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"Looking Forward: Household Food Security in Niger in an Era of Climate Change,"

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Selected Paper prepared for presentation at the 2018 Agricultural & Applied Economics Association Annual Meeting, Washington, D.C., August 5-August 7

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Looking Forward: Food Security in Niger in an Era of Climate Change

Draft for Presentation in AAEA 2018: Please do not cite

Abstract: This study explores the likely impacts of climate change induced crop yield changes on household food security outcomes in Niger i.e. malnutrition –headcount, -index, and -gap. We use a historically validated multi-scale partial equilibrium model named SIMPLE. The analysis is conducted at Niger's climate zone level and projections are made for 2050. We find that under assumed population, income and total factor productivity (TFP) projections, without considering climate change impacts, food security outcomes improve from 2009 to 2050. However, climate change induced yield shocks worsen the situation as much as doubling the malnutrition index from pre-climate shock levels. The most important thing to note is the dependence of these predictions on a "medium variant" of fertility rates in Niger, which is currently the highest in the world. Any negative variation can result in a much worse situation and population control will be one of the key to improving food security outcomes.

Key words: climate change, Niger, household food security, agriculture, partial equilibrium model

1. Introduction:

A few statistics for future Niger. Niger's current population is 21.5 million with 46 percent of the population aged between 15-59 years old. By 2050, assuming fertility drops below 5 and under five mortality is halved (to 46 per 1000 births), it is still projected to triple its population and be among the 30 most populous nations in the world. Even if fertility drops close to 2.5 by 2100, the population increase will be fivefold from its current level at the end of this century (UNDESA 2017). On top of that the human capital of this growing population is among the lowest in the world[1] . In 2010, 48.2 percent of the population was living under the national poverty line with rural areas contributing to 90 percent of the poverty (Hederschee et al. 2014) and 43 percent of the children under five suffered from chronic malnutrition[2], which is above World Health Organization's critical threshold level chronic undernutrition (40 percent). Although poverty rates have been declining and GDP has been increasing, population growth outpaces the rate of decline resulting in an increasing number of people living in poverty with decreasing GDP per capita. All in all, Niger faces the task of feeding and employing a very

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[1] Niger's HDI value for 2015 is 0.353— which positioned it at 187 out of 188 countries and territories. The average in Sub-Saharan Africa is 0.523. (UNDP 2016).

[2] World Health Organization, Global Database on Child Growth and Malnutrition. Country-level data are unadjusted data from national surveys, and thus may not be comparable across countries.

young and growing population in an increasingly harsh climate with limited natural resources and human capital.

Niger's rapid population growth is occurring in the Sahel region which is identified as one of the most climate change vulnerable region due to its high exposure and low adaptive capacity (Niang et al. 2014). The economies in most Sahelien countries are reliant on rainfed agricultural activities. The agriculture sector is the main employment sector in Niger and contributes to 40% of the total GDP. 80% of the labor force works in agriculture. Large parts of Niger where its dominant crop millet is grown is characterized by low, variable and irregular rainfall (annual 250-800mm), a short rainy season, high evaporative demand, and very low water holding capacity of the soil. The abrupt drying and desertification of the Sahel in recent decades appears to be in large part due to natural variability, but with significant anthropogenic component (Gianni et al. 2008). Regional model studies suggest concentration of rainfall into fewer, more extreme events over West Africa and the Sahel (Vizy and Cook 2012), which can lead to occurrences of flood (Lebel and Ali 2009) and disturbances in growing period rainfall. While projecting future rainfall variability in the Sahel is difficult, climate scientists are more certain about the projected temperature increase (Mohamed 2011, Christensen et al. 2007). Diffenbaugh and Giorgi (2012) identify the Sahel and tropical West Africa as hotspots of climate change, and unprecedented climates are projected to occur earliest (late 2030s to early 2040s) in these regions (Mora et al. 2013).

Increased warming and rainfall infrequency affect yields of crops, and extreme events can lead to total crop failures. Climate change and climate variability pose risks to poor households in the form of adversely affecting agricultural income, and affecting household food consumption through higher prices, reduced financial access to food, and reduced overall food availability. Extreme climate variations can also lead to chronic malnutrition (Fuentes and Seck 2007). In absence of widely established formal risk insurance or credit programs, household risk coping mechanisms in developing countries often consist of self-insurance, income smoothing, and social insurance arrangements. However, when risks such as a climatic stress is posed to the whole community, albeit at different levels to each household, community-level risk pooling mechanisms often fail (Kazianga and Udry 2006).

In the realm of consequences of climate change induced productivity shocks, this study considers effects on metrics for household food security. Food security in the paper is measured by average caloric consumption and indicators for average shortfall in caloric consumption and is limited to the quantity of food aspect of food security and does not account for the quality of food consumption. This can be considered a serious limitation from the nutrition point of view given the recent emphasis on diet diversity. However, in absence of worldwide data on diet diversity index, this is a plausible measure.

Changes in per capita food consumption is converted into changes in average caloric consumption. Shifts in the log-normal distribution of caloric consumption cause changes in the malnutrition index (as the fraction of population whose daily dietary energy intake is below the minimum requirement), malnutrition gap, and malnutrition headcount. These are the key variables to be observed.

The study is not the first one to analyze socio-economic implications of future climate change for Nigerien agriculture. Using a Dynamic Recursive Computable General Equilibrium model (DCGE), Montaud et al. (2017) conducts an extensive study on changes in income, poverty levels, and food insecurity ratio, food access index, and food availability index in Niger due to climate induced yield changes. The most important value addition of our study is analysis at sub-national level. Analysis of crop supply and future yield projections are conducted at grid cell level and aggregated to Niger's distinct climate zones that cut across horizontally in the country. As the size of the crop producing zones shrink with southward movement of isohyets, these will have important implications on crop production and in turn on household food security.

In addition, as a measure of household food security, the paper looks at both incidence and gap of dietary energy deficit. The reporting of the undernutrition gap, provides the variations of dietary energy deficits that is critical in estimating the depth of undernutrition.

For our purposes, we use SIMPLE (Simplified International Model of Crop Prices, Land Use and the Environment) model[3] (Baldos and Hertel, 2013), a static partial equilibrium global model of crop supply and demand in the agriculture sector. This framework is selected due to its parsimonious nature which is well suited to the data scarce environment which we are confronted with in Niger. The research problem is focused on what has happened in the agriculture sector and the future policy action effects in agriculture. We are not analyzing economy-wide effects, and thus it is parsimonious to use a partial equilibrium model for the analysis. The advantage of the partial equilibrium SIMPLE model of Nigerien agriculture that the study uses is that it is simple enough to be historically validated (separate paper). Placing the agriculture sector in a general equilibrium (GE) model makes it challenging for validation and reduces the validation to a few key variables. Having tested the model's ability to replicate the past, this makes it reasonably suitable to predict the future bearing in mind the deviations that are associated with exogenous shocks that are implemented in the model. The model has been used in studies focusing on

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[3] A complete listing of model variables, equations, and source of data is listed in Supplementary Materials of Baldos and Hertel (2013) available at http://iopscience.iop.org/1748-9326/8/3/034024/media/erl472278suppdata.pdf

climate change mitigation and adaptation (Lobell et al. 2013), climate change and food security (Baldos and Hertel 2015) as well as model validation and evaluation (Baldos and Hertel 2013).

The partial equilibrium framework in its current form does not capture the impacts of higher food prices on rural incomes. To the extent that the majority of the poor continue to reside in rural areas in 2050, the impact of agricultural productivity growth on overall poverty and undernutrition will hinge critically on rural incomes, yet the current study does not disaggregate rural households and treats income as exogenous. This, despite the clear link between crop prices, rural incomes, and poverty (Headey et al. 2014, Ravallion 1990). This study will modify the model to consider rural income to be endogenous.

We emphasis on understanding the capacity of the agricultural sector to absorb labor in the future, and the trends in marginal productivity of labor. It has to do with the dynamics of labor supply and the potential for migration out of agriculture. The absence of labor dynamics is also a limitation in Hertel and Hertel (2016) where the authors analyze the future of an African Green Revolution in the context of climate change. In their analysis, this element of the problem is buried in a single, aggregated non-land input. Shifting employment in SSA contributed to nearly half of its overall growth in the 2000s (McMillan et al 2014). Many countries in SSA expect continued strong growth in the proportion of working-age adults, thereby potentially accelerating rural-urban as well as cross-border labor mobility (Ahmed et. al., 2016). Rural income diversification can also have positive welfare implications (Beegle et al. 2011, Christiansen and Todo 2014). In short, explicit modeling of labor markets is key for understanding agricultural development in Niger.

To explore the implications of climate change on undernourishment and labor employment and wages in agriculture[4], the study creates a future baseline scenario from the 2009 (base year for the model) to the 2050 (without agricultural productivity shocks due to climate change). In the baseline scenario, the distributional impacts of population, income and TFP growth in future crop production is studied. Afterwards the model is shocked to 2050 with climate change induced productivity shocks and the new scenario results with climate change is compared with baseline scenarios without climate change shocks.

2. The Model:

2.1 SIMPLE-the model at use:

SIMPLE is a model of global crop supply and demand, designed to capture the major socio-economic forces at work in determining cropland use, output, prices and nutritional attainment. The current database for SIMPLE is disaggregated for 16 regions and the model

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[4] Results for labor employment and wages in agriculture are not presented in this working paper. Once all model modifications are complete, they will be included in updated versions. For now we focus on food security outcomes.

has been historically validated for these regions – one of which is the Sub-Saharan Africa (SSA) region taken as a whole. On the demand side crop demand is determined by four uses: i) direct food consumption by households ii) feedstuffs for livestock iii) crop inputs to processed food production, and iv) feedstocks for biofuels (exogenous in the model). Food demand in each region is a function of population, per capita income and commodity prices. Per capita income and commodity prices govern individual demand through the income and price elasticities of demand, which vary by commodity type (crop, livestock, and processed foods) as well as consumers' income level.

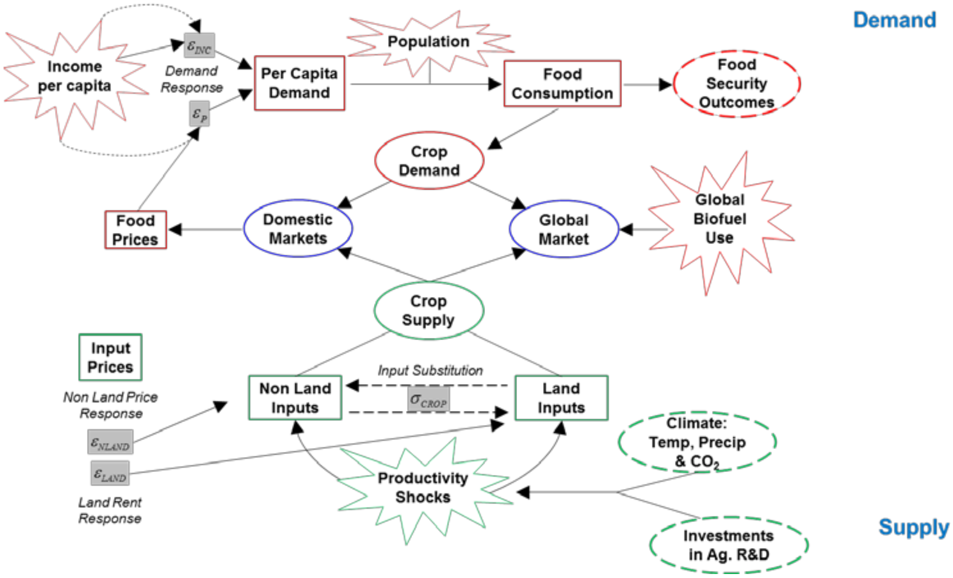

Figure 1: Structure of original SIMPLE model (Baldos and Hertel 2013)

On the supply side, in the original SIMPLE model crop production is modeled via a Constant Elasticity of Substitution (CES) production function employing land and non-land inputs. Use of inputs is governed by the extensive and intensive margins of supply (See Gohin and Hertel, 2003 for mathematical derivation). Taking the land input as an example, when land scarcity changes, farmers can expand or contract land use (expansion effect-extensive margin) as governed by input supply elasticities, and they can also substitute land for other inputs (substitution effect-intensive margin), as governed by substitution elasticities. Intensification of non-land inputs allows for crop yield growth even in absence of technological change. However yield growth through intensification should not be assumed to be total factor productivity (TFP) growth – as it may simply reflect more intensive use of non-land inputs. Agricultural TFP growth in SIMPLE results from adoption of new technologies stemming from agricultural research, development, and dissemination; policy changes, and climate change. Positive changes in productivity can shift the regional crop product supply schedules outward-the amount of each input required to produce a given amount of output decreases.

2.2 Food security module: We use the food security module introduced in SIMPLE in Baldos and Hertel (2014) to extract information on nutritional outcomes in Niger. Details of the module construction and data construction is described in the paper and its supplementary material. Here we describe the essentials.

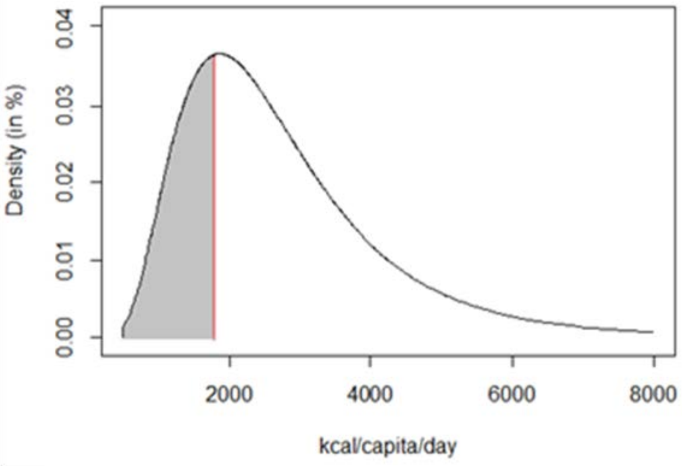

Figure 2: Log normal distribution of per capita food calorie intake, MDER and malnutrition incidence

We concentrate on two indicators: malnutrition incidence, and malnutrition gap. The malnutrition index is defined as the fraction of population whose daily dietary energy intake is below the MDER (grey area to the left of the red line) while the malnutrition gap represents the average dietary energy deficit that an undernourished person needs to close in order to satisfy the minimum requirement. The malnutrition gap is derived by integrating the caloric deficits of each malnourished person and dividing it by the malnutrition headcount. Reporting only malnutrition incidence is not enough as this measure does not represent the variations in dietary energy deficit among malnourished individuals. Malnutrition gap indicates the intensity of hunger. These measures are undoubtedly not sufficient indicators of undernutrition. Stunting among children under 5, vitamin and micronutrient deficiency are complementary measures of undernutrition. However malnutrition index or gap is a comparable measure of food security with better data availability.

The distribution of per capita caloric consumption is assumed to be log-normal which is consistent with the traditional assumption used by FAO regrading the dietary energy intake within a country (Neiken 2003). Following equivalent terms in the poverty literature (poverty index and poverty gap) , Baldos and Hertel (2014) uses growth elasticities of malnutrition index (ε_{MI}) and malnutrition gap (ε_{MGI}) to link the measures to changes in average per capita dietary energy intake.

$$\varepsilon_{MI} = -\frac{1}{\sigma}\frac{\tau}{\pi}\left[\frac{ln(w/y)}{\sigma} + \frac{\sigma}{2}\right]$$

$$\varepsilon_{MGI} = -\frac{\pi[ln(w/y)/\sigma - \sigma/2]}{(w/y)\pi[\ln(w/y)/\sigma + \sigma/2] \ - \pi[\ln(w/y)/\sigma - \sigma/2]}$$

where, w is the MDER, y is the average per capita dietary energy consumption (DEC), and σ is the standard deviation of the DEC. τ and π are the standard normal probability density and CDF.

Growth elasticities are the percentage change in these indices in the wake of a 1 percent change in average dietary caloric intake. The per capita caloric intake is in turn linked to per capita income. For agricultural households in the model, this creates a direct link between changes in household income and purchasing power due to climate change induced production and crop price changes, and caloric intake i.e. household's food security.

2.3 Modifications to the SIMPLE model: There are two main modifications that are made to the model: i) including Niger as a single country region and disaggregating its supply and demand regions, and ii) modeling income as an endogenous variable: linking changes in crop prices directly to household income.

Disaggregation of geographical regions:

Niger is disaggregated out from the Sub-Saharan Africa region, thereby making it the 17th region in the model. This introduces the model from regional to country level analysis. The supply regions within Niger are further broken up into 5 broad agro-ecological zones defined by isohyets (which are horizontal parallel lines on the map connecting points similar rainfall range). And the demand side population is disaggregated into rural and urban households, where the income of rural households is affected by the crop income.

The crop supply region is divided into 5 climate zones: Saharienne, Saharo-Saheliene, Saheliene, Sahelo-Soudaniene, and Soudaniene. More than 60% of Niger is in the Sahara Desert zone (Saharienne zone) in the north with less than 200 mm of rain per year. It is mostly unsuitable for rainfed cultivation. South of the Sahara desert is the central belt (200-400 mm rain per year) comprising of Saharo-Saheliene and Saheliene regions, where pastoralism is the main activity. Transhumant cattle herding dominates (where the herd move to green pastures after short rainy season and back to dryland after harvest) this zone. The highest concentration of livestock resides in this climatic zone. Most of the country's agricultural land falls within a narrow band comprising the area from the Nigerian border northward for 150 km. These are called the Sahelo-Sudanian and the Sudanian zones, where average annual rainfall is in the 400-800 mm range. The main crop in these regions is millet (Niger is the world's top producer per capita) which is often intercropped with sorghum and cowpea (niebes) and requires at least 350mm rain. Extensive farming of millets with mixed-stock keeping dominate the Sahelo-Sudanian zone

(Pender et al. 2008). Due to low yields in this region, most households engage in goat rearing, casual labor, small trade and seasonal migration. The Sudanian rain-fed zone (the Maradi and Zinder region) is small and is characterized by semi-intensive agricultural practices, and livestock rearing. Irrigated cash crops are grown in pockets of oasis along the Niger river. This zone is the most productive region for cereal and cash crop production.

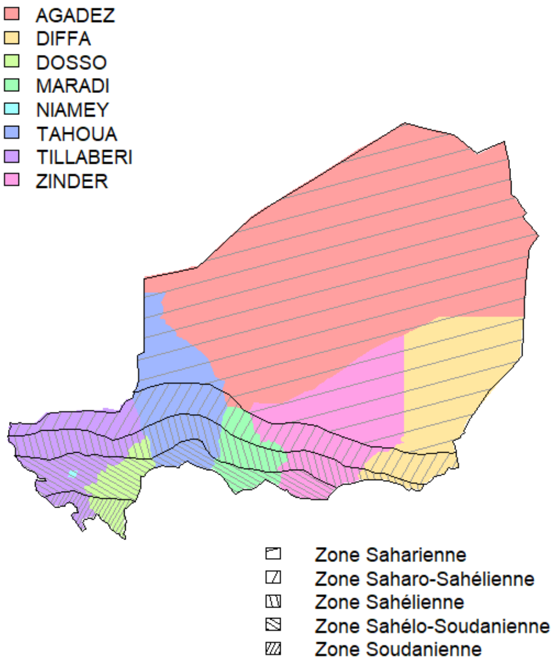

Figure 3: Niger admin regions and climate zones

It is evident from the studies of Daouda et al. (1998) for the period from 1950–1967 to 1968–1985, and by Sivakumar (1992) for 1969-1988 that isohyet lines moved southward from 1950s to 1980s, resulting in the most productive zones to shrink. The isohyets moved north again from 1988-1998 (Mohammed et al. 2002). Although this looked promising whether the trend will continue is debated and what is evident is even though rainfall may have increased the rainfall season has become shorter and there is more variability throughout the seasons.

A model of endogenous rural income:

To capture the dynamics of labor employment and wage changes and to link crop income to rural household income, non-land (NLAND) inputs is broken out into valued added: labor (LAB) and capital (CAP), and other intermediate inputs (OTH). Partly following GTAP-AGR (Keeney and Hertel 2009) rural income is made endogenous in the model. In the GTAP-AGR framework, all endowments in primary agriculture is assumed to be farm owned. Household income is divided into on-farm and off-farm earnings. Off–farm earnings are earnings from employing farm-owned labor and capital in non-agricultural activity. A single incomes share is used to break out off-farm earning. The on-farm income is linked to be endogenous in the model through linkages to market price of inputs i.e. land rent, labor wage, and price of other inputs which is in turn linked to price of crops. So if crop prices change it affects rural household's food security in two ways. The price change affects agricultural household's income from crop and it also affects their purchasing power of buying crop based food.

3. Data and Context:

The details of the original SIMPLE model's database construction are available in Baldos and Hertel (2012). Data from external sources include income, population, consumption expenditures, and crop production and their sources are as follows. Information on GDP in constant 2000 USD and population are obtained from the World Development Indicators and from the World Population Prospects, respectively. Consumption expenditure data was taken from the GTAP V.6 database (2006) while data on cropland cover and production, utilization and prices of crops are derived from FAOSTAT. In this section we describe only the additional database that had to be constructed for modified model and in the context of Niger.

3.1 Crop commodity:

In the standard SIMPLE model, the crop commodity is an aggregate of all crops in the FAOSTAT database, weighted to be in corn-equivalent units. For our purposes, we concentrate on the 6 crops in Niger which together comprise of atleast 90% of the harvested land area: millet, sorghum, groundnut, cowpea (niebes), rice, and maize. Instead of aggregating all crops these 6 crops are chosen on the basis that i) it allows for aggregration to climate zones using available sub-national data (which is not available for all crops in the FAOSTAT database) and ii) we can project yield changes due to climate change for these particular crops.

Crop quantity, value and harvested area: We combine data from FAOSTAT, FAO CountryStat, and EarthStat (Ramankutty et al. 2008) to aggregrate crop production (in millet-equivalent quantity) and harvested area data to the 5 climate zones in Niger. For the other 16 regions in the rest of the world, national level data from FAOSTAT for 175 countries for these 6 crops is aggregated to regional level.

FAOSTAT provides data at national level. CountryStat provides data at sub-national level for the 8 admin regions in Niger. The same sub-national data has also been collected from the national offices which has a finer disaggregation at department and commune level. However, the climate zones cut across horizontally through these regions. In order to aggregate to climate zones we use grid cell level data from EarthStat which is circa 2000 to share out the 2009 sub-national level production quantity and harvested land area to grid level. These grid level data are presented at 5 min (~10 km) spatial resolution in latitude by longitude. Scaling down the sub-national level data to grid level thus assume that the distribution of crops in 2009 remained same as in 2000. We then aggregrate the grid level data to climate zones.

To be able to aggregate production quantities across different crops, it is necessary to use a conversion of production quantities into millet-equivalent tons. Following Hayami and Ruttan (1985), we converted the crop quantities into millet-equivalent quantities using weights constructed from world crop prices and the world price of millet. The conversion approach is described in the following.

Producer price data is obtained from the FAOSTAT database for each crop and each country. The price data covers the period from 1991 to 2014 but availability of this price data varies by country and crop. FAO prices for crops in USD/ton are equal to producer prices in local currency (LCU) times the exchange rate of the selected year. The main exchange rates source used is the IMF. Where official and commercial exchange rates differ significantly, the commercial exchange rate are applied.

For each crop, production quantity in each country and each year is multiplied by the corresponding price to obtain a total production value:

$$Value_{crop,cntry,year}(\$) = Production_{crop,cntry,year}(tons) * Price_{crop,cntry,year}\ (\$/ton)$$

The global production value is calculated by aggregating the production value for each crop over all countries by item and by year. Then the global production value ($Value^{W}_{crop,year}$ (\$)) is divided by the global production quantity of the same crop to obtain world price for each crop by year.

$$Price^{W}_{crop,year}(\$) = \frac{Value^{W}_{crop,year}\ (\$)}{Production^{W}_{crop,year}(tons)}$$

Next, the millet-equivalent (ME) weights are obtained by dividing the world price for each crop by the world price for millet:

$$ME\ Weights^{ME}_{crop,year} = \frac{Price^{W}_{crop,year}}{Price^{W}_{millet,year}}$$

By multiplying the production quantity of each crop in each year with its corresponding millet-equivalent weight, we obtain the production quantity in millet-equivalent units by year and the world price of crops is multiplied with millet-equivalent production quantities to get the value of crops production.

3.2 Input cost shares in crop production: Under the assumption of zero profits, the total value of land, labor, capital, and other intermediate inputs costs in the regional crop sectors were calculated us using GTAP v.6 cost shares. The GTAP database, however, do not have Niger as a representative country. We use the Niger 2011 Living Standard Measurement Survey- Integrated Surveys on Agriculture (LSMS-

ISA, also known as ECVM/A 2011) and the Niger SAM matrix jointly to calculate shares of value added (land, labor, and capital) and other intermediate inputs in crop production in Niger. The ECVM/A-2011 includes a sample of 1,538 (38.76%) urban households and 2,430 (61.24%) rural households and is nationally representative, as well as representative of Niamey, other urban and rural areas. The survey was conducted in two phases, that is to say the households were visited twice: post planting and post harvest.

Information on use of labor, land, and inputs such as fertilizer, pesticides, compost were collected at parcel level by crop. The calculated cost shares using the Niger SAM matrix and the household survey are land (30%), labor (48%), capital (12%), and other intermediate inputs (10%). Average farm household size in Niger is around 7 people and average cultivated area by a farming household is around 13 acres which is much larger than other LSMS-ISA countries (Ethiopia, Malawi, Tanzania,and Uganda) studied in Dillon and Barrett (2017). It appears there is a small land rental market in Niger: 80% of the cultivated land is owned. Farming household cultivate almost all of the land owned. Land rental market participation is (7-8.5% renting land in) (Dillon and Barrett 2017, Deininger et al 2016). The presence of a thin land market required imputation for cultivated land value from median land rents by agro-ecological zones (agricultural zones, agro-pastoral zones, and pastoral zones). Although land is relatively abundant in Niger compared to its East African counterparts, the land is very unfertile with high spatial high spatial and temporal intra-annual and inter-annual rainfall variability risk, thus rendering low productivity and comparatively low value of land. Farmers sow more surface than they can manage to diversify risk (Abdoulaye and Sanders 2005).

Given the large size of farm households in Niger, farm labor employment is closely associated with size of household. Most workers are household members. 49% of surveyed farm households hired workers who did 10% of the total farm work (Dillon and Barett 2017). This is also consistent with the minimal labor wage share in total income (3%) (Davis et al 2017). The total labor cost from the survey sample was calculated by aggregating labor costs for preparation, cultivation, and harvest periods. For household members a shadow wage was imputed from the labor wage paid to non-family hired labor. Rate of hiring for non-harvest activity (cultivation period, 38%) is almost twice that of harvest activities. Wage payment is infact lowest during harvest period and highest during preparation period.

Because of low use of inorganic fertilizer and other inputs such as pesticides and herbicides share of intermediate inputs in crop production is estimated to be 10%. The soil type in Sahel and Sudanian zones is loamy sandy, naturally low of phosphorous and nitrogen (Baidou-Forson and Bationo 1992), and has low water holding capacity. The traditional soil-fertility-maintenance technique was shifting cultivation and application of organic fertilizer and manure. Application of fertilizer grew at a rate of 9% annually from 1961 to 2006, but started from a very low base and still remains very low. Estimates from recent surveys (LSMS-ISA) show approximately 3% of the surveyed farm households in Niger used inorganic fertilizer (compared with 41% in neighboring Nigeria) and mostly relied on organic fertilizer (48%) for soil fertilization (Binswanger and Savastano 2014). Applying organic fertilizer is much more labor intensive than applying inorganic fertilizer as it has to be collected and transported by the farm household. Seeds are mainly produced and not purchased. Farmers in Niger appear to be profit maximizers and make stepwise intensification decisions starting with traditional methods such as labor and manure, and move to modern inputs like inorganic fertilizer, improved varieties, and pesticides after exhausting traditional options (Abdoulaye and Lowenberg-DeBoer 2000).

Fixed capital such as farm machinery, tools, and structures remain very low in SSA and Niger is no exception. The main asset is livestock. Unlike in South Asian countries where soil is dense, livestock is not used for land preparation. Manure from livestock is used as an input to cropping. Machinery use is mostly limited to irrigated land where rice is grown. Hence the share of capital in crop production is estimated to be only 12%. Fixed structures mainly include cereal storages.

3.3 Establishing future baseline scenario (2009-2050):

To create the future baseline scenario, the farm and food system is projected from 2009 to 2050 in the absence of climate change. The exogenous shocks to the system to create the scenario are population, per capita income and agricultural productivity growth. The first is likely to dominate Niger's demand for crops. Population and income growth rates is based on the Shared Socio-economic Pathways (SSP) database, which provide alternative trends in socio-economic development when climate change impacts are ignored. The SSPs are part of a new framework that the climate change research community has adopted to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation (O'Neill et al 2017). In the baseline, data on population and income growth are based on SSP2, the "middle of the road" scenario which reflects a development trajectory that does not depart much from historical patterns. Inequality in income and development continues to exist, population growth is moderate, and there are imperfect global markets.

Agricultural productivity growth is difficult to measure, let alone forecast several decades into the future. For crop productivity shocks, following Hertel and Baldos (2016), we assume that the historical patterns of productivity growth persist into the future (Ludena et al., 2007; Fuglie 2012). Regional TFP growth rates for the crops and livestock sectors are based on adjusted historical estimates from Fuglie (2012) and projections from Ludena et al. (2007). Historical rates from Griffith et al. (2004) are used for the processed food sector, assuming that these rates apply in the future and across all regions.

Table 1: The point-to-point (2009-2050) cumulative growth rate of population, income and total factor productivity

2009-2050	***Population (%)***	***Income (%)***	***TFP (%)***
Niger	283.5	625.9	73.5
SSA	148.1	438.8	31.4

3.4 Climate change induced productivity shocks: Predicting climate change impacts on crop yields is challenging; involving combination of crop models and climate models and uncertainties are grounded in both climate and agricultural literature. The biggest uncertainty in the crop models is the size of the effects of CO_2 fertilization[5] (Long et al. 2006, Moore et al 2017). There are mainly two types of studies that govern the literature on examining the impact of climate on agricultural yields- process based crop modelling, that simulate biological mechanisms of crop growth and statistical approaches that looks at relationships between climate or weather and crop yields. Moore et al (2017) estimate a meta-function based on 1010 data points for maize, rice, wheat and soybeans from both type of studies and finds that if CO_2 fertilization is controlled for there is little evidence of differences between these two methods in yield response to warming.

Another source of uncertainty is the forecasts of climate change itself at national level. Global Circulation Models (GCMs) are used to simulate the effect of variables that might affect the climate which are by nature uncertain (Burke et al. 2015). Although the Intergovernmental Panel on Climate Change (IPCC) stresses on the improvement of climate models to simulate surface temperature changes at regional level, the predictions are much less certain at national level. These uncertainties are even more prominent when it comes to rainfall patterns in the Sahel. The climate models have not in general been able to make satisfactory reproduction of observed climate variability in the Sahelien region (Mohamed 2011). Rainfall predictions are more uncertain than temperature predictions (Rowell 2012). However temperature changes have a much stronger impact on yields than precipitation changes because the marginal impact of a one standard deviation change in precipitation is smaller compared to a one standard deviation change in temperature and projections of temperatures increases are much larger relative to precipitation changes. Christiensen et al. (2007) predicts an increase of 1.5 and 4.7 degrees C in the minimum and maximum temperature in West Africa. To put this into perspective, this is far above the

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[5] The release of CO_2 in the air from the burning of energy sources like oil, coal and wood are chief sources of climate change. Plants vary in how they process the increasing layer of CO_2. Those with C_4 photosynthesis systems, which can concentrate CO_2 onto reaction sites, have low responsiveness to CO_2 than crops with C_3 photosynthetic systems (e.g. wheat, rice), which cannot.

Paris climate accord target of keeping global temperature rise this century well below 2 degrees Celsius above pre-industrial levels.

Schlenker and Lobell (2010) were one of the earliest studies which focused on climate change yield impacts of crops specific to Sub-Saharan Africa, namely maize, sorghum, millet, groundnut, and cassava. Maize, sorghum, and millets all possess a C_4 photosynthetic pathway, which has much smaller sensitivity to CO_2 than other crops, and so are likely to be more adversely affected. The study combines historical crop production and weather data into a panel analysis, to create a model of yield response to climate change. They do not consider CO_2 fertilization but reasons the crops under study are less sensitive to it. Their model results predict that by mid-century, the mean estimates of yield changes in SSA are -22, −17, −17, −18, and −8% for maize, sorghum, millet, groundnut, and cassava, respectively. Schlenker and Lobell (2010) was based on panel models which use deviation from country-specific averages in the identifications of the yield response function and does not consider CO_2 fertilization. For data poor regions like SSA, the use of country averages can amplify measurement error.

Hertel and Baldos (2015, 2016) combined the Global Gridded Crop Model (GGCM) inter-comparison project, which has a comprehensive evaluation of yield impacts varying across crop, space, time and presence/absence of CO_2 fertilization, and gridded production maize, soy, rice and wheat from Monfreda et al. (2008) to derive aggregated regional productivity shocks. However the shocks are projected from maize, soy, rice, and wheat responses which are not dominant crops in the Sahel region.

Studies concentrating on Niger are hard to come by. So it is necessary to draw upon studies focusing on West Africa or the Sahel region for the dominant crops in Niger. Millet is more heat tolerant and has lower water requirement than sorghum. Based on statistical analysis, Mohamed (2011) calculated a fall of 20 and 40 percent for 2^o and 4^o C temperature increase and Van Duivenbooden et al. (2002) estimated reductions in cowpea and groundnut yields between 12 and 30 percent in Niger. At a higher degree of temperature drop (6^o C) and 20% drop in precipitation, Sultan et al. (2013) predicts millet and sorghum yields to drop by up to 41%. Thomas and Rosegrant (2015) calculate changes in yields by -5.8 to 0.3 percent for groundnuts and -9.5 to 15.9 percent for sorghum in West Africa. The general consensus is the changing climate will have adverse effects on crop yields in Niger.

Our yield projections for maize is drawn from Haqiqi (2018) who extends Schlenker and Roberts (2009) to estimate crops yield response functions for irrigated and non-irrigated crops at global level. He employs NASA NEX-GDDP (Global Daily Downscaled Projections) conducted under CMIP5 and RCP 8.5 for future projections. These estimations are used to compare the change in yields of irrigated and non-irrigated crops under climate change. The comparison includes average yield damage, average year on year yield changes, year on year yield variations, likelihood of bad years, and likelihood of consecutive bad years.

The grid level yield projections for millet, sorghum, and groundnut are estimated by borrowing coefficients of average temperature and precipitation on log yields of these crops in low fertilizer use SSA countries from Schlenker and Lobell (2010) (see Table A1 of Supplementary Files of the paper). The grid level yield projections for each of these crops are aggregated to the climate zones in Niger weighing them by cropland share. Finally the climate zone and crop specific yield shocks are weighted by harvested area share in each zone to estimate an aggregate yield shock for all four crops by each climate zone.

Table 2: % Reduction in crop yields in Niger's climate zones by 2050 due to future climate heat

Crops	**Zone Saharienne (NCZ1)**	**Zone Saharo-Sahelienne (NCZ2)**	**Zone Sahelienne (NCZ3)**	**Zone Sahélo-Soudanienne (NCZ4)**	**Zone Soudanienne (NCZ5)**
Groundnut	-16.3	-15.8	-15.7	-15.3	-14.6
Maize	-38.7	-35.4	-32.8	-28.6	-27.0
Millet	-18.0	-17.5	-17.3	-16.9	-16.1
Sorghum	-12.1	-11.8	-11.6	-11.3	-10.8
Weighted aggregate yield shock due to CC	-15.86	-15.74	-15.71	-15.36	-14.89

Undernutrition data: The availability of household survey data on food consumption for Niger is an advantage over FAO's DEC estimates from food balance sheets (Smith et al. 2008). The current approach in Baldos and Hertel (2016, 2014) follows the UN FAO methods (Neiken 2003) and is based on a representative national distribution of food caloric intake. In this method, mean DEC is estimated from mean Dietary Energy Supply (DES) which refers to food available for human consumption during the course of the reference period and is based on crop production and trade data.

The minimum dietary energy requirement (MDER) calculated for an adult in Niger is 1682 kcal/day[6] with rural inhabitants requiring more. As expected, rural households source more of their dietary energy from own produced food than urban households do (32% vs 4%) and consequently urban households have a larger share of purchased food in total food consumption (monetary value) (89% in urban vs 67% in rural). Both type of households spend around one third of total income of food

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[6] www.fao.org/fileadmin/.../ess/.../food.../MinimumDietaryEnergyRequirement_en.xls

consumption (71% in urban and 82% in rural). Compare estimates with Bangladesh, which is a populous middle-income country where households source 22% of DEC from own produced food and spend 55% of total income on food.

72% of the DEC comes from carbohydrates, which is typical of least developed countries where households rely on cheap sources of starch for meeting energy requirements. As per capita income grows individuals shift from heavy starch based diet to one that consists more of meat and dairy products (Gerbens-Leenes et al 2010). With Niger's per capita real at a very low base and only recently improving (per capita income was growing but real income has not), a shift in diet composition is not foreseen very soon. Meaning reliance on staple crops which are projected to be adversely affected by climate change will remain high.

Table 3: Dietary energy consumption, MDER, and prevalence of undernourishment in Niger calculated from Niger 2011 LSMS-ISA/ECMVA household survey

	Sources	**National**	**Rural**	**Urban**	**Unit**
Average dietary energy intake	Niger 2011 ECMVA/LSMS_ISA	2385.59	2171.95	2436.20	kcal/capita/day
Minimum dietary energy requirement (kcal/person/day)	Niger 2011 ECMVA/LSMS_ISA	1682	1,759.5	1,663.7	kcal/capita/day
Prevalence of undernourishment (%)	Niger 2011 ECMVA/LSMS_ISA	7.3	21.2	4.2	%

4. Results and Discussion:

The results are presented for Niger and for Sub-Saharan Africa (SSA) as a measure of comparison. SSA excludes Southern Africa. "Baseline 2050" refers to projections into 2050 from 2009 without climate change induced yield shocks. "CC shock" refers to outcomes with crop yield shocks on 2050 baseline.

Dominated by the assumed high income growth (Figure 8), projected food security outcomes indicated by malnutrition -index and –headcount improve in Niger in baseline 2050 more than in the rest of SSA (Figure 4). The malnutrition count is estimated to improve by around 60% in 2050, decreasing from a small base of 4.3 million in 2009 and the index improves by almost 90%. However malnutrition gap, which indicates the intensity of hunger, does not improve as much as in SSA and a crop yield shock worsen the situation for both regions from baseline 2050.

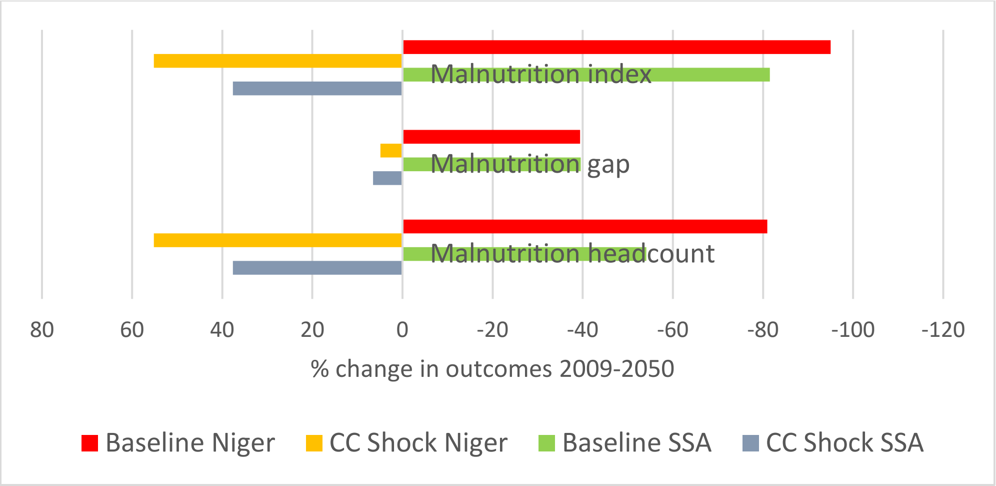

Figure 4: Food security outcomes in 2050 in Niger and SSA (% change)

Notes: Baseline refers to projections for 2050 without considering climate change induced yield shocks. CC shock refers to % change from 2050 baseline when yield shocks are imposed.

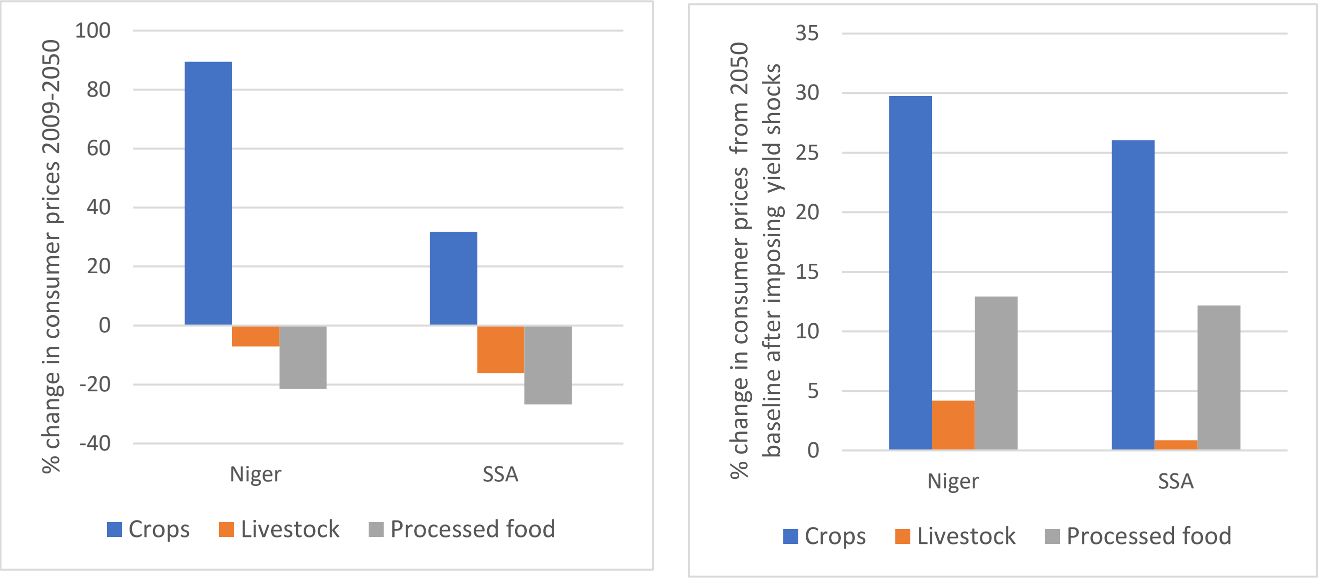

Figure 5: % Changes in consumer prices from 2009 to 2050 without considering crop yield shocks (left panel) and from 2050 baseline considering crop yield shocks (right panel)

The improvements in food security outcomes occur in Niger despite consumer prices of crops increasing (% increase in 2050 from 2009) comparatively more than in rest of SSA (Figure 5). This re-emphasizes that increases in crop prices do not necessarily translate into worsening food security outcomes. The crop price increases are driven by demand from a growing population and its growing ability to purchase (growing income). Growth in TFP alternatively drives down prices as fewer inputs are required to produce the same amount of outputs. Niger's projected population growth is larger than in SSA and the net effect of the three drivers results in a higher crop price increase in Niger than in rest of SSA (Figure 6). Crops are used as inputs in the livestock processed food sector. The prices of these commodities do not increase despite increase in their input (crop) prices as TFP growth is large in these sectors.

A climate induced contraction in output means there is less amount of crop produced with the same amount of inputs. With relatively price inelastic demand and a decrease in output due to reduced TFP, consumer prices for crops increase while that of livestock and processed food decrease.

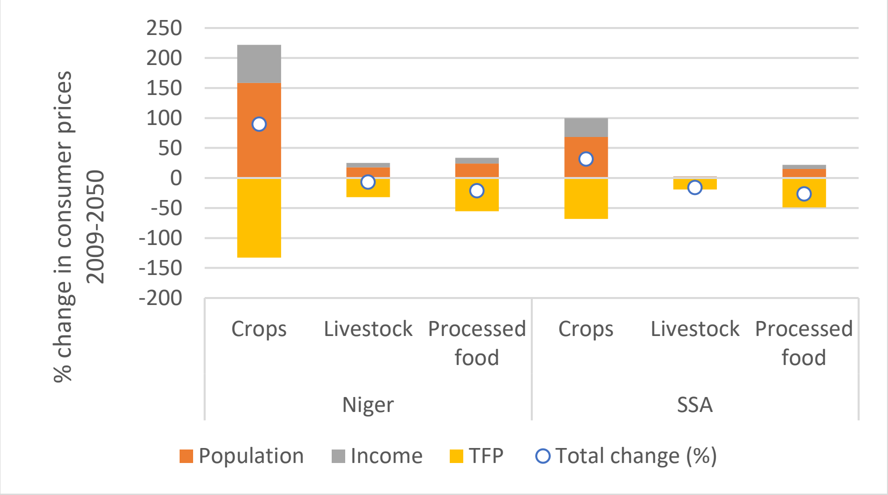

Figure 6: Contributors to change in consumer prices of crops, livestock, and processed food in 2050

The decomposition of the drivers (i.e. population growth, income growth, and TFP growth) of these outcomes provides us a deeper dive into these results. Recall, that all projections of growth from 2009 to 2050 are higher for Niger than for SSA. Niger's optimistic per capita income and TFP growth subsides the negative contribution of the population growth on its food security outcomes. Unlike richer economies (Hertel and Baldos 2016), population growth continues to have relative importance as a driver of crop output growth in Niger and in SSA (Figure 7). Much of the positive improvement in baseline 2050 is dependent on the assumption of the "medium variant" of fertility rates.

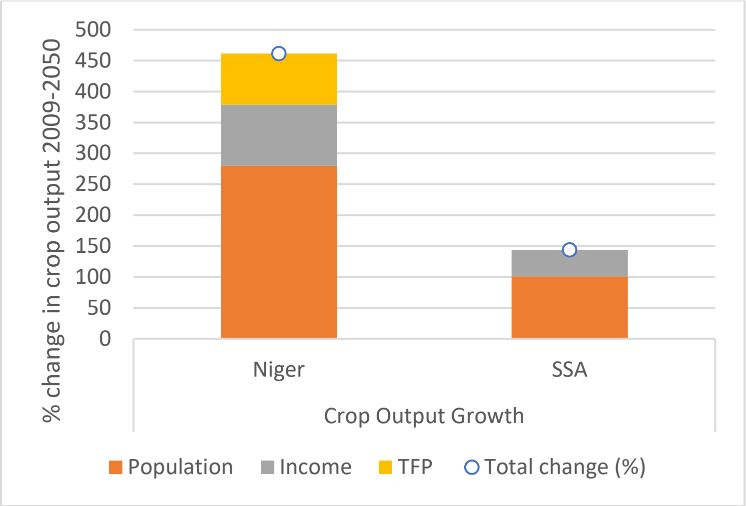

Figure 7: Drivers of future crop output growth in Niger and SSA from 2009 into 2050

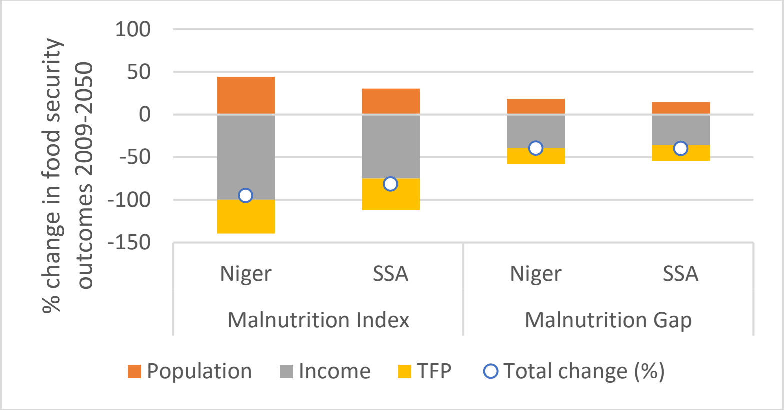

Figure 8: Decomposition of drivers of % changes in malnutrition index and gap at 2050 baseline

Given the results, we can conclude climate change induced productivity shocks at its upper bound projections (without CO_2 fertilization) can have significant negative effect on the fight against malnutrition and that focusing on population control and crop yield improvements can contribute to mitigating these negative effects.

5. Limitations and Extensions: The results in this paper is yet to consider income as exogenous in the model - thus not taking into account how household income changes as crop price changes. Depending on the composition of household income sources and if the household is a net buyer or net seller, net effect of changes in income due to food price can be positive or negative. By treating income as endogenous variable in the model, we can look at the distributional impacts of climate change through its effect on household earnings. That is the next step in this working paper.

There are opportunities for improvement in impact estimation with better estimates of price elasticities of land and labor supply. Econometric estimates on labor supply in agriculture specific to Sub-Saharan Africa let alone Niger is hard to come by.

The experiments in the paper implements climate change affect productivity shock at a future point in time (2050), where the 2050 baselines are projected without any consideration of climate change from 2009 to 2050. This was done more so to stark the contrast between existence and non-existence of shocks in the two trade scenarios. However in reality climate change is a gradual effect occurring over the period and future experiments can take into account projections of 2050 baselines along with climate change, whereby it will also be possible to measure (through sub-totals) which components are contributing to malnutrition reduction most.

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