso (e.g. Cockburn et al., 2016; Zidouemba et al., 2018). In the absence of reliable data on the elasticities of substitution between female and male labour, we have chosen a low value (0.5) reflecting the relative rigidity of male and female labour roles in the country (see Fontana, 2020). Regarding the values of the variables and parameters concerning the domestic sphere which are not explicitly introduced in the SAM, we have used data from the CREG (2019) obtained from the National Time Budget Survey of Burkina Faso (ENBT, 2018). It can be noted that men spend an average of 25% of their daily time (excluding biological sleep time) engaged in economic activities, 1.3% on domestic tasks and 73.7% on their leisure activities. By comparison, women's time-use patterns are 15%, 16% and 69% respectively. Based on this, we used the calibration method of De Melo and Tarr (1992), by setting the values of the income elasticity of labour supply (ε_h^l) and the Frisch parameter ($Frisch_h$) (here respectively at -0.2 and -1.5), to derive the values of the parameters βl_h^l, βz_h, $MAXHOUR_h^l$, $\beta c_{h,i}$ and $\overline{Cmin_{h,i}}$ (see Fofana, 2003).

4. Effects induced by rainfall variability

4.1. Definition of the scenario

The first objective of our analysis is to simulate the effects caused by an interannual rainfall variability such as might occur in Burkina Faso. The definition of our scenario is therefore primarily based on the choice of a reference period for our simulations. We have chosen to use the evolution of rainfall as observed in Burkina Faso between the years 2006 and 2020. This 15-year period seems sufficiently long to consider the effects of the rainfall variations experienced by the country, but also sufficiently short to ensure that the structure of the economy remains in line with the initial calibration of the model. Graph 2 shows these rainfall variations observed at the national level.

Graph 2 - Annual variations in rainfall in Burkina Faso (in %)



Source: Authors based on data from https://climateknowledgeportal.worldbank.org/

The definition of our scenario is based secondly on the estimation of the exogenous shocks induced by this variability in rainfall. Here, in the CGE model, rainwater is considered to be an implicit production factor whose variations affect positively or negatively the overall productivity of factors in agricultural activities.

(16) $B_{j,t}^{VA} = (1 + \varepsilon_j . \frac{Rain_{j,t} - Rain_{j,t-1}}{Rain_{j,t-1}}) . B_{j,t-1}^{VA} \qquad \forall j \in Agriculture$

Where $\varepsilon_j = \frac{dYield_{j,t}}{Yield_{j,t}} \Big/ \frac{dRain_{j,t}}{Rain_{j,t}}$ is the yield elasticity of a crop j with respect to rainfall

To estimate the different elasticities ε_j, we used data on agricultural yields and on regional rainfall provided respectively by the FAO and the World Bank for the period 1986-2020. Our empirical strategy is presented in the Appendix. One of the main difficulties we faced here is that there are significant differences in rainfall patterns across the country as well as an unequal geographical distribution of agricultural activities. Therefore, in this context, $Rain_{j,t}$ is a synthetic rainfall index, specific to each crop *j*, and corresponding to the average regional rainfall totals weighted by the share of each region in the production of this product. The results of these estimates are shown in Table 1.

Table 1 - Yield elasticities for each crop type in relation to rainfall (in %)

	Corn	Rice	Millet & Sorghum	Fonio	Tubers	Pulses	Oilseeds	Fruit & vegetables	Other crops
Elasticities	0.618	0.656	0.578	0.509	0.938	0.156	0.028	0.09	0.136

Sources: authors' calculations based on World Bank (https://climateknowledgeportal.worldbank.org/) and FAOSTAT-Data (2022)

4.2. Results of the simulation

Consistent with the logic of dynamic CGE modelling, we first simulate the evolution of the Burkinabe economy over 15 periods without rainfall variability. In this counterfactual

scenario (Sc_{Trend}) of a balanced growth path, agricultural yields are therefore assumed to be constant and the various exogenous variables of the model evolve according to the average annual population growth of 3%. Secondly, we introduce rainfall-induced yield variations between the years 2006 and 2020 for each crop and simulate the evolution of the economy in response to these annual shocks (Sc_{Var}).

The results obtained (Table 2) are presented for some key indicators for both the total period of 15 years and for two sub-periods corresponding to "good" and "bad" years, here defined as those with positive and negative effects respectively on agricultural production. In line with our counterfactual interpretation, the results in terms of average (Av_{dev}) or maximum deviation (Max_{dev}) are calculated from the relative differences (in %) found, year by year, between the values obtained in Sc_{Var} and those obtained in Sc_{Trend}. They thus make it possible to distinguish, all other things being equal, the effects of rainfall variations over the considered period. But given the nature of our scenario, in which variability is an essential element, two additional indicators over the 15-year period have also been included for each variable in Table 2. The first (ΔCV) corresponds to the difference in the coefficient of variation observed between SC_{Var} and SC_{Trend}. Therefore, it can be considered here as the part of the variability in the SC_{Var} that is attributable to yield variability. The second indicator (Δrc) corresponds to the average of the absolute values of the differences in interannual rates of change observed between the SC_{Var} and the SC_{Trend} over 15 years. This can be interpreted as an indication of the level of interannual variability caused by exogenous yield shocks. By way of comparison, these indicators are also calculated for average agricultural yields.

4.2.1. Macroeconomic and sectoral effects

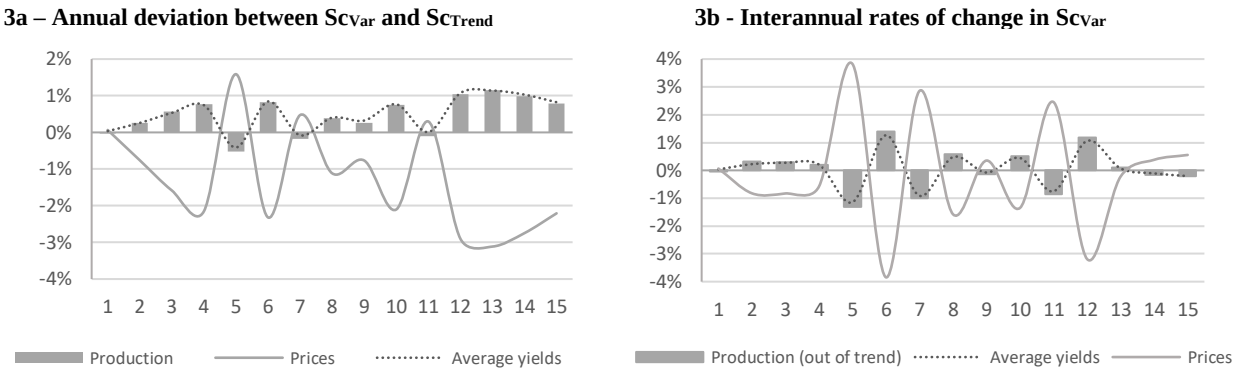
The macroeconomic and sectoral effects of rainfall variations are presented in the first part of Table 2. A first insight is that, over the 15 periods and for all the indicators selected, the average positive effects of "good" years outweigh the average negative effects of "bad" years with regard to rainfall. At the national scale, the decrease in rainfall during "bad" years contributes for instance to a deviation in real GDP from the trend by -0.08% on average over the timeframe while the increase in rainfall during "good" years contributes to a deviation by +0.22%, resulting in a net effect of +0.14%. These variations in rainfall also generate a price deviation of +0.32% ("bad" year) and -0.90% ("good" year) for an overall net effect of -0.57% over the period. As a result, real household income deviates on average by -0.23% ("bad" year) and +0.69% ("good" year), resulting in a net increase of +0.44% over the period.

The second finding is that the effects of the shocks are particularly pronounced in the agricultural sector but relatively limited in the non-agricultural sector. For the agricultural sector it can be seen that during "bad" years the volume of production, imports, exports as well as

price levels deviate on average from the references values of the trend by -0.21%, +0.30% -0.05% and +0.61% respectively. On the other hand, during "good" years these values are +0.71%, -1.81%, + 0.49% and -1.98% respectively. Concerning the non-agricultural sector for "bad" years, it can be seen that production and prices deviate on average from the trend by +0.01% and +0.02% respectively, while imports deviate slightly by +0.06% and exports by -0.01%. During "good" years these deviations are +0.03%, -0.16%, -0.11% and +0.07% respectively.

The third finding is that, logically, rainfall fluctuations increase the variability of the selected macroeconomic and sectoral indicators. For the non-agricultural sector, less affected by rainfall shocks, these increases in variability are relatively modest. However, they are particularly significant for the agricultural sector. This is particularly true for prices, whose variability appears even greater than that of yields, indicating that a large proportion of the effects of shocks are passed on through this channel. This is equally the case for the volume of agricultural imports which, given our "Armington assumption" and the relatively high degree of product substitutability, are particularly sensitive to changes in relative prices. For illustrative purposes, Graph 3 shows, period by period, the relative annual deviations of agricultural prices, production and yields between the SC_{Var} scenario and the counterfactual scenario (3a), as well as the evolution of interannual rates of change (excluding the trend effect) in the SC_{Var} scenario (3b).

Graph 3 - Indicators of agricultural production and price variability over the period



Source: Authors based on the simulation results

In order to explain these different results and to better identify the transmission channels of rainfall shocks on the Burkinabe economy at the national level, it is appropriate to review the mechanisms at work in our model. For a given year, rainfall variations represent a shock (negative or positive) on the overall productivity of the agricultural activities, the severity of which depends on the respective elasticities of each crop. The agricultural sector, which is

directly affected by this initial supply shock, is therefore logically the most affected. The variations in its overall productivity effectively impact its production capacity, modifying in particular its demand for labour factor (the capital factor is assumed to be fixed for each period). Yet, given the circular logic that characterises our model, this direct initial supply effect on the agricultural activities also generates indirect secondary effects on the overall economy, through changes in the conditions of equilibrium on the various markets (labour and products) and the associated variations in prices, wages and finally incomes. Therefore, the non-agricultural sector is also indirectly impacted by rainfall variability, but to a lesser extent. In the Walrasian logic that governs our model, one of the first channels of transmission of these effects is through the mobility of the production factors between the two sectors. Nevertheless, in our modelling options, we have considered that agricultural capital (mainly land) is not used by the non-agricultural activities. Likewise, we assumed that the agricultural activities relied heavily on family labour for production and that this specific labour force was concentrated exclusively within the agricultural sector. Lastly, considering our assumption that these workers are generally underemployed, we have also assumed that their overall productivity can be adjusted both upwards and downwards according to the needs of production. In this rather dualistic setting, inter-sectoral factor mobility therefore only concerns salaried workers and is ultimately not very significant in terms of indirectly transmitting the effects of rainfall shocks from the agricultural sector to the non-agricultural sector. This transmission therefore takes place mainly through the other types of linkages that exist between these two sectors, or, more generally, between rural and urban areas of the country. At this level, we can, for example, mention the backward and forward linkages that the agricultural and non-agricultural branches maintain through the input-output matrix of intermediate consumption. Depending on the intensity of these linkages, the variation in the volume of agricultural production caused by rainfall, for example, mechanically affects the volume of demand it makes on other branches, and consequently the production and labour factor demand of the latter. In addition, we can also mention the final demand for goods and services that agricultural and non-agricultural households generate in the different activities, and which is notably influenced by the respective incomes of these households in these different areas of the country.

4.2.2. Effects in rural areas

The most specific effects of rainfall variations in rural areas are presented in the second part of Table 2. One of the first findings is that female agriculture is more affected by rainfall shocks than male agriculture, both in terms of the average deviation from the trend and the variability of these indicators. This differentiated impact is mainly due to the nature of the respective production functions of each type of agriculture. In comparison to male agriculture, female production processes are in fact characterised by a lower capital intensity (reflecting

the structural difficulties that women face in gaining access to land) and by a lower labour productivity. These characteristics, which are taken into account in the model during calibration, subsequently make them more sensitive to rainfall shocks. In the event of a negative shock, since the quantity of land is assumed to be fixed, it is therefore necessary for them to call for more labour, to compensate for the resulting decline in total factor productivity and production capacity. However, this call for additional labour is partly limited because it is also called for by male farmers, who are themselves affected by the shock and represent a larger share of total agricultural production. Ultimately, these difficulties are reflected in a greater decline in female production compared to the trend (-0.22% for female and -0.20%, for male agriculture respectively) but also in a greater increase in the prices of its products (+1.20% for female and +1.17%, for male agriculture respectively). In our General Equilibrium approach, this price effect also reinforces the differentiated impact between the two types of agriculture through the substitution effects that it creates, in terms of consumer demand for the different products. In the event of a positive rainfall shock, the same mechanisms are at work, but this time they favour female agriculture. The increase in total factor productivity leads to a more significant increase in production (+0.91% compared to +0.57% for male agriculture), while at the same time decreasing the demand for labour factor. Given the lower productivity of female agriculture compared to male agriculture, the average labour variations observed are higher for female labour (-3.97% in male agriculture compared to -3.44% in female agriculture) than for male labour (-3.92% in male agriculture compared to -3.38% in female agriculture).

The second conclusion is that rainfall shocks also have an impact on the participation of men and women in domestic production in agricultural households. It can be seen, that participation increases for both sexes during 'bad' years and decreases during 'good' years, although these variations are slightly greater for women than for men. Several mechanisms are at work here. First and foremost, due to the mutually exclusive use of time by each type of worker, the level of participation in domestic tasks is indirectly determined by the amount of time they allocate to the market sectors of the economy. In accordance with the logic of the consumer analysis on which equation 6 of our model is based, several effects, sometimes contradictory, determine these labour supplies. This is the case, for example, for changes in wages (for salaried workers only) where the increase (decrease) has, all other things being equal, two opposite effects. On the one hand, it increases or decreases (depending on the type of year, “good” or “bad”) the opportunity cost of leisure and therefore contributes to increasing or decreasing the supply of labour in the economy (substitution effect). On the other hand, it also contributes to increasing or decreasing the nominal income of the household, thus generating an increase or decrease in its consumption of normal goods (including leisure) and

thus a decrease or increase in the labour supply (income effect). The same income effect can also be generated by an increase in non-wage household income. In addition, price variations also have an influence on the labour supply of agents. On the one hand, they increase or decrease the price of the minimum consumer basket (depending on the type of year experienced, “good” or “bad”). On the other hand, all other things being equal, since leisure, market goods and household goods are net substitutes in the utility function, an increase (“bad” years) or decrease (“good” years) in prices in the economy increases or decreases the demand for leisure, thus helping to decrease or increase the supply of labour. Secondly, the amount of domestic labour for each category of worker (female or male) is also determined by their respective behaviours regarding the allocation of their time between its different possible uses. These distribution modalities were defined during the initial calibration of equations 6 and 7 of the model using data from the Burkina Faso National Time-Budget Survey-2018 (CREG, 2019). This survey shows, for instance, that in comparison to women, men spend almost 12 times less time doing domestic tasks and 1.5 times more time on leisure activities. These behavioural differences, which in fact determine an over-representation of women in the production of domestic goods within the household, can, for example, help to explain why an increase in the amount of time that men spend on economic activities results in a proportionally greater decrease in their participation in the performance of domestic tasks.

The third finding is that the welfare of agricultural households logically deteriorates in “bad” years and improves during “good” ones, and that there is considerably more variability to be observed among the different selected welfare indicators, than observed for yields. For instance, their real income deviates from the trend by an average of -0.76% in "bad" years and by +2.72% during "good" years. To complete the analysis, some additional welfare indicators of have been introduced at this level. Three food security indicators were calculated from the results of the CGE model (see Escalante and Maisonnave, 2022): *availability* (approximated by the per capita amount of agricultural goods produced for the local market); *access* (approximated by their actual consumption of agricultural goods); and *vulnerability* (approximated by the ratio between the amount of imported agricultural goods and their actual consumption of agricultural goods). Based on these indicators, the results confirm that agricultural Burkinabe households logically see their food situation deteriorate in 'bad' rainfall years and improve during 'good' years. Lastly, a poverty indicator was also estimated. Since this could not be obtained from the CGE model (due to the representative agent assumption) we calculated it by simply applying, period by period, the rate of change in per capita consumption of the representative agricultural household head, observed in the CGE simulation to the consumption data of each of these households present in the Harmonised Survey on Living Conditions of Households (HHSLC, 2018). At the same time, a new poverty

line is also calculated for each period based on the variations of the price index, obtained in the CGE simulation for the products that constitute it. This "minimal" microsimulation does not consider the intra-group heterogeneity of the agricultural household and does not endogenize the behaviour of its different members, but it nevertheless seems to provide a satisfactory proxy for the evolution of the poverty rate. The results show that while, on average, rather favourable rainfall over the fifteen years helps to reduce the poverty rate by -1.19%, "bad" years, on the other hand, increase it by +0.54%. The variability of these food security indicators is also particularly pronounced.

Table 2 - Effects of rainfall variability similar to that observed in Burkina Faso between 2006 and 2020

	Over the 15-year period			"Good" years		"Bad" years	
	Av_{dev} (1)	ΔCV (2)	Δrc (3)	Av_{dev} (1)	Max_{dev} (4)	Av_{dev} (1)	Max_{dev} (4)
Average agricultural yields	*0.50*	*0.47*	*0.48*	*0.72*	*1.14*	*-0.11*	*-0.41*
Macroeconomic and sectoral effects							
Real GDP	0.14	0.09	0.18	0.22	0.35	-0.08	-0.18
Price index	-0.57	0.65	0.71	-0.90	-1.40	0.32	0.78
Real household income	0.44	0.28	0.56	0.69	1.08	-0.23	-0.58
Non-agricultural sector							
Production (volume)	0.03	0.01	0.02	0.03	0.05	0.01	-0.01
Price index	-0.11	0.10	0.10	-0.16	-0.22	0.02	0.11
Imports (volume)	-0.07	-0.04	0.10	-0.11	-0.03	0.06	0.02
Exports (volume)	0.05	0.02	0.04	0.07	0.10	-0.01	-0.04
Agricultural sector							
Production (volume)	0.46	0.29	0.55	0.71	1.14	-0.21	-0.53
Price index	-1.29	1.42	1.53	-1.98	-3.11	0.61	1.59
Imports (volume)	-1.25	-0.69	1.24	-1.81	-0.70	0.30	1.16
Exports (volume)	0.35	0.21	0.31	0.49	0.76	-0.05	-0.27
Impacts in rural areas							
Female Agriculture							
Production (volume)	0.61	0.37	0.68	0.91	1.44	-0.22	-0.64
Prices	-2.97	1.85	3.29	-4.48	-6.94	1.20	3.51
Female labour	-2.28	-1.22	2.62	-3.44	-5.24	0.90	2.66
Male labour	-2.21	-1.20	2.68	-3.38	-5.25	1.01	2.73
Female labour income(real/head)	0.57	0.66	0.74	0.90	1.44	-0.35	-0.80
Male labour income (real/head)	0.50	0.65	0.75	0.83	1.39	-0.40	-0.82
Male Agriculture							
Production (volume)	0.36	0.23	0.47	0.57	0.95	-0.20	-0.44
Prices	-2.76	1.72	3.11	-4.19	-6.53	1.17	3.32
Female labour	-2.62	-1.37	3.08	-3.97	-6.08	1.10	3.14
Male labour	-2.54	-1.34	3.18	-3.92	-6.13	1.26	3.26
Female labour income (real/head)	0.58	0.68	0.76	0.92	1.47	-0.36	-0.82
Male labour income (real/head)	0.52	0.69	0.79	0.87	1.47	-0.43	-0.86
Agricultural Households							
Total income (real/head)	1.79	1.86	2.01	2.72	4.22	-0.76	-2.07
Female labour supply	1.46	0.92	1.71	2.22	3.45	-0.65	-1.77
Male labour supply	0.33	0.20	0.39	0.50	0.78	-0.15	-0.40
Female domestic labour	-1.11	-0.63	1.32	-1.69	-2.63	0.49	1.34
Male domestic labour	-1.04	-0.60	1.25	-1.59	-2.48	0.48	1.27
Availability of food	3.05	3.13	3.40	4.62	7.31	-1.28	-3.42
Access to food	2.67	2.81	3.06	4.08	6.49	-1.20	-3.09
Food vulnerability	-1.37	1.38	1.44	-2.03	-3.15	0.46	1.39
Poverty rate (5)	-1.19	2.44	2.79	-1.82	-2.81	0.54	1.54

Notes: (1) $Av_{dev} = \frac{1}{n}\sum_{t=1}^{n} 100.\frac{x_{i,t}^{Sim} - x_{i,t}^{Trend}}{x_{i,t}^{Trend}}$; (2) $\Delta CV = CV^{Sim} - CV^{Trend}$; (3) $\Delta rc_i = \frac{1}{14}\sum_{t=2}^{15}\left|\frac{\Delta x_{i,t}^{Sim}}{x_{i,t-1}^{Sim}} - \frac{\Delta x_{i,t}^{Trend}}{x_{i,t-1}^{Trend}}\right|$; (4) $Max_{dev} = MAX(\frac{x_{i,t}^{Sim} - x_{i,t}^{Trend}}{x_{i,t}^{Trend}})$;
(5) Absolute deviation

Source: Authors, based on the simulation results

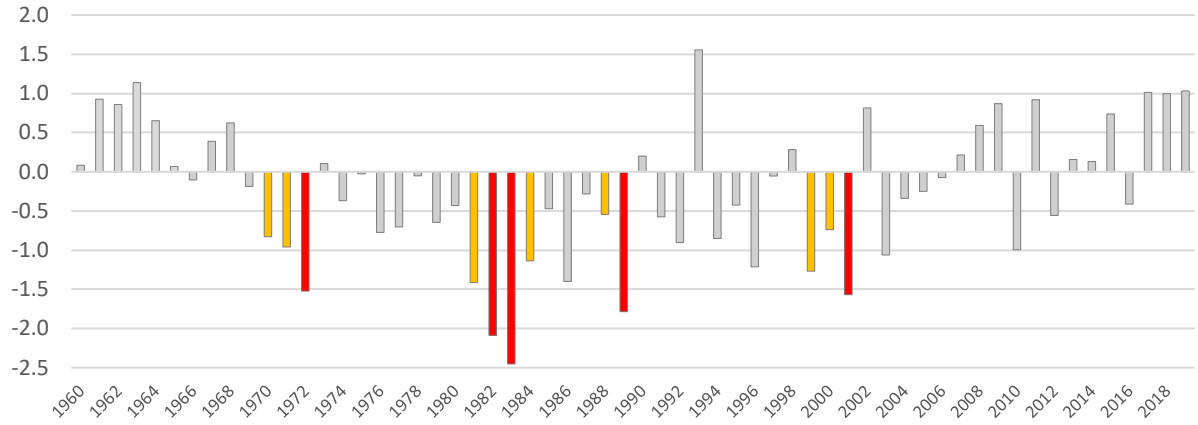
5. Effects induced by an “exceptional” variability in rainfall

In addition to the "normal" variability of rainfall, the climate in Burkina Faso is also characterised by the occurrence of extreme droughts. This type of event is recognised by the authorities as being one of the most significant shocks that the country can encounter (MERH, 2015). In this context, our second objective is to simulate the effects induced by these extreme events, which are relatively rare but have potentially very negative consequences. This new perspective then gives us the opportunity to address the issue of climate change, as the latter is likely to increase the frequency and intensity of these extreme events (see for example Zao and Dai, 2016; IPCC, 2022).

5.1. Definition of the scenarios

The first step in defining our drought scenarios is to estimate the average frequency of the occurrence of such events in the country over a 15-year period. To define an episode of drought, we chose to calculate a weighted *Standardised Precipitation Index* (SPI) that considers the seasonality of rainfall, regional disparities in rainfall and the geographical distribution of agricultural activities in Burkina Faso. In a first step, average rainfall levels for the “useful” months of vegetative growth (May to October) were therefore collected separately for each region in the country using long-term data (1960-2020) provided by the World Bank. A probability density function (here a *Gamma distribution*) was then fitted to the distribution of each of these regional data sets. Then the newly obtained sets of data were transformed into a normal distribution. Here, the positive or negative annual values of the regional SPI indicate precipitation above or below the median, respectively. In a second step, these regional SPI values were weighted, crop by crop, by the respective weight of each region in the national yields of the crop concerned, and then by the respective weight of each crop in national agricultural production. This was based on data provided by the Burkina Faso Ministry of Agriculture (MAAH, 2020). Graph 4 shows the final results obtained. It shows that the severe drought threshold (-1.5) has been exceeded five times during the period 1960-2020 (in 1972, 1982, 1983, 1989 and 2001). It also shows that severe droughts take place during periods of rainfall deficits which can last for several years, thereby confirming the long-lasting nature of a phenomenon that progressively sets in overtime and goes beyond the calendar year. Considering that these consecutive years constitute a single event, four exceptional drought episodes (with an average duration of 3 years) can be identified over the period: 1970-1972, 1981-1984; 1988-1989 and 1999-2001. They are consistent with the various major agricultural crises that have been recorded in Burkina Faso (World Bank, 2011, MERH, 2015; International Disaster, 2020).

Graph 4 - Weighted Standardised Precipitation Index in Burkina Faso



Source: Authors, based on World Bank (2020) and MAAH (2020 data)

The second stage in the definition of our scenarios consists in evaluating the intensity of these drought periods, i.e. the shock they represent for the Burkinabe agricultural sector. In our model, it is assumed that drought shocks occur randomly over the 15-year period and directly affect crop yields:

$$B_{j,t}^{VA} = B_{j,t-1}^{VA} . \left(1 - \tau_t . Drought_{j,t}^{Yields}\right) \quad \forall j \in Agriculture$$

Where: $Drought_{j,t}^{Yields}$ is the impact on crop yields observed during a drought year

τ_t is an exogenous parameter taking the value 1 for a year in which a drought occurs and 0 otherwise.

In the absence of statistical data on the effects of this type of extreme event, we are forced to follow an ad-hoc approach to define $Drought_{j,t}^{Yields}$, and to consider as references the impacts observed during past occurrences. These different values are shown in Table 3.

Table 3 - Variation in average yields for each crop type during a drought episode

	Corn	Rice	Millet & Sorghum	Fonio	Tubers	Pulses	Oil seeds	Fruit & vegetables	Other crops
$Drought_{j,t}^{Yields}$	-14%	-15%	-14%	-13%	-21%	-4%	-1%	-3%	-3%

Sources: Authors based on FAOSTAT-Data (2022)

On these bases, we consider a first scenario (Sc_{Dr}) in which a drought event (with an average duration of three years) occurs every 15 years ($n_d \approx 1$) and has effects on the yields of each crop comparable to what has been observed in the past since 1960. However, to take into account the potential effects of climate change in the Sudan-Sahel region, we also include two additional scenarios. In the first one, considered as optimistic (Sc_{Opt}), the number of severe droughts over the 15-year period is multiplied by 2 ($n_d \approx 2$) and their intensities increased by +10%. In the second so-called pessimistic scenario (Sc_{Pess}), the number of such droughts is multiplied by 3 ($n_d \approx 3$) and their intensities are increased by +20%.

5.2. Results of the simulations

The results of the simulations are presented in Table 4. They show the average one-off impact of a drought event when it occurs, and given that this event may occur several times over the 15 years, their average impact over that period. They also include the indicator ΔCV for the entire period, which can be interpreted as being the share of the new variability attributable to the droughts.

First and foremost, these results confirm the negative consequences of severe droughts in the country both in terms of average effects and variability. Logically, the effects here are of the same nature as those obtained for the "bad" rainfall years in the Sc_{Var} scenario simulation but are greater here as the shocks are stronger and longer. The same mechanisms are indeed at work here. A period of drought greatly reduces the productivity of agricultural activities, reducing their production capacity and modifying their factor demand. Given the way in which agriculture is integrated into the national economy, these effects have repercussions on other activities and the various economic agents through a combination of price, income, supply and demand effects through changes in the conditions of equilibrium on the various markets. In the Sc_{Dr} scenario, for instance, there is a one-off deviation of national GDP by -1.50% with respect to the trend, accompanied by a strong price deviation of +6.55%. Logically, these deviations are particularly pronounced for those agricultural activities strongly affected by the drought. Their production volume and prices deviate significantly from the trend by -4.16% and +13.12%, respectively. This has a significant negative impact on household incomes (-4.78%). As a result, the situation in rural areas deteriorates considerably. This is particularly true for female agriculture which, given the nature of its production functions, is more adversely affected than male agriculture by drought shocks. In the Sc_{Dr} scenario, when a drought occurs, there are for example, changes in their production levels by -5.24% and by -3.45% for the male agricultural sector. Similarly, price levels deviate by +29.69% for female agricultural products and by +27.87% for male agricultural products. Again, the demand for female and male labour factor increases significantly to compensate for the decline in productivity, although to a greater extent for male agriculture than for female agriculture. The income of agricultural households deviates sharply from the trend (-16.86%) while the distribution of domestic tasks within the household evolves to the detriment of women. As a consequence, food security and poverty indicators are particularly worsened.

The results also show that the risk associated with climate change as defined in our scenarios is particularly high. With increasing frequency and intensity of droughts, the negative effects described above would be further amplified. Under the most pessimistic scenario (Sc_{Pess}), national GDP would deviate by -1.86% during a period of drought and prices by +8.19%. Female agricultural production would decline by -6.34% compared to -4.18% for male

agricultural output. As a result, agricultural household incomes would fall sharply and the welfare indicators of these households in terms of food security and poverty would further deteriorate.

Table 4 - Effects of severe drought events in Burkina Faso under different climate scenarios

	Effects over the 15-year period						Effects during a drought		
	SC_{Dr} $n_d = 1$		SC_{Opt} $n_d = 2$		SC_{Pess} $n_d = 3$		SC_{Dr} $n_d = 1$	SC_{Opt} $n_d = 2$	SC_{Pess} $n_d = 3$
	Av_{dev} (1)	ΔCV (2)	Av_{dev} (1)	ΔCV (2)	Av_{dev} (1)	ΔCV (2)	Av_{dev} (1)	Av_{dev} (1)	Av_{dev} (1)
Average agricultural yields	*-0.21*	*0.43*	*-0.47*	*0.58*	*-0.75*	*0.65*	*-3.21*	*-3.49*	*-3.76*
Macroeconomic and sectoral effects									
Real GDP	-0.10	0.03	-0.22	0.05	-0.37	0.06	-1.50	-1.68	-1.86
Price index	0.44	0.88	0.98	1.21	1.64	1.38	6.55	7.35	8.19
Real household income	-0.32	0.11	-0.71	0.18	-1.19	0.21	-4.78	-5.35	-5.94
Non-agricultural sector									
Production (volume)	-0.01	0.00	-0.02	0.00	-0.04	0.01	-0.16	-0.18	-0.19
Price index	0.07	0.15	0.17	0.21	0.28	0.24	1.11	1.25	1.40
Imports (volume)	0.06	-0.02	0.14	-0.03	0.23	-0.03	0.91	1.02	1.14
Exports (volume)	-0.03	0.01	-0.07	0.01	-0.11	0.02	-0.45	-0.51	-0.57
Agricultural sector									
Production (volume)	-0.28	0.09	-0.61	0.15	-1.01	0.17	-4.16	-4.60	-5.05
Price index	0.87	1.75	1.95	2.40	3.24	2.69	13.12	14.64	16.20
Imports (volume)	0.71	-0.13	1.59	-0.19	2.65	-0.19	10.71	11.96	13.26
Exports (volume)	-0.16	0.05	-0.35	0.08	-0.57	0.09	-2.35	-2.60	-2.85
Impacts in rural areas									
Female Agriculture									
Production (volume)	-0.35	0.12	-0.77	0.19	-1.27	0.22	-5.24	-5.79	-6.34
Prices	1.98	0.38	4.43	0.99	7.39	1.65	29.69	33.25	36.95
Female labour	1.51	-0.12	3.37	-0.09	5.61	0.01	22.61	25.27	28.03
Male labour	1.52	-0.12	3.40	-0.09	5.65	0.02	22.77	25.47	28.27
Female labour income (real/head)	-0.43	0.88	-0.97	1.22	-1.62	1.40	-6.50	-7.28	-8.09
Male labour income (real/head)	-0.42	0.86	-0.95	1.20	-1.58	1.37	-6.35	-7.12	-7.92
Male Agriculture									
Production (volume)	-0.23	0.07	-0.51	0.12	-0.84	0.14	-3.45	-3.82	-4.18
Prices	1.86	0.33	4.16	0.88	6.94	1.50	27.87	31.22	34.70
Female labour	1.78	-0.08	3.98	0.02	6.62	0.16	26.66	29.82	33.09
Male labour	1.80	-0.07	4.03	0.03	6.72	0.18	27.03	30.24	33.58
Female labour income (real/head)	-0.44	0.89	-0.99	1.25	-1.65	1.43	-6.63	-7.42	-8.24
Male labour income (real/head)	-0.44	0.89	-0.99	1.25	-1.65	1.43	-6.62	-7.42	-8.25
Agricultural Households									
Total income (real/head)	-1.12	2.29	-2.50	3.20	-4.13	3.67	-16.86	-18.75	-20.67
Female labour	-0.98	0.41	-2.18	0.72	-3.63	0.87	-14.66	-16.37	-18.13
Male labour	-0.22	0.07	-0.49	0.12	-0.82	0.13	-3.31	-3.69	-4.09
Female domestic labour	0.74	-0.14	1.66	-0.19	2.76	-0.19	11.15	12.45	13.79
Male domestic labour	0.70	-0.13	1.56	-0.19	2.58	-0.19	10.46	11.67	12.92
Availability of food	-1.80	3.70	-3.99	5.18	-6.57	5.98	-27.05	-29.93	-32.85
Access to food	-1.62	3.32	-3.59	4.65	-5.92	5.35	-24.36	-26.96	-29.59
Food vulnerability	0.82	1.65	1.83	2.25	3.04	0.22	12.34	13.75	15.19
Poverty rate (3)	0.86	3.18	1.93	4.26	3.19	4.60	12.97	14.48	15.96

Notes: (1) $Av_{dev} = \frac{1}{n}\sum_{t=1}^{n} 100.\frac{x_{i,t}^{Sim} - x_{i,t}^{Trend}}{x_{i,t}^{Trend}}$; (2) $\Delta CV = CV^{Sim} - CV^{Trend}$; (3) Absolute deviation

Source: Authors, based on the simulation results

6. Effectiveness of adaptation strategies

6.1. Strategies for improving agricultural water management

Although the cultivated area in Burkina Faso is about 6.3 million hectares, only 140,000 ha (less than 2%) currently benefit from full or partial water management equipment. These are mainly limited to three crops (*corn, rice, fruit and vegetables*) in varying proportions. Yet, there is still considerable potential in the country to develop irrigable land (235,000 ha) or lowlands that can be easily developed (500,000 ha), along with reserves of groundwater or surface waters that can be mobilised relatively easily (MAAH, 2018).

Table 5 - Breakdown of rainfed and irrigated areas for the main crops

	Cultivated area (ha)	Rainfed share	Irrigated share
Corn	1089389	99.4 %	0.6%
Rice	201 734	65.8%	34.2%
Fruit and vegetables	251678	73,7%	26.3%
Total	**1542801**	**90.8%**	**9.2%**

Source: MAAH (2020)

Given this context, the development of water management systems appears to be a potentially interesting strategy to allow farmers to be less dependent on the level and seasonality of rainfall. Nevertheless, defining such a strategy is not simple. Firstly, because water management for agriculture is a complex area involving a wide range of technical solutions. For instance, it can be achieved (partially or fully) through the development of large-scale facilities (dams, reservoirs, water transport, etc.) or on a smaller scale. In this case, several technologies can be used depending on the nature of the land (lowlands, wetlands, flood-lands, etc.) and can cover different areas such as the collection of water (wells, boreholes, etc.), its extraction (manual or motorised pumps, etc.) or its distribution (gravity, drip, Californian system, etc.). Secondly, because examining the financial aspects of such a strategy is tricky without having clear information on the type and real costs associated with the chosen technical solutions or indeed on who in fact will be implementing them (State, farming communities or individual farmers).

Given these multiple uncertainties, we have therefore chosen not to include these technical or financial aspects in our simulations, but to simply assess the extent to which, once implemented, such a strategy might make it possible to reduce the negative effects of rainfall variability on Burkinabe agriculture. With this in mind, the Sc_{Var}, Sc_{Dr}, Sc_{Opt} and Sc_{Pess} scenarios are once again simulated with the assumption that certain water management objectives have been achieved from the first simulation period. To define realistic hypotheses concerning these

objectives, we chose as a reference the National Strategic Plan for Agro-Sylvo-Pastoral Investment (PSNIASP 2021-2025) for Burkina Faso, which aims to increase the area of irrigated land by 35,000 ha and the area of managed lowlands by 30,000 ha within five years. We adopt these objectives here, while also considering that the distribution of this newly developed land is evenly distributed between the production of *corn, rice* and *fruit and vegetables*. Moreover, in view of our concerns, we are also interested in finding out the manner in which these lands are distributed amongst men and women. The first hypothesis (H_{IR1}), is based on the objectives established by the Burkinabe government in its Rural Development Strategy (SDR), which is to grant 70% of these lands to men and 30% to women. However, considering the fact that this share had already reached 46% by 2019 for the latter, we decided to include two alternative hypotheses (H_{IR2} and H_{IR3}) where this land is split between the two groups at 50%-50% and 30%-70% respectively. Technically, the increase in the share of land with water management facilities is assumed to have two effects in our simulations. Firstly, by allowing some production outside the rainy season, it increases the yields of the affected crops in each of the 15 periods. Based on the data provided by AQUASTAT (2022), this increase has been set at 30%. Secondly, it is assumed that it also reduces proportionally the effects of negative shocks on yields during periods of rainfall deficits ("bad" years or drought). The results of these simulations for the rural areas are given in Table 6. They are presented in terms of the percentage change in average rainfall effects (over the whole period) compared to the same scenario without a water management strategy.

The first observation that can be made from these results is that improving water management appears to be an effective strategy for mitigating the socio-economic effects caused by rainfall variability on Burkinabe agriculture. Under the Sc_{VAR} scenario, the initial positive balance observed over the simulation period between "good" and "bad" years would be considerably strengthened. For instance, the average positive effect of rainfall variability on female and male agricultural production would be increased by +33.7% and +8.8% respectively in the H_{IR2} hypothesis. The positive effect on the income of agricultural households would be increased by +17.2%. That on poverty would be increased by +15.4%. Improved water management would also help to mitigate the negative effects of the occurrence of severe droughts during the period. Both female and male farmers would, for example, continue to see a decline in production, but to a lesser extent than if the strategy were not put in place. This is also the case for the indicators relating to agricultural households. It is worth noting, however, that in the case of the Sc_{Dr} scenario, the negative effect on households' food vulnerability would be more than offset, regardless of the different assumptions made about the distribution of newly developed land between men and women.

The second observation is that, while the protection provided by water management strategies against severe droughts would remain somewhat effective under climate change, this protection would nevertheless tend to decrease, regardless of land-sharing assumptions, as the frequency and intensity of droughts increase. For example, concerning the H_{IR1} hypothesis, the negative effect on the poverty rate of agricultural households would be lowered by -16.4% in the Sc_{Dr} scenario, by -12.9% in the Sc_{Opt} scenario and by -4.4% in the Sc_{Pess} scenario. Under the H_{IR3} hypothesis, these decreases would be -34.4%, -17.7% and -5.9%, respectively.

The final insight is that, while both sexes seem to benefit from the strategies put in place, the ones that provide for a more favourable redistribution of land among women would logically help to reduce women's vulnerability more significantly. Firstly, due to the fact that they are already more vulnerable to rainfall variability and therefore potentially more likely to benefit from the strategy. Secondly, given the unequal distribution of land, any change in the distribution of newly developed land in their favour, represents a greater change for them than for men. In the Sc_{Dr} scenario, for example, the average negative effect of severe droughts on production over the period would decrease by -21.6% for men and by -41.6% for women when the latter receive only 30% of the newly developed land (H_{IR1} assumption). In the scenario where they benefit from 70% (H_{IR3} hypothesis), these same decreases would be -10.8% and -95.7% respectively.

Table 6 - Changes in average rainfall and drought effects in rural areas in the presence of water management strategies

Increase or decrease (in %) of Av_{dev} compared to the same scenario without water management improvements

	Sc_{Var}			Sc_{Dr} $n_d = 1$			Sc_{Opt} $n_d = 2$			Sc_{Pess} $n_d = 3$		
	H_{IR1} M: 70% W : 30%	H_{IR2} M: 50% W : 50%	H_{IR3} M: 30% W : 70%	H_{IR1} M: 70% W : 30%	H_{IR2} M: 50% W : 50%	H_{IR3} M: 30% W : 70%	H_{IR1} M: 70% W : 30%	H_{IR2} M: 50% W : 50%	H_{IR3} M: 30% W : 70%	H_{IR1} M: 70% W : 30%	H_{IR2} M: 50% W : 50%	H_{IR3} M: 30% W : 70%
Female agriculture												
Production (volume)	16.9	33.7	46.8	-41.6	-68.9	-95.7	-20.0	-33.1	-46.0	-13.0	-21.5	-29.9
Prices	23.6	53.2	72.1	-61.1	-97.8	-132.2	-29.9	-47.8	-64.6	-19.9	-31.7	-42.8
Female labour	14.0	36.9	50.3	-42.8	-69.4	-94.6	-21.2	-34.3	-46.8	-14.3	-23.1	-31.4
Male labour	13.3	30.6	41.8	-35.0	-56.9	-77.8	-17.6	-28.6	-39.0	-12.0	-19.4	-26.5
Female labour income	17.2	22.9	29.0	-27.5	-37.8	-47.4	-13.7	-18.7	-23.3	-9.2	-12.5	-15.5
Male labour income	12.5	-17.5	-25.9	4.6	13.9	22.4	0.6	4.2	7.6	-0.8	1.1	2.8
Male agriculture												
Production (volume)	32.9	8.8	5.9	-21.6	-16.3	-10.8	-10.4	-7.8	-5.2	-6.8	-5.1	-3.4
Prices	30.5	9.1	5.8	-24.8	-18.3	-11.6	-12.7	-9.4	-6.0	-8.9	-6.5	-4.2
Female labour	15.5	5.7	3.0	-17.5	-12.1	-6.7	-9.2	-6.4	-3.6	-6.5	-4.6	-2.6
Male labour	13.9	5.5	3.1	-16.2	-11.4	-6.6	-8.5	-6.0	-3.5	-6.1	-4.3	-2.5
Female labour income	17.6	20.2	24.8	-25.7	-33.5	-40.8	-12.8	-16.7	-20.2	-8.7	-11.2	-13.5
Male labour income	6.7	20.8	27.4	-22.4	-31.9	-40.7	-11.5	-16.0	-20.1	-8.0	-10.8	-13.5
Agricultural Households												
Total income	14.1	17.2	21.2	-25.8	-33.5	-40.6	-12.8	-16.4	-19.8	-8.5	-10.9	-13.1
Female labour	14.3	19.4	24.2	-27.6	-36.5	-44.9	-13.9	-18.2	-22.3	-9.5	-12.3	-15.0
Male labour	14.2	19.1	23.8	-27.6	-36.0	-44.3	-13.7	-18.0	-22.0	-9.4	-12.2	-14.8
Female domestic labour	14.4	19.4	24.2	-27.2	-36.6	-45.0	-13.9	-18.2	-22.3	-9.5	-12.3	-15.0
Male domestic labour	14.0	18.3	22.7	-26.3	-34.6	-42.4	-13.3	-17.3	-21.1	-9.1	-11.7	-14.2
Availability of food	15.2	18.8	23.3	-28.2	-37.2	-45.7	-13.7	-18.0	-22.0	-9.0	-11.7	-14.3
Access to food	14.5	16.7	20.9	-24.7	-33.0	-40.8	-12.1	-16.0	-19.8	-8.0	-10.6	-12.9
Food vulnerability	72.5	87.7	109.1	-118.6	-162.3	-200.7	-55.4	-75.5	-93.3	-35.0	-47.6	-58.6
Poverty rate	12.1	15.4	18.0	-16.4	-25.6	-34.4	-12.9	-14.5	-17.7	-4.4	-5.6	-5.9

Source: Authors, based on the simulation results

6.2. Strategies to encourage the use of crop varieties tolerant to water stress

The use of short-cycle crop varieties that are more tolerant to water stress situations is often suggested as a possible adaptation strategy in the face of increasing rainfall deficits (Shiferaw et al. 2014; CGIAR, 2015; Zougmoré et al. 2018). The process of producing and disseminating this type of seed has long been undertaken in Burkina Faso, especially after the great drought of the 1970s. Since 2011, this approach has been formalised in the Sustainable Development Strategy for the Seed Sector (SDDSS). However, although the proportion of land sown with improved seeds has risen sharply since 2011, from 12% to 21% for all crops combined (MAAH, 2021), it remains relatively low. However, the proportion of land sown with

improved seeds is now close to 95% for cotton, which is the country's main cash crop. The use of such seeds depends on many economic factors (availability of seeds, cost of supply, storage difficulties, etc.) and institutional factors (organisation and coordination of the sector, efficiency of distribution channels, seed certification, etc.). It also depends on many socio-cultural factors and, in particular, on some degree of resistance on the part of farmers, who are accustomed to using traditional seeds (which they themselves have selected for decades) and who may sometimes be reluctant to use products stemming from agronomic research, which may lead to new forms of 'dependency' on the seed industry.

On this basis, and following the same logic as above, we simulate the SC_{Var}, SC_{Dr}, SC_{Opt} and SC_{Pess} scenarios, assuming that different targets for the use of these improved seeds have been reached at the beginning of the simulation period for each crop (except cotton). Three assumptions were made. In the first of these (H_{SE1}), male agriculture is considered to have increased its utilisation rate to 70% and female agriculture to 30%. In the two others (H_{SE2} and H_{SE3}) these rates are assumed to have been increased to 50% and 50% and 30% and 70% respectively. Technically, in our simulations, the negative effect of rainfall deficits on individual crop yields is assumed to decrease in proportion to the new percentage of farmers using these seeds, given the level of protection they offer. Regarding this last point, the CGIAR (2015) stresses, for example, that their use reduces the effects of low rainfall by 30% to 50% under ideal production conditions and by less than 10% under the most adverse conditions. We have adopted a conservative approach, considering a 20% reduction for all crops. The results of the simulations are shown in Table 7. They show that the implementation of such an approach mitigates the negative effects of 'bad' rainfall years and severe droughts on farm households and their respective female and male family members. In general, as all simulations show, the welfare indicators of the latter continue to deteriorate, but to a lesser extent than without the adaptation policy. Nevertheless, the protective effects are weaker here than those associated with the strategy to improve water management, as here they only concern years with low rainfall or severe droughts.

Table 7 - Changes in average rainfall and drought effects in rural areas with improved seed use strategies

Increase or decrease (in %) of Av_{dev} compared to the same scenario without the use of improved seeds

	Sc_{Var}			Sc_{Dr} $n_d = 1$			Sc_{Opt} $n_d = 2$			Sc_{Pess} $n_d = 3$		
	H_{SE1} M: 70% W : 30%	H_{SE2} M: 50% W : 50%	H_{SE3} M: 30% W: 70%	H_{SE1} M: 70% W : 30%	H_{SE2} M: 50% W : 50%	H_{SE3} M: 30% W : 70%	H_{SE1} M: 70% W : 30%	H_{SE2} M: 50% W : 50%	H_{SE3} M: 30% W : 70%	H_{SE1} M: 70% W : 30%	H_{SE2} M: 50% W : 50%	H_{SE3} M: 30% W : 70%
Female agriculture												
Production (volume)	2,3	2.8	3.3	-6.0	-10.4	-14.8	-6.0	-10.4	-14.9	-6.0	-10.5	-14.9
Prices	2.4	2.9	3.4	-7.2	-11.6	-15.9	-7.3	-11.8	-16.1	-7.4	-12.0	-16.4
Female labour	2.1	2.6	3.1	-7.0	-11.4	-15.8	-7.1	-11.6	-16.0	-7.2	-11.8	-16.2
Male labour	2.4	3.0	3.5	-7.0	-11.5	-15.8	-7.1	-11.6	-16.1	-7.3	-11.8	-16.3
Female labour income	4.2	4.2	4.2	-11.5	-11.6	-11.6	-11.7	-11.8	-11.8	-11.9	-12.0	-12.0
Male labour income	5.1	5.2	5.3	-11.5	-11.7	-11.7	-11.7	-11.9	-11.9	-11.9	-12.1	-12.1
Male agriculture												
Production (volume)	4.6	4.0	3.4	-14.7	-10.5	-6.2	-14.7	-10.5	-6.3	-14.8	-10.6	-6.3
Prices	3.5	3.0	2.5	-15.9	-11.6	-7.2	-16.2	-11.8	-7.3	-16.4	-12.0	-7.4
Female labour	3.4	2.8	2.3	-15.9	-11.5	-7.0	-16.1	-11.6	-7.1	-16.4	-11.8	-7.2
Male labour	3.9	3.3	2.7	-15.9	-11.5	-7.0	-16.2	-11.7	-7.1	-16.4	-11.9	-7.2
Female labour income	4.3	4.2	4.1	-11.8	-11.6	-11.3	-12.0	-11.8	-11.5	-12.2	-12.0	-11.7
Male labour income	5.6	5.4	5.2	-11.9	-11.6	-11.2	-12.1	-11.8	-11.4	-12.3	-12.0	-11.6
Agricultural Households												
Total income	2.9	2.9	2.8	-11.4	-10.9	-10.4	-11.5	-11.0	-10.5	-11.6	-11.2	-10.6
Female labour	3.1	3.0	2.9	-11.6	-11.3	-10.9	-11.8	-11.5	-11.1	-12.0	-11.6	-11.2
Male labour	3.1	3.0	2.9	-11.6	-11.3	-10.9	-11.8	-11.5	-11.1	-11.9	-11.6	-11.2
Female domestic labour	3.1	3.0	2.9	-11.6	-11.3	-10.9	-11.8	-11.5	-11.1	-12.0	-11.6	-11.2
Male domestic labour	3.1	3.1	3.0	-11.6	-11.3	-10.9	-11.7	-11.4	-11.0	-11.9	-11.6	-11.2
Availability of food	2.9	2.8	2.8	-10.9	-10.5	-10.1	-10.9	-10.6	-10.2	-11.0	-10.6	-10.2
Access to food	3.2	3.1	3.1	-10.7	-10.5	-10.3	-10.8	-10.6	-10.3	-10.9	-10.7	-10.4
Food vulnerability	3.4	3.3	3.2	-11.6	-11.1	-10.5	-11.8	-11.2	-10.6	-12.0	-11.4	-10.8
Poverty rate	2.1	2.1	2.1	-12.5	-12.0	-10.6	-12.7	-11.5	-10.5	-12.7	-11.7	-10.5

Source: Authors, based on the simulation results

7. Conclusion

Using a Computable General Equilibrium model that explicitly included gender dimensions allowed us to firstly determine the vulnerability of Burkinabe farmers, particularly women, in the context of the highly irregular rainfall experienced in the country. Secondly, it also allowed us to evaluate the effectiveness of various strategies to better protect them against such variability. Our results indicate, for example, that improved water management, including specifically improved access to irrigated land for women, could be an effective strategy. The strategy could also be effectively combined with another one encouraging the use of improved seeds that are more resistant to rainfall deficits. These results show that the specific situation of Burkinabe women needs to be taken into account when designing and

implementing national strategies for dealing with rainfall variability and climate change in general. Nevertheless, the results should be interpreted with caution given the methodological limitations of our analysis and the scope for improvement.

With this in mind, an initial line of research could be, to better take into account the structural regional differences in Burkina Faso through, for example, the development of a multi-regional CGE model. At this level, a disaggregation of the model and its associated SAM according to the country's climatic zones (*Sahelian* in the North, *Sudanese-Sahelian* in the Centre and *Sudanian* in the South) would be particularly interesting given the specific characteristics of these zones in terms of rainfall but also in terms of the nature and performance of the agricultural activities located there.

A second line of research could also be to take better account of the specific situation of women in our analysis. Here, a disaggregation of households according to the gender of the household head would, for example, allow for a finer analysis of the gender impacts associated with rainfall variability. Likewise, taking into account the endogenous adaptation behaviours of economic agents, particularly women, in the face of rainfall shocks, outside the framework of the CGE model, would be worthwhile. Coupling the model with a real microsimulation model would certainly provide an interesting opportunity to examine, for example, changes to individual behaviours regarding labour supply, savings, consumption, production or even migration.

Finally, our analysis of adaptation strategies for dealing with rainfall variability also deserves to be further explored because there are certainly other avenues that could be considered and even combined. The financial aspects of these strategies and their funding arrangements could also be considered, which would allow a more precise cost-benefit analysis to be carried out in order to shed light on whether or not they should really be implemented.

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APPENDIX - Empirical strategy for estimating crop yield elasticities with respect to rainfall

To take into account the climatic differences across the country and the uneven regional distribution of agricultural activities, we combine regional rainfall data provided for the period 1986-2020 by the World Bank with data on the regional production level of each crop provided by the Burkinabe Ministry of Agriculture. Firstly, we evaluate the cumulative rainfall corresponding to the vegetative growth periods of the different crops in each region (from sowing to harvesting). These periods are presented in Table A1. Secondly, we estimate the weight of each region in terms of the production of each crop. These are shown in Table A2. For each agricultural crop *j*, we then construct a national annual rainfall indicator $(Rain_{j,t})$ corresponding to the average regional rainfall totals, weighted by the share of each region *r* in the production of that crop.

On this basis, using national yield data provided by the FAO over the same period 1986-2020, we estimate the effect of the respective rainfall index of each crop on its yield. Here, we have chosen a linear econometric model which is presented as follows for each crop *j*:

$$lnYield_{j,t} = \beta_{j0}\varepsilon_j . lnRain_{j,t}\mu_{jt}$$

With $Yield_{j,t}$ the yield of crop j at time t

$Rain_{j,t}$ the level of rainfall related to crop j at time t

Our empirical strategy is based on a preliminary study of the stationarity of the two variables (yield and rainfall) using the Augmented Dickey-Fuller (ADF) unit root tests. It can be seen (see Table A3) that the two variables linked to the cultivation of *Corn*, *Rice*, *Millet* and *Sorghum*, *Fonio*, *Tubers* and *Oilseeds* are integrated of order 0 (stationary at level). Here, the ordinary least squares (OLS) method seems appropriate for our estimations. However, the yield variables for *Pulses*, *Fruit and Vegetables* and *Other crops* are integrated of order 1 (stationary at first difference) and the rainfall variables for the same crops are integrated of order 0 (stationary at level). As the two variables are integrated at different orders, we then use staggered delay autoregressive (ARDL) models to conduct our estimations. The econometric results are presented in Table A4.

Table A1 - Selected vegetative growth periods for the regions of Burkina Faso

Crops	Corn	Rice	Millet& Sorghum	Fonio	Tubers	Pulses	Oil seeds	Fruit & Vegeta-bles	Others
Regions									
Boucle Du Mouhoun	May-Sept.	May-Oct.	June-Aug.	June-Aug.	May-Sept.	June-Sept.	May-Sept.		May-Oct.
Cascades	June-Sept.		June-Oct.	June-Oct.		July-Sept.	June-Oct.	Jan-Dec.	May-Oct.
Centre		June-Sept.	June-Sept.			June-Sept.	July-Sept.	Nov.-March	May-Oct.
Centre Est	June-July	June-Sept.	June-Sept.			June-Sept.	June-Sept.	Febr-May	May-Oct.
Centre Nord	June-Aug.	June-Sept.	June-Sept.			June-Sept.	July-Sept.	Nov.-March	May-Oct.
Centre Ouest		June-Sept.	June-Sept.			June-Sept.	July-Sept.	Nov.-March	May-Oct.
Centre Sud	June-July	June-Sept.	June-Sept.			June-Sept.	July-Sept.	Febr-May	May-Oct.
Est	June-Aug.	June-Sept.	June-Sept.			June-Sept.	June-Sept.	Febr-May	May-Oct.
Hauts Bassins	June-Sept.	June-Aug.	June-Oct.	June-Oct.		June-Sept.	June-Oct.	Jan-Dec.	May-Oct.
Nord	June-Aug.		June-Sept.	June-Sept.		June-Aug	June-Sept.		
Plateau Central		June-Sept.	June-Sept.			June-Sept.	July-Sept.	Nov.-March	May-Oct.
Sahel	June-Aug.		June-Sept.			June-Aug.	June-Sept.		
Sud-Ouest	May-Sept.	May-Aug.	May-Nov.		May-Aug.	May-Sept.	June-Aug.	April-Aug.	May-Oct.

Source: USAID, 2010

Table A2 - Contribution of each region and produce to the overall national agricultural production of each crop in 2020 (in %), as well as the share of each crop in the overall national production

	Corn	**Rice**	**Millet - Sorghum**	**Fonio**	**Tubers**	**Pulses**	**Oil seeds**	**Fruit – Vegetables**	**Others**	
Crop share	21.7	5.1	31.4	0.1	2.1	8.0	20.5	11.0	0.1	**100**
Regions' share										
Boucle du Mouhoun	14.6	14.4	22.0	95.6	4.7	11.1	21.6	10.3	26.4	
Cascades	11.2	10.9	1.0	0.0	2.5	1.9	6.3	2.6	4.5	
Centre	1.6	1.3	1.0	0.0	0.1	1.5	0.6	1.3	0.5	
Centre Est	7.6	14.8	4.7	0.0	9.5	7.0	10.7	7.4	16.8	
Centre Nord	0.9	3.5	12.2	0.0	0.0	15.1	2.9	11.6	3.4	
Centre Ouest	7.5	5.9	11.5	0.0	14.5	12.2	8.7	13.0	16.2	
Centre Sud	6.3	6.5	4.1	0.0	2.4	3.9	7.4	4.1	2.8	
Est	4.5	15.0	10.1	0.0	5.3	7.1	10.5	5.8	1.4	
Hauts Bassins	32.3	17.0	5.0	2.8	24.1	4.4	20.6	9.4	7.1	
Nord	1.9	3.0	8.6	1.6	11.4	15.2	2.9	13.7	14.1	
Plateau Central	2.7	3.6	5.6	0.0	0.5	6.5	2.9	5.1	0.0	

Sahel	0.2	0.4	8.9	0.1	0.0	10.9	0.7	8.1	3.1
Sud-Ouest	8.5	3.6	5.3	0.0	25.0	3.2	4.3	7.8	3.6
	100	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Sources: Yearbook of Agricultural Statistics of Burkina Faso (2020)

Table A3 - Integration orders and choice of estimation method

Crops	**Yields**	**Rainfall**	**Methods**
Corn	I(0)	I(0)	OLS
Rice	I(0)	I(0)	OLS
Millet and sorghum	I(0)	I(0)	OLS
Fonio	I(0)	I(0)	OLS
Tubers	I(0)	I(0)	OLS
Pulses	I(1)	I(0)	ARDL
Oil seeds	I(0)	I(0)	OLS
Fruit and vegetables	I(1)	I(0)	ARDL
Other crops	I(1)	I(0)	ARDL

Source: Authors based on data from World Bank (2022) and FAO (2022)

Table A4 - Econometric estimation results for each crop

Independent variable	Dependent variable: ***Crop yields***								
	Corn	Rice	Millet & Sorghum	Fonio	Tubers	Pulses	Oil seeds	Fruit & vegetables	Other crops
Rainfall	0.618*** (0.208)	0.656** (0.272)	0.578** (0.225)	0.509* (1.90)	0.938** (0.402)	0.156** (0.065)	0.028*** (0.005)	0,09* (0.055)	0,136** (0.057)

NB: Values in brackets represent standard errors; ***, **, * represent statistical significance of coefficients at 1, 5 and 10 per cent respectively.
Source: Authors based on data from World Bank (2022) and FAO (2022)