LONG RUN FOOD SECURITY IN NIGER: AGRICULTURAL PRODUCTIVITY, CLIMATE CHANGE AND POPULATION GROWTH

by

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To my parents,

Hosne Ara Kabir and Commodore Md. Ahsan Kabir

Ammu who taught me to read and write.

Abbu who would have read this thesis cover to cover.

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ABSTRACT

This dissertation examines long-run food security in Niger in an era of climate change and comprises three interlinked essays. The first essay investigates the socio-economic projections for Niger in the current climate change literature in a growth accounting framework and provides a critical assessment to evaluate global projections in the context of a low-income developing country. The second essay quantifies the combined and individual impacts of income, population growth, agricultural productivity, and climate change on food security outcomes by mid-century in rural and urban Niger. Finally, the third essay assesses three policy scenarios considering accelerated investments in agricultural research and dissemination (R&D), reductions in fertility rates, and regional market integration.

INTRODUCTION

Niger is a landlocked country in the Sahel region of Africa. Dependent on rainfed agriculture, much of its land is relatively infertile, even as it has the highest human fertility rate in the world. Niger faces the task of feeding and employing a very young and fast-growing population in a harsh climate with limited natural resources and human capital. And the challenge is likely to be amplified by climate change. How will Niger go from feeding 20 million people to around 50 million people in 30 years? This challenge is even greater, given the recent shift in budgetary priorities away from social development and towards national security. When there are so many forces acting together, under such a ‘perfect storm’, where should the government concentrate its limited resources? In this dissertation I explore the status of food security in Niger in mid-century, identify key food security drivers for policy consideration, and investigate the potential for alternative policy scenarios to enhance food security outcomes.

To quantify any impact in the future, we need projections of the broader global economy. One such projection in the climate change literature is that of socio-economic conditions: Shared Socio-Economic Pathways (SSPs). This essay assesses selected SSPs for Niger and provides a framework to evaluate global projections in a low-income developing country context. Key quantifiable results are identification of key factors of production in economic growth of Niger and consistency check between SSP quantitative projections and the underlying narrative. To conduct this analysis I used the Mitigation, Adaptation, and New Technologies Applied General Equilibrium (MANAGE) model with inputs from the Niger Social Accounting Matrix. I find GDP growth in Niger is accounted mostly by growth in labor volume and in more recent decades by capital formation. The changes in GDP growth in the future stem mainly from changes in the growth rate of labor productivity. And there are certain inconsistencies in SSP that stem from interactions between different assumptions and projections for a country like Niger are far removed from historical trends. The findings call for attention to more refined national projections for countries like Niger which are identified as climate change hotspots.

In the second essay I assess the individual and combined impacts of growth in population, income, and agricultural productivity on household food security in rural and urban Niger. It quantifies the likely impacts of climate change induced crop and agricultural labor productivity shocks on undernourishment. For this analysis, a historically validated multi-scale partial equilibrium model, Simplified International Model of Crop Prices, Land Use and the Environment (SIMPLE) is modified for Niger and is combined with a range of secondary data sources from micro to macro level. Among the forces governing household food security in Niger, population growth is the single largest driver. An additional 2 million people will likely be pushed into undernourishment solely due to climate change shocks on crop yields and agricultural labor productivity. Prevalence of undernourishment is higher in urban areas, and climate change shocks will have a larger negative impact in urban households than rural households as urban households struggle to cope with higher food prices due to productivity shocks without associated increase in income.

Having identified the major drivers of food security outcomes in Niger in the second essay, in the final essay I look at three different interventions: accelerated investments in agricultural research and dissemination (supply-side intervention), reduction in population growth rate (demand side intervention), and regional market integration. Abstracting from the full extent of distributional effects, on average a more restricted market is not beneficial for household food security in Niger. The adverse impact of a more restricted market on undernourishment levels shows up in rural areas but is greater in urban areas where households are more dependent on imported food. Another potential policy intervention involves additional investments in agricultural R&D to boost TFP growth. However, given the historically low rate at which R&D dollars are translated into productivity growth, such accelerated investments are unlikely to be sufficient to resolve the food security challenge in Niger. Advancements in agricultural productivity will likely be outpaced by the rapid population growth and climate change setbacks. Demand side interventions will also be required, suggesting the urgent need for measures to reduce the rate of growth in population in Niger and invest in raising human capital.

CHAPTER 1. REASSESSING NIGER'S SSPS IN THE GROWTH ACCOUNTING FRAMEWORK[1]

1.1 Introduction

Niger in the Sahel is confronting a perfect storm. With the highest population growth rate (3.8 percent in 2017) in Africa that is yet to show any signs of slowing down[2], the demands for food and rural employment are exploding. Niger has the highest human fertility rate[3] in the world in a vastly unfertile territory. Dependent on a rainfed agriculture-based economy[4] where farming employs eighty percent of the population, it is ranked the poorest globally in the human development index[5]. A Nigerien in 2018 is poorer[6] than a Nigerien in 1960. Population growth far outpaced Niger's GDP growth. As a result, per capita real GDP continued to decline until the early years of the new millennium. As dire as it sounds, there are signs of improvement with agricultural productivity increasing and potential for a demographic dividend. However, it faces the task of feeding and employing a very young and fast-growing population in an increasingly harsh climate with limited natural resources and human capital. How is Niger going to fulfil this task in the future, more specifically in the mid-century?

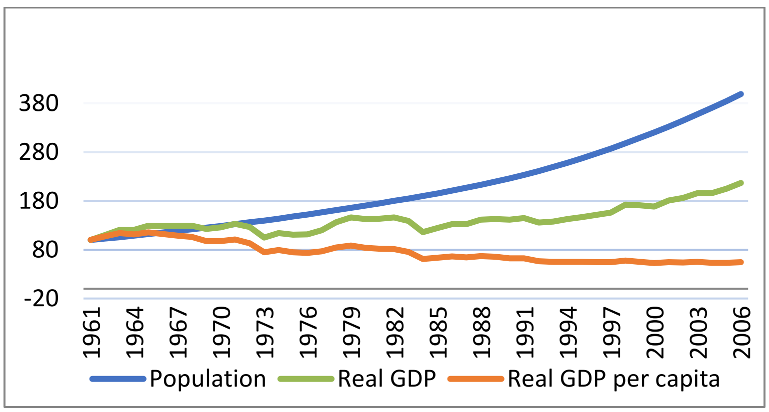


Figure 1: Population, Real GDP and Per Capita Real GDP in Niger, base 1961=100

[1] This paper has been co-authored with Dominique van der Mensbrugghe, Center for Global Trade Analysis.
[2] The population growth rate is fourth highest in the world. The average population growth rate in SSA is 2.7 percent per annum. The growth rate in Niger rate is increasing at an average of 0.07 percent points a year.
[3] Total fertility rate is estimated to be the highest in the world at 7.5 children per woman and below the desired fertility rate (DHS 2012)
[4] Contribution of agriculture to GDP is 40-45%.
[5] Ranked 188th among 188 countries in Human Development Index 2017.
[6] By per capita real GDP.

One of the first steps into conducting any future impact assessments is making long-run projections. But making long-run projections is no easy task specially when it comes to climate change models and socio-economic conditions. The Shared Socioeconomic Pathways (SSPs) (O'Neill et al 2014, Van Vuuren et al. 2014), look at five different ways in which the world might evolve in the absence of climate policies, beyond those which are already adopted by countries[7]. The SSPs consist of two complementary components: country-level yearly forecasts for socio-economic factors such as population, economic growth, education, urbanization, and the rate of technological development (quantification of key variables), and broad regional narratives (qualitative descriptions) (O'Neill et al 2017). Paired with Representative Concentration Pathways (RCPs), which describe different levels of greenhouse gas emissions and other radioactive forcing that might occur in the future, the SSPs form the base for analysis of how different levels of climate change mitigation targets[8] could be achieved (Moss et al. 2010) and will play an important role in design of policy responses.

One of the challenges of making long run socio-economic projections in an era of globalization is that the global economy is interlinked. One cannot simply project Niger's future in the absence of any changes in the rest of West Africa – or anywhere else. There must be consistent global projections. On the other hand, SSPs have necessarily been light on country detail for smaller countries. Yet when making projections for Niger, these details matter. For example, the average annual per capita GDP growth rate during 2001-15 was 1.1 percent, while the SSPs estimate it to average from 1.8 percent to 6.4 percent into 2050, depending on the scenarios.

While the GDP projections in SSPs (Dellink et al. 2017, Cuaresma 2017) were built by the scientific community with a focus to integrate the qualitative and quantitative components into Integrated Assessment Models (IAMs), these pathways are not complemented by country-level analysis of drivers of economic growth such as growth in productivity and volume of production factors by economic sectors. This is perhaps beyond the current scope of SSPs. However, to the extent that they are a central determinant to climate change adaptation and mitigation, understanding the use of land, labor, and capital in a country's production and hence the sources of economic growth is important.

[7] These also exclude any commitments to enact policies within Paris Agreements up to 2025 and 2030.
[8] Climate change mitigation consists of actions to limit the magnitude or rate of long-term global warming and its related effects.

Hence this chapter seeks to better understand the implications of SSPs for Niger, and follows this assessment with country-level analysis of drivers of economic growth. Most importantly, it builds the basis for the following chapters in making long run projections of food security outcomes in Niger.

This essay makes three main contributions. First, compared to RCPs which were built in time for inputs to UN Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, the SSPs are more recent additions[9] from the climate change research world. However, their use is fast growing in multi-disciplinary research and are evolving. The projections were made from an internally consistent set of assumptions within a narrow economic framework and disregards a wide range of country-specific drivers of economic growth, such as external shocks, governance barriers and feedbacks from environmental damage. This chapter contributes by complementing the SSP GDP growth scenarios and narratives (Dellink et al. 2015) with a growth accounting exercise.

Second, the SSPs narratives are primarily defined for the global scale and at broad regional level. Climate change policy actions are taken at country level. If countries are to test their adaptation and mitigation options for robustness across plausible future socio-economic conditions, then SSPs require country-relevant detail to understand climate change risks at the national and local scales. Analyzing sectoral level growth, factors of production and returns to the factors provides a framework for SSPs to be internally consistent at country level. For example, SSP4 describes a world of growing inequality through unequal investments in human capital among other factors. Consistent with this narrative, do simulation results indicate a growing wage premium among skilled and unskilled labors?

Finally, at a more specific country level, Niger has the task of sustaining an economy for the fastest growing population in Sub-Saharan Africa. It has a growing strategic significance partly due to its geographic location in the Sahel region. Climate adaptation challenges are particularly high. Although past studies have looked at drivers of growth in the past (Nachega and Fontaine, 2006), none have analyzed drivers of growth under long-term future scenarios.

I use data from the 2015 Niger Social Accounting Matrix as inputs to Mitigation, Adaptation, and New Technologies Applied General Equilibrium (MANAGE) Model to

[9] SSPs are only now just starting to be used in the next round of climate modelling – known as the Coupled Model Intercomparison Project version 6, or CMIP6 – in preparation for the IPCC's sixth assessment report.

decompose the economic growth in Nigerien sectors while targeting the SSP-projected GDP and population growth scenarios for 2030. MANAGE is a single country, dynamic recursive model built to focus on climate change, energy, and emissions. I choose to analyze only SSP4 scenario – a road divided by inequality with high challenges to adaptation and low to mitigation, for reasons described in section 1.2.2.

The rest of the chapter is structured as follows. Section 1.2 presents the current conditions of the Nigerien economy and the Shared Socio-Economic Pathways in relation to future growth. Section 1.3 describes the main features of the economic model and Section 1.4 presents the results of the different simulations. The main reported results are the decomposition of GDP growth, the changes in labor productivity across sectors, and the changes in wage indexes across education levels. The results are compared with the SSP4 narrative for consistency check.

The paper limits the "deep dive" to a discussion of the drivers of economic growth to labor volume and productivity growth, because of its growing relative importance in economic growth in the country. It will not discuss in details the scenarios for capital accumulation, which is so far the largest driver of economic growth in Niger and the different variables that can result in changes in growth in capital accumulation or productivity. With growth in labor productivity, it is possible for a greater quantity of goods and services to ultimately be consumed for a given amount of work. This consumption is possible with gains in labor productivity, wages, profits and capital gains of businesses, as well as public sector revenue.

1.2 Background

1.2.1 Niger's Socioeconomic Structure

Except for a brief period of uranium boom during 1979-82, GDP growth has been modest until quite recently. In the 1990s, GDP growth rate averaged 2.1 percent and peaked at 5 percent in the 2010s. Traditional, informal sectors contribute to two-thirds of Niger's GDP. Apart from agriculture, the other main contributing sectors are wholesale and retail trade (15 percent of GDP) and government services (12 percent of GDP). With around 40 to 45 percent of the GDP contribution coming from agriculture, the performance of the agricultural sector largely drives GDP growth. Drought years severely affect GDP performance, e.g. 1968-74, 1999-2000. Although there have been recent booms in investments in the petroleum sector[10], half of the GDP growth observed in the past decade is attributed to stable performance in the agricultural sector, geared by improvements in agricultural productivity.

The dominant role of agriculture in the economy is also evident from the fact that the majority of the Nigerien labor force is employed in this sector. Based on household survey estimates (ENBC-2007/08), over 80 percent[11] of working-age adults are employed in agriculture, yet this sector has the lowest level of output per worker in the economy.

Although a large country, 95 percent of the population lives in 35 percent of its land area as four-fifth of the country is covered by the Sahara Desert. The Nigerien population quintupled within 50 years to 16.4m in 2010. It has a very young population (50 percent between 0-14 years, 19 percent between 15-24 years), 84 percent of which live in rural areas. The human capital level of this growing population is among the lowest in the world (Figure 2).

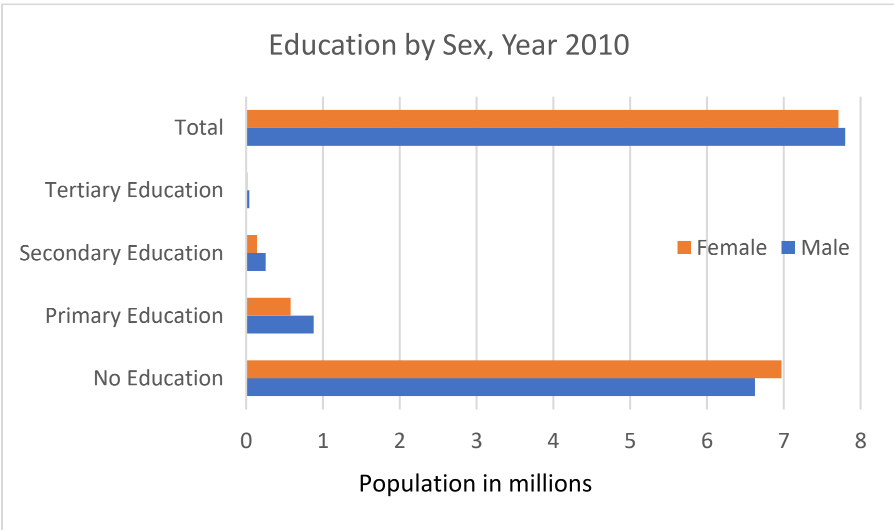


Figure 2: Education levels of total population in Niger by sex, Source: SSPs

[10] Between 2002-2007, the oil sector observed a growth rate of 42.6% at factor cost due to large investments. Despite the spike its contribution to GDP growth during that period was less than 1%.

[11] If over 60% of the population in a country is employed in the agricultural sector, it is categorized as highly dependent. Only 33 other countries fall in this category. (C. Holleman, F. Rembold and O. Crespo, forthcoming. The impact of climate variability and extremes on agriculture and food security: an analysis of the evidence and case studies. FAO Agricultural Development Economics Technical Study 4. Rome, FAO).

1.2.2 Shared Socio-Economic Pathways

Within the conceptual framework for integrated scenarios (Delink and Chateau 2012), the Shared Socio-Economic Pathways (SSPs) are designed to span a relevant range of uncertainty in societal futures (both human and natural) in the mitigation required to achieve a given climate outcome, or the adaptation possibilities associated with that outcome (O'Neill et al., 2017, Riahi et al. 2017). The design process of SSPs is associated with back casting where by an end state is already in mind (a particular outcome is identified) and then the key elements of society that could determine this outcome is identified, although not necessarily assuming that these states are all desirable (O'Neill et al., 2014).

The SSPs consist of i) qualitative narratives of socio-economic conditions under each of the five SSPs at global scale (O'Neil et al. 2017, see Figure) and ii) quantitative projections of central socio-economic variables under each of these SSPs: population and education projections by IIASA (Samir and Lutz 2017); urbanization projections by NCAR (Jiang and O'Neill 2012); and GDP projections by OECD (Dellink et al. 2017), IIASA (Cuaresma 2017), and PIK (Leimbach and Kriegler 2017). All the projections are based on assumptions made for countries of high-, medium-, and low-income groups by each modeling team (Dellink et al. 2017).

Figure 3: Five SSPs representing different combinations of challenges to mitigation and to adaption (originally based on O'Neil et al. 2014)

Table 1: Assumptions in SSPs for low income country like Niger

	SSP 1	SSP 2	SSP 3	SSP 4	SSP 5
GDP growth	M,H	M	L	L	H
Population growth	L	M	H	H	L
Urbanizaiton rate	H	M	L	H	H
Educaiton	H	M	L	L	H

Note: L=Low, M=Medium, H=High

The SSP GDP growth rate projections by OECD for Niger range from 5.4 percent (SSP4) to 8.9 percent per annum until mid-century. Recently (2000-2015) observed GDP growth rate is around 5 percent, while the 25 year average is around 4 percent. GDP is only one of the components of the SSP projections. The other important component-population growth-in turn determines the per capita GDP growth. Given Niger's high population growth rate, looking at only GDP growth rate is not a sufficient indicator of macro-economic conditions. Derived from the GDP and population growth projections in the SSPs, the per capita real GDP projections range between 1.8 to 6.4 percent, which is at least 0.7 percent higher than the current scenario (2000-2015 average). Projections do not necessarily have to follow historical trends, however they also cannot be far removed from the trends.

Table 2: Socio-economic projections for Niger under different SSPs and historical averages

	SSP 1	SSP 2	SSP 3	SSP 4	SSP 5	1990-2015	2000-2015
GDP (p.a.)	8.1	6.9	5.9	5.4	8.9	3.8	4.9
Population (p.a.)	2.4	3.1	3.6	3.6	2.4	3.7	3.8
Per capita GDP (p.a.)	5.6	3.7	2.2	1.8	6.4	0.2	1.1
Urbanization (% of total population)	50%	35%	24%	50%	50%	16%	16.2%

Of the five SSPs I focus on SSP4 for Niger, the central tenet of which is rising inequality due to low and highly unequal investments in education, skill-based technology return or capital returns. I choose this scenario for the analysis as the quantitative projections are closest to historical trends, and the narrative pictures a possible scenario for Niger given current conditions. The SSP4 narrative assumes limited access to education can increase inequality in the long term. While mitigation challenges could be low, challenges to adaptation are high with substantial proportion of populations at low levels of development: low income and education and little access to effective institutions – leaving a large portion of the population vulnerable to climate change

I use the GDP projections by the OECD which is considered to be the "marker" of GDP projections[12] for SSPs (Jiang 2014). GDP projections are generated using an augmented Solow Growth Model based on the assumption of conditional convergence (each country gradually catches up to its frontier level of income that is consistent with its endowments and institutions). SSP scenario-specific assumptions are made for the long term projections of the 6 main economic growth drivers in the model: human capital based on education, employment levels, physical capital, TFP growth, energy demand, and fossil fuel value added. For SSP4 scenario, the speed of convergence is assumed to deviate by - 0.025 from SSP2 scenario.

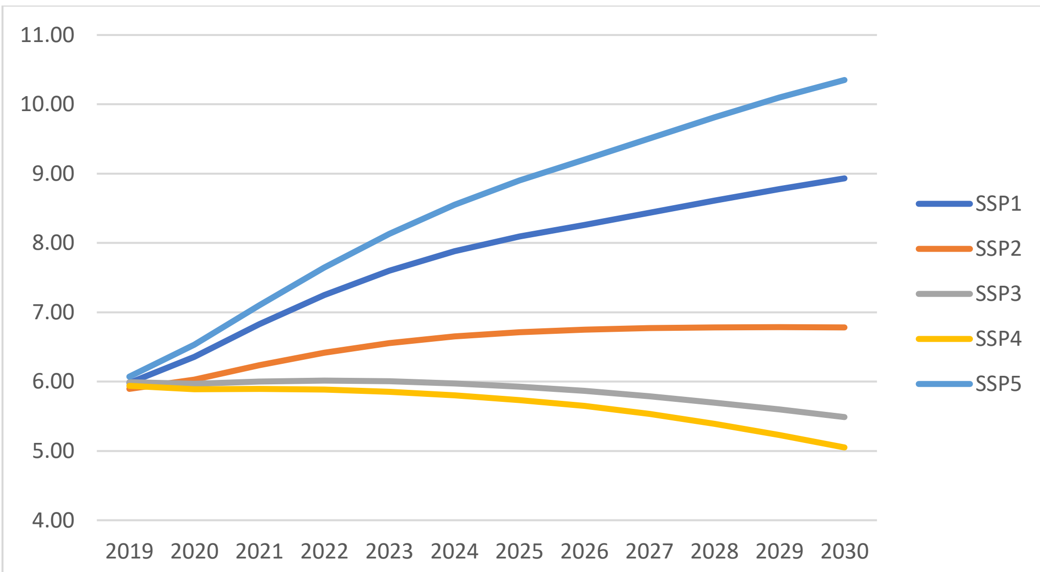


Figure 4: Real GDP growth rate in Niger (% per annum), 2019-2030, under different SSPs

[12] 206 Google scholar citations as of June 23, 2019 vs. 84 of Cuaresma (2017)

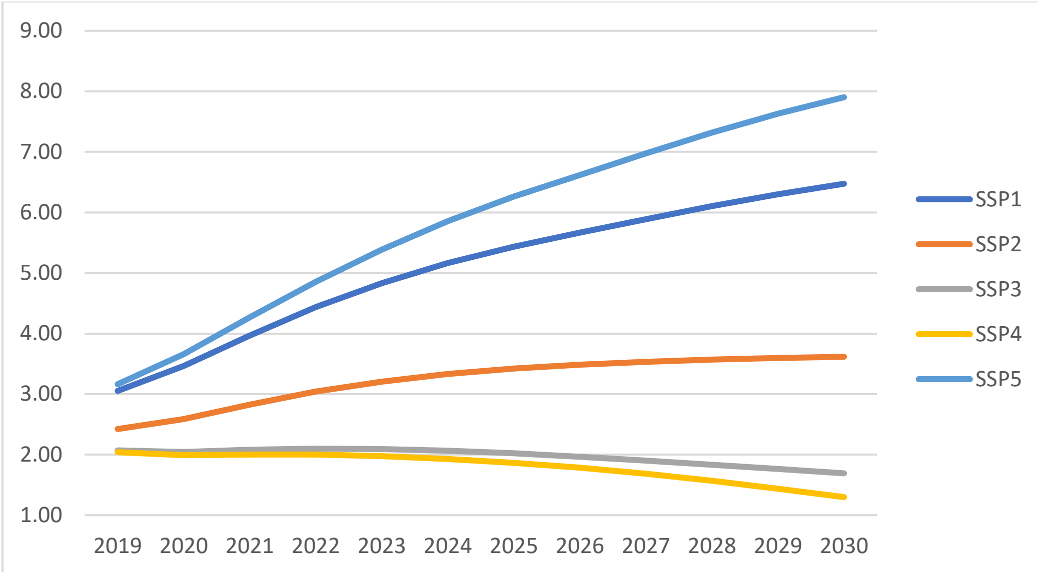


Figure 5: Per capita real GDP growth rate (% per annum) in Niger, 2019-2030, different SSPs

The population projections are made by IIASA which uses a different approach than the UN in defining the assumptions underlying future fertility and mortality trajectories. In addition to the conventional population growth projections by age and sex, IIASA also makes projections by education levels as this has major input into fertility rates (Lutz et al. 2013). For each of the SSPs, countries are grouped by low fertility, high fertility and rich-OECD groups and assumptions on fertility, mortality, migration, and education are made for each of these group of countries for each SSP. For example, for Niger (which falls into high fertility group) in SSP4 scenario it is assumed that there will be continued high levels of fertility and mortality, medium migration, and inequal access to education. To create a scenario of polarized education, the SSP4 scenario assumes different education trends for lower (no education to lower secondary) and higher levels of education[13].

[13] Continued enrollment ratio – 10% is assumed for educational attainment progression for the transitions from no education to incomplete primary, incomplete primary to completed primary and from completed primary to completed lower secondary. Global education trend (GET) is assumed for higher levels of education. See KC and Lutz (2014) for more details on these trends.

1.3 The Economic Model, Data and Growth Accounting Theory

1.3.1 The Theory behind Growth Decomposition

Growth accounting is viewed as a preliminary step towards understanding fundamental factor side sources of economic growth. It received considerable attention in analyzing the performance of East Asian countries in the 1990s (Hsieh 1999). The standard primal model of growth accounting14 provides a breakdown of GDP growth by changes in factor inputs, usually capital and labor, and a residual that reflects technological progress and other elements (Solow 1957), also known as Solow residual.

Growth accounting framework is a useful tool to understand growth experiences across countries and over time. A key limitation in the methodology is that the measured residual is fully attributed to gains in productivity (TFP), whereas the residuals could also reflect a number of other factors such as political disturbances and conflicts, droughts, external shocks, changes in government policies, and measurement errors (Bosworth and Collins 2003). As such, the results from growth accounting exercise should not be construed as providing the fundamental causes of growth (rather the proximate sources of growth).

Assuming that factors are paid their social marginal products, the growth is decomposed into components of growth in quantity of factors and productivity of factors, namely labor and capital. In this paper, in addition to labor and capital, land is included as a production factor. And labor is disaggregated by education and region. Griliches and Jorgensen (1967) and Jorgenson et al. (1987) demonstrated the importance of disaggregating the inputs by quality classes such as labor by school attainment, age, and sex. If a population's average educational attainment is rising over time, then this procedure attributes a portion of economic growth to the rise of that particular labor type. This is particularly important in this analysis as Niger like many other Sub-Sahara African countries emphasize on the potential to benefit from demographic dividend.

1.3.2 Main features of the economic model (MANAGE)

We use the Mitigation, Adaptation, and New Technologies Applied General Equilibrium (MANAGE) Model to assess the growth in labor productivity in Nigerien sectors in order to target

[14] There are different approaches to growth accounting such as the dual approach (Hsieh 1998), which considers changes in factor prices rather than quantities. However when done properly the primal and dual approach should be producing same results (Barro 1998)

the SSP projected GDP growth scenarios. MANAGE is a (recursive) dynamic single country computable general equilibrium (CGE) model designed to focus on climate change, energy, and emissions. Manage model includes a detailed energy specification that allows for capital/labor/energy substitution in production, intra-fuel energy substitution across all demand agents, and a multi-output, multi-input production structure. Furthermore, MANAGE is a dynamic model, using mostly the neo-classical growth specification.

The model uses the Armington structure of imperfect substitution between imported and domestic goods. It assumes Niger is a small country whose imports and exports do not affect the world prices of goods.

Figure 6: Production Nests in standard MANAGE (van der Mensbrugghe 2018)

The dynamics of MANAGE is in three elements:

Population and labor stock growth are exogenous. In this paper, the population growth rate is coming from the chosen SSP. Labor growth rate is equated to the growth rate of the working age population.

The aggregate capital stock grows according to the overall level of saving (enterprises, households, public and foreign), but will also be influenced by the investment price index and the rate of depreciation. The household savings rate is fixed. Government savings is fixed in levels (at base year levels). Foreign savings grow at the same rate as GDP. Given these assumptions, one would assume that investment grows around the same rate as GDP. The rate of return of capital in base year in Niger is estimated at 15.6%. The estimates of the capital stock are computed using the perpetual inventory method (PIM) and assuming a depreciation rate of 5 percent and a capital-output ratio of 1.6 (similar to Nachega and Fontaine, 2006) in the base year 1960. The capital-labor ratio is 40:60. Data used in this exercise are from the Penn World Table.

The third component relates to productivity assumptions. By default, labor productivity in services (gl) is assumed (or calibrated dynamically to achieve a per capita growth target). Since we fix GDP in the baseline, the model calculates gl to be consistent with the exogenous GDP trend (and subject to all of the other dynamic assumptions). Labor productivity in other sectors is calculated relative to labor productivity in services using a linear schedule that allows for both multiplicative and additive components. In this paper labor productivity in agriculture is assumed to be growing 2% (additive) faster than in services. This assumes that in a developing country labor productivity in agricultural sector grows faster resulting in releasing labor from agriculture to other sectors.

Agricultural land is fixed and agricultural yield grows at 1% per annum. The elasticities of substitution used in the model are based on the best estimates found in the literature and expert advice.

1.3.3 Niger Social Accounting Matrix

A national Social Accounting Matrix (SAM) is a consistent set of accounts representing economic flows for production activities, commodity flows, incomes and expenditures of households, government and other institutions, transactions with the Rest of the World, savings, and investment between agents in a certain economy during a certain period15 (Round and Pyatt, 1985; Reinert and Roland-Holst, 1997). The 2015 Niger SAM is the reference database for calibration of MANAGE. The 2015 SAM of Niger16 was constructed using data from the national accounts, sectoral production and prices, the balance of payments, and the National Survey on Household Living Conditions and Agriculture (ECVMA 2014).

This SAM distinguishes between home (own) consumption of activities and marketed consumption of commodities by households, an aspect especially relevant to developing countries like Niger. Since the SAM provided an ample disaggregation in household consumption with geographic location (rural-urban) and education levels, the paper use the richness of the data and further disaggregated MANAGE. Factors of production are labor, land, and capital with labor categorized into 8 categories: rural and urban labor; and by education level (uneducated, primary school educated, secondary school educated, and tertiary level educated).

Table 3: Categories of labor in the Niger SAM

Code	Description	Notes
flab-rn	Labor-rural uneducated	0-6 years of formal schooling
flab-rp	Labor-rural primary	7-11 years of formal schooling
flab-rs	Labor-rural secondary	12+ years of formal schooling and/or incomplete tertiary education
flab-rt	Labor-rural tertiary	Completed tertiary education (e.g. degree, certificate, diploma)
flab-un	Labor-urban uneducated	0-6 years of formal schooling
flab-up	Labor-urban primary	7-11 years of formal schooling
flab-us	Labor-urban secondary	12+ years of formal schooling and/or incomplete tertiary education
flab-ut	Labor-urban tertiary	Completed tertiary education (e.g. degree, certificate, diploma)

[15] It is a square matrix in which a row and a column represent each account and each cell reflects a payment from the column account to the row account. Double-entry accounting requires that, for each account, total revenue (row total) equals total expenditure (column total). See Appendix for an aggregate standard SAM

[16] Until now unpublished SAM provided by the International Food Policy Research Institute (IFPRI) for use of this research. It is the product of NEXUS project, led by IFPRI. Published SAMs are freely available online.

The 68 SAM activities and 74 SAM commodities are grouped into 13 activities and 13 commodities respectively (oil, gas, mineral mining, electricity, processed foods, textile and wearing apparels, other manufacturing, refined oil, construction, private services, and public services). Households are disaggregated by per capita expenditure quintiles, with poor households defined as those in the bottom 40 percent of the per capita expenditure distribution.

1.4 Results and Discussion

What are the projected sources of economic growth in Niger?

GDP growth in Niger is accounted mostly by growth in labor volume and in more recent decades by capital formation (see author's calculation in Table 4). In the near future capital formation is estimated to make the largest but constant or slightly decreasing contribution to GDP growth. The changes in GDP growth stems mainly from changes in growth in labor productivity (see simulation results in Figure 7).

The historical growth decomposition is consistent with the high population growth rate, and more recently, the increasing public and private investments. In recent decades, Niger experienced GDP growth rates around 4.5 percent and it coincides with capital deepening. Growth in real investment increased to 12 percent from 2 percent in the 1990s. There was, however, little embedded technical change (Nachega and Fontaine 2006, Aka et al. 2004)17. Given the low education level and absence of substantial manufacturing sector (where labor productivity can be relatively high for semi-skilled workers), it is not surprising that changes in labor has played a smaller role in explaining growth.

[17] Nachega and Fontaine (2006) analyzed Niger's sources of growth for four periods between 1964 and 2003 and found TFP growth to be negative during the 1960-2000s which is not contrary to performance in sub-Saharan African countries on average during that period where the growth was nil (Bosworth and Collins 2003,). Aka et al. (2004) estimates the contribution of capital and labor in GDP growth rate in Niger during 1960-2000 to be 1 percent and 1.7 percent respectively while TFP growth is negative (-0.1%).

Table 4: Historical GDP growth decomposition, Niger, 1961-2014. Source: Author's calculation

Periods	Growth in GDP (Y)	Growth in physical output per worker (Y/L)	Growth in lab volume (L)	Growth in capital per worker (K/L) (PIM)	Growth in K volume (PIM)	Growth in TFP=(Y/L)/(K/L)^0.4	Growth in real investment	Average RoRK=Y(t)*(0.4)/K(t)
1961-2014	1.55	-1.60	3.14	-1.17	1.97	-1.13	1.35	14.71
1961-1970	2.41	0.60	1.81	5.71	7.52	-1.68	2.69	20.81
1971-1980	1.35	-1.17	2.52	0.73	3.25	-1.47	5.29	13.27
1981-1990	-1.58	-3.99	2.41	-2.51	-0.10	-2.99	-7.96	10.75
1991-2000	2.92	-1.60	4.52	-4.50	0.02	0.20	1.95	12.01
2000-2014	**4.72**	**1.04**	**3.68**	**0.14**	**3.81**	**0.98**	**11.58**	**15.62**

Source: Author's calculation from Penn World Table (PWT)

*Labor share in PWT is assumed 32-35% of the population and growing at the same rate.
*Capital stock (K) calculated by perpetual inventory method (PIM) using data from Penn World Table. Depreciation rate 5%, initial K/Y ratio 1.6 as used in IMP studies

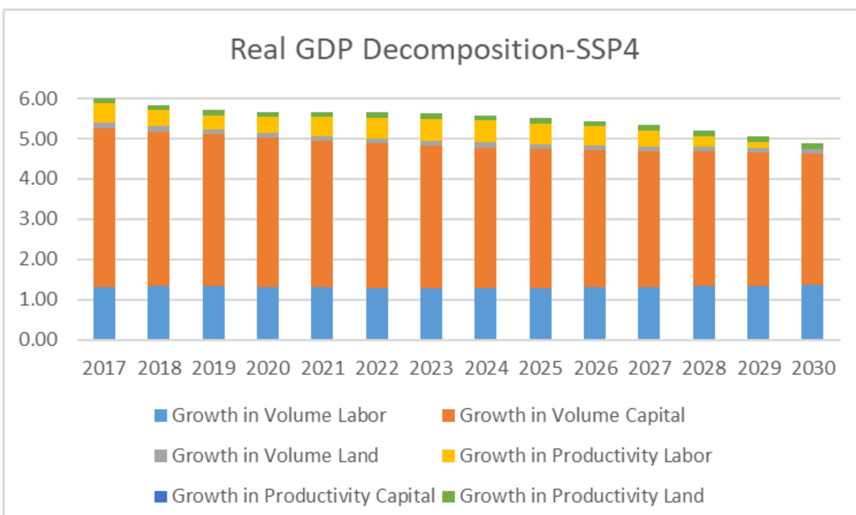


Figure 7: Future Real GDP growth decomposition, Niger, SSP4 scenario

Source: Simulation results

Overall labor productivity growth, as measured by physical output per worker, was negative until in the turn of the century. Since then it is estimated to be growing at around 1 percent per annum, which is lower than average estimates in West Africa. Labor productivity grew by 3.1 percent between 2005 and 2016 in West Africa, much of which came from within sector productivity growth in agriculture and services (AFDB 2018). For SSP4 GDP scenario, the model estimates a downward sloping labor productivity growth of around 0.5 to 1 percent in the services sector until 2030 and an additional 2 percent in the agricultural sector (due to the additive productivity assumption). The SSP scenario with the lowest GDP growth rate requires a more than average labor productivity growth in Niger. Which sectors would be generating the labor productivity growth?

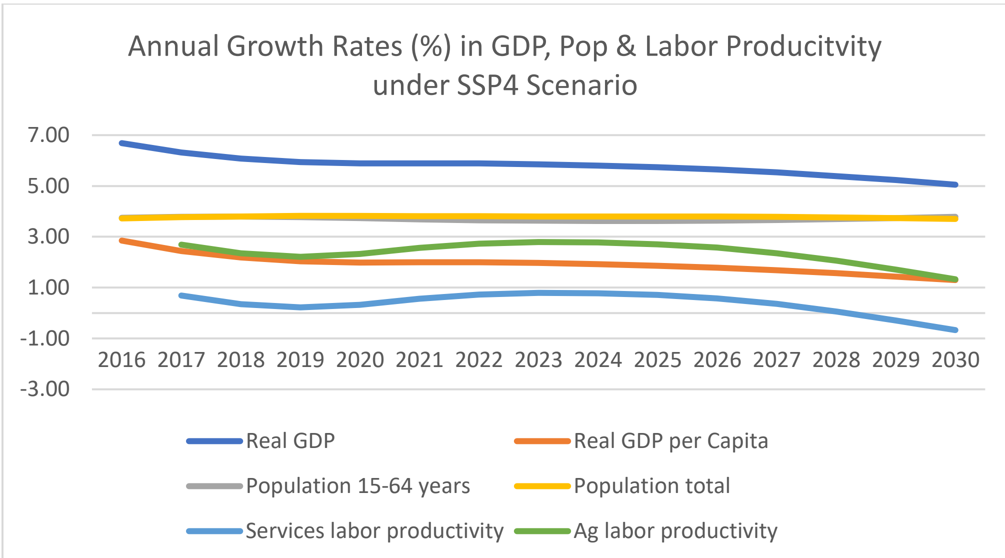


Figure 8: Future growth trends in GDP, population and labor productivity in Niger

Source: Population and GDP growth rates are SSP4 projections, productivity trends are simulation results under SSP4 scenario

Structural change and labor productivity in Niger

When labor and other resources move from less productive to more productive activities, the economy grows (between-sector productivity growth) even if there is no productivity growth within sectors. There has been little indication of structural change in Niger. The share of agriculture in employment and value added has not dropped in Niger in the past few decades. Nor does it look likely in the immediate future (see Figures). Sectoral share of outputs remain similar in 2030 in comparison to 2015.

Agriculture sector contributes most to GDP growth followed by private service (a-psv) and government service (a-gsv). Contribution of growth from labor volume is highest in agriculture and services sector (government services and private services). Most of the labor productivity growth also occurs in these sectors with a downward turn in the SSP4 scenario with low human capital due to inequality in education. The contribution of labor being mostly in agriculture and services sector is similar to patterns in West Africa (AfDB 2018). The absence of a substantial manufacturing sector means structural transformation in Niger could be potentially growth reducing (McMillan and Headey2014) whereby labor is released from agriculture to low productive informal services sector.

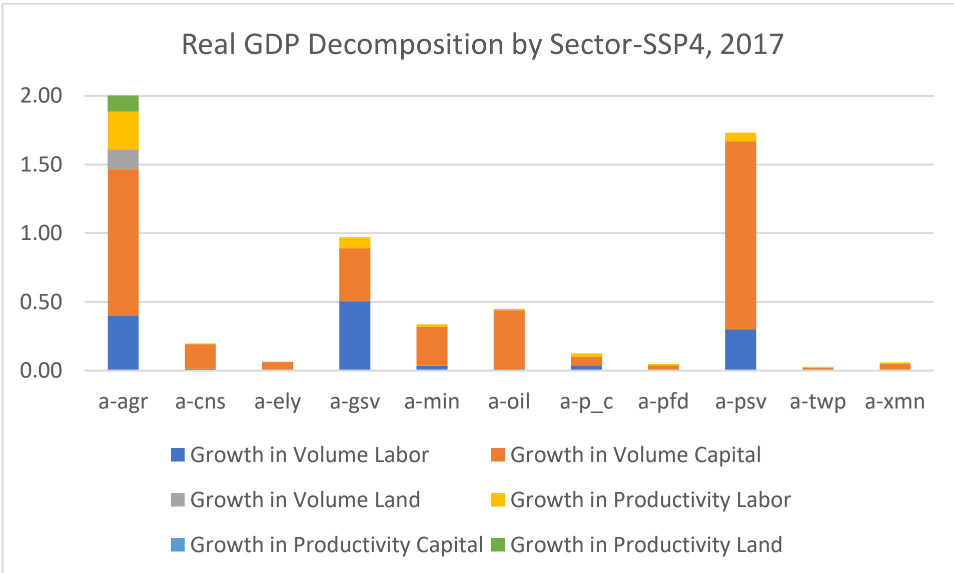


Figure 9: Real GDP growth decomposition by sectors in Niger, 2017

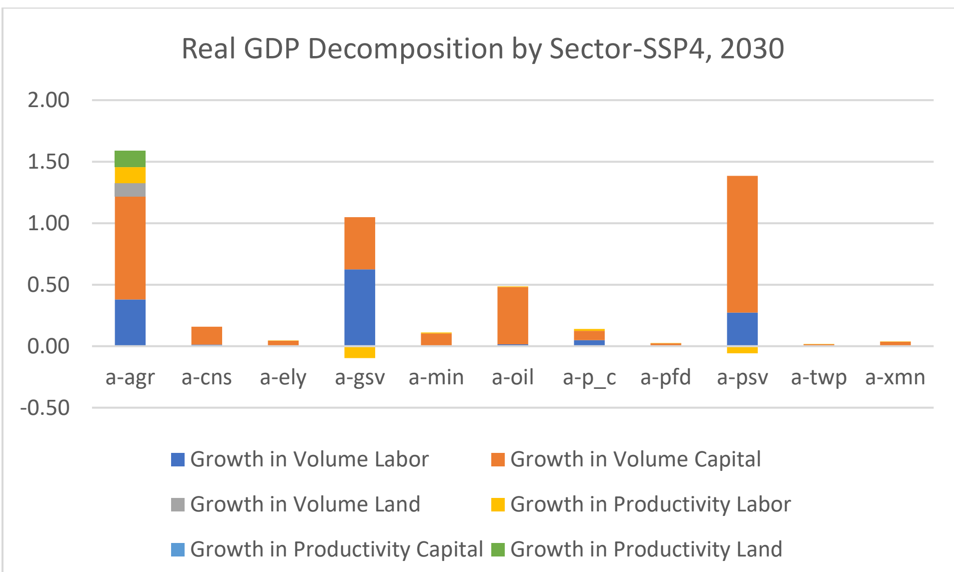


Figure 10: Future Real GDP growth decomposition by sectors in Niger, year 2030

Oil, electricity, construction, and mining sectors are mostly based on capital formation; and much of the recent speculation has been on resource-led growth. The caveats of a natural resource led growth is well known[18]. From a labor absorption and income point of view, capital intensive sectors, such as mining and oil production and refining, absorb little labor and the resource windfalls create small economic enclaves which is part of the reason small economies (e.g. Bostwana, Cape Verde) do better with resource led growth (Rodrik 2014). But Niger is not set to be a small economy with its projected population growth and landmass (6th largest country in SSA).

Slower labor productivity growth means lower increases in wage index. There is excess labor supply due to high population growth (4%) and growing inequality in wage index by education levels.

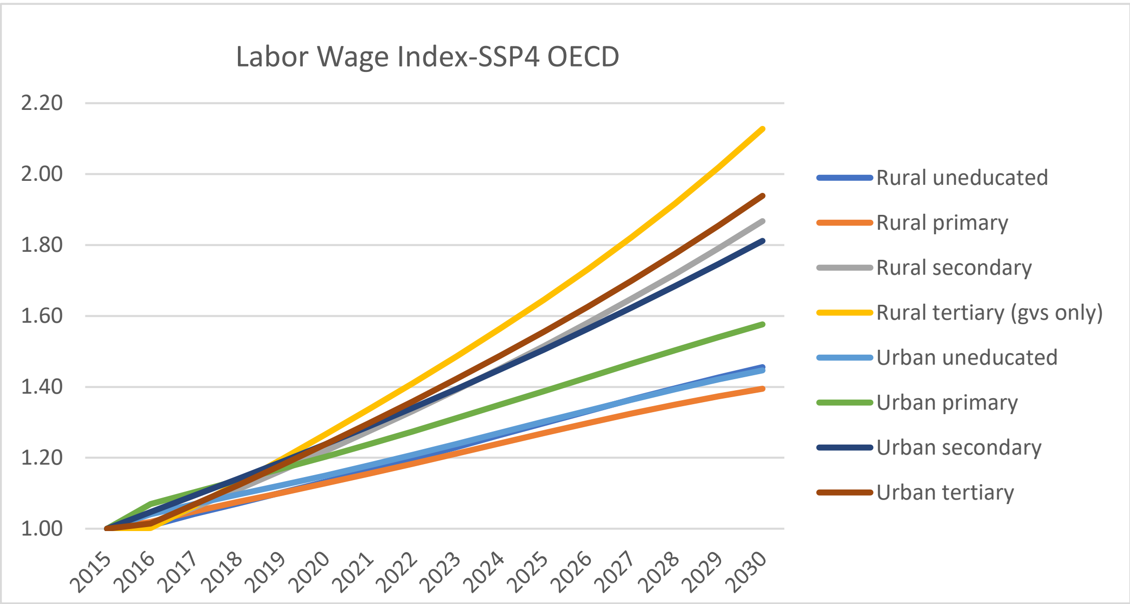


Figure 11: Trends in labor wage index in Niger by education levels and rural-urban location

Source: Simulation results under SSP4 scenario

Are the SSP4 projections consistent with the narrative?

The education assumptions imply that a decreasing share of the population has access to proper schooling, and hence human capital levels are falling over time in this scenario (Dellink et

[18] Dutch Disease (Corden and Neary, 1982), resource curse (Gelb, 1988, Auty 1994) – and more recently, conflicts (Collier and Hoeffler, 2004).

al. 2017). The share of population that has access to education does not change much over the years in Niger under SSP4. However, given that the population growth rate is assumed to be around 3.6 percent, it means a growth in absolute number of people who do not have proper access to education—leading to rising inequality, and slowing labor productivity. For a country like Niger where education levels are extremely low and so is labor productivity, can it fall even further? The SSP4 is narrated to create a scenario where there is polarized education and a section of the population is very highly educated and internationally connected. For cases like Niger where secondary and tertiary education levels are very low to begin with it is not surprising to have model projections of decreasing labor productivity.

More puzzling is that SSP4 assumes high urbanization rates for low income countries. For Niger it assumes, 50 percent of population will be living in urban areas. The UN projects 28 percent urbanization rate for Niger by mid-century. SSP4 likely assumes rapid urbanization without growth (Fay and Opal 1999). The relationship between urbanization and education is not straightforward. Bertinelli and Zou (2008) suggests an inverted U-shaped relationship between urbanization and education. They find that urbanization rate below 40 percent deter human capital formation. At a rate as high as 50 percent-as assumed in SSP4-it is not entirely clear how urbanization and human capital formation stands in this framework. The model simulations indicate growing inequality by education levels rather than rural-urban location.

1.5 The Way Forward

The purpose of this chapter is not to propose new revisions to the SSPs in the context of Niger. Proposing new projections scientifically without creating a competing method and rather improvising on existing methods is out of the scope of this study. But the point of this discussion chapter is to bring attention to scientists and researchers, who conduct elaborate research on making these projections, to the need for taking a closer look at the projections for smaller (small but definitely growing fast!), data scarce countries. The current work can be extended in two ways: i) include a critical assessment of all the SSP narratives in the context of Niger, and ii) disaggregate initial wages by location, sectors and education. Currently we do not have adequate information to perform this analysis.

This chapter identifies the need for additional research in the SSP formulation along few dimensions. Checking GDP projections and population projections is not adequate. Combining them and looking at GDP per capita trends is mandatory for consistency check- how realistic or how far removed they are from scenario narratives and historical trends.

The climate change research community could benefit from consistency checks between GDP projections by IIASA and OECD. And the projections by IIASA are framed in the context of complementing the reference projections by OECD (Cuaresma 2017). IIASA projections are increasingly in use specially for research related to human capital. Yet there are marked differences in trends large enough to question the complementarity (see Appendix) and result in differences in analysis (e.g. see labor productivity in Niger in Fig in Appendix). There is a need for guideline on their use and re-evaluation of these two parallel approaches.

1.6 Appendix

A.1. Growth accounting formula in the simulation

The growth accounting formula is linearized:

$$\dot{GDP} = \sum_{fp} S_{fp} \dot{\lambda_{fp}} \dot{fp}$$

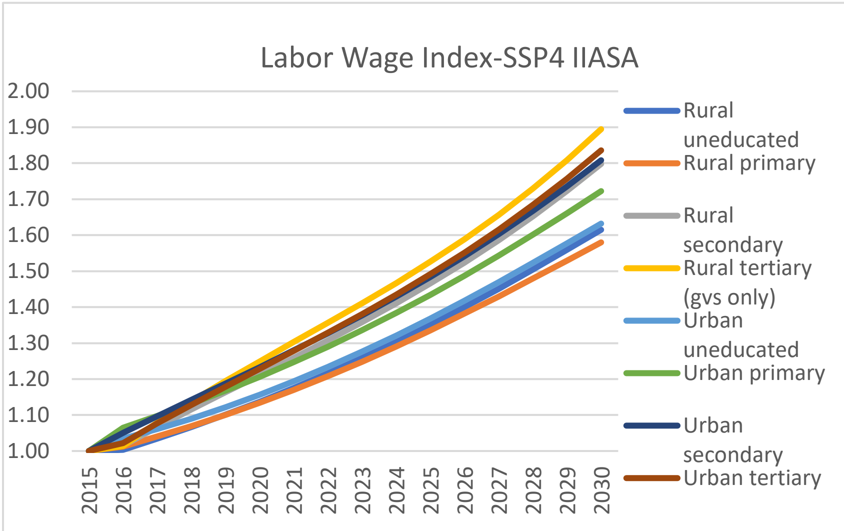
Where fp is the set of factors of production, $\dot{\lambda_{fp}}$ is the growth rate of the productivity of factors of production, and S_{fp} is the factor share in GDP

The following code estimates the growth decomposition, where:

```
  fshr(fp,a,t)     Factor share in value added
  qdel(fp,a,t)     Growth in volume
  ldel(fp,a,t)     Growth in productivity of factor
  gdpfc(t)         GDP at factor cost excl indirect taxes
  rgdpfc(t)        Real GDP at factor cost excl indirect taxes
Productivity variables:
          lambdanr(a,t)       Productivity of natural resources
          lambdan(a,v,t)      Productivity of intermediate inputs
          lambdav(a,v,t)      Productivity of value added bundle
          lambdat(a,t)        Land productivity
          lambdal(a,l,t)      Labor productivity
          lambdak(a,v,t)      Capital productivity
Price variables:
          swage(a,l,t)        "Sectoral wage by skill"
          pk(a,v,t)           "Sectoral price of capital by vintage"
          pland(a,t)          “Price of land by sector”
```

```
        pnr(a,t)              "End-user price of natural resource"
Factor demand variables:
      ld(a,l,t)            "Demand for labor by skill"
      kd(a,v,t)           "Demand for capital by vintage"
      land(a,t)           "Demand for land by sector"
      xnr(a,t)            "Demand for natural resource factor"

    fshr(l,a,t) = swage.l(a,l,t)*ld.l(a,l,t) ;
    qdel(l,a,t) = ld.l(a,l,t) ;
    ldel(l,a,t) = lambdal.l(a,l,t) ;

    fshr(cap,a,t) = sum(v, pk.l(a,v,t)*kd.l(a,v,t)) ;
    qdel(cap,a,t) = sum(v, kd.l(a,v,t)) ;
    ldel(cap,a,t)$qdel("cap",a,t) = sum(v, lambdak.l(a,v,t)*kd.l(a,v,t))/qdel("cap",a,t) ;

    fshr(lnd,a,t) = pland.l(a,t)*land.l(a,t) ;
    qdel(lnd,a,t) = land.l(a,t) ;
    ldel(lnd,a,t) = lambdat.l(a,t) ;

    fshr(nrs,a,t) = pnr.l(a,t)*xnr.l(a,t) ;
    qdel(nrs,a,t) = xnr.l(a,t) ;
    ldel(nrs,a,t) = lambdanr.l(a,t) ;

    fshr(fp,a,t) = fshr(fp,a,t) / gdpfc.l(t) ;
    if(years(t) gt years(t0),
      loop((fp,a)$qdel(fp,a,t-1),
        put   sim.tl,   "qdel”,   a.tl,   fp.tl,   years(t):4:0,   (100*0.5*(fshr(fp,a,t-
1)+fshr(fp,a,t))*((qdel(fp,a,t)/qdel(fp,a,t-1))**(1/gap(t))-1)) / ;
      ) ;
      loop((fp,a)$ldel(fp,a,t-1),
        put   sim.tl,   "ldel”,   a.tl,   fp.tl,   years(t):4:0,   (100*0.5*(fshr(fp,a,t-
1)+fshr(fp,a,t))*((ldel(fp,a,t)/ldel(fp,a,t-1))**(1/gap(t))-1)) / ;
      ) ;
      put sim.tl, "yfcdel", "", "", years(t):4:0, (100*((rgdpfc.l(t)/rgdpfc.l(t-1))**(1/gap(t))-1)) / ;
      put sim.tl, "ympdel", "", "", years(t):4:0, (100*((rgdpmp.l(t)/rgdpmp.l(t-1))**(1/gap(t))-1))
/ ;
    ) ;
```

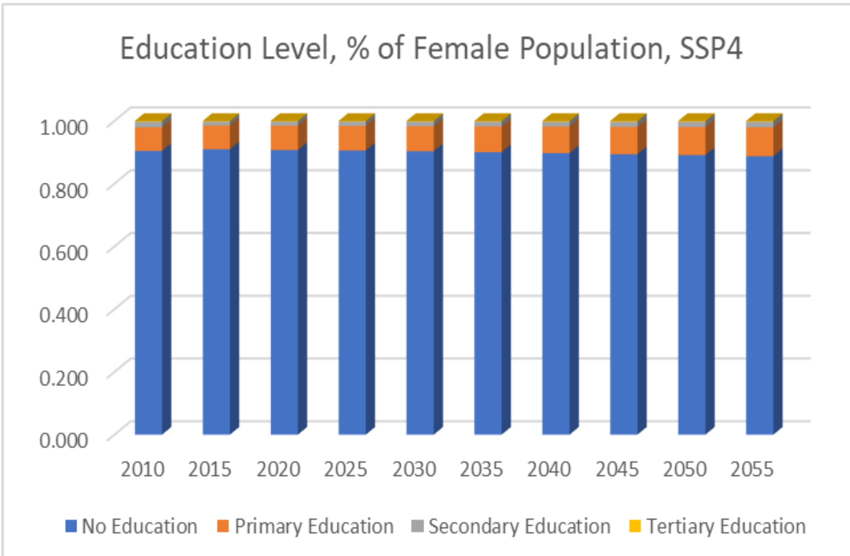
A.2 Trends in labor wage index and productivity differ widely by IIASA and OECD GDP projections

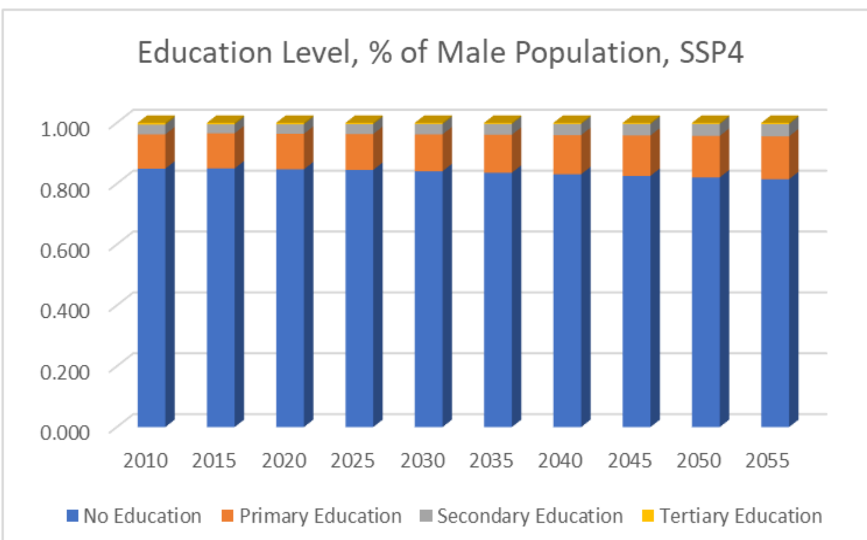


A.3 General Structure of the Niger Social Accounting Matrix

	Activities	Commodities	Factors	Enterprises	Households	Government	Taxes	Investment	Rest of the World	Total
Activities		Marketed outputs			Private non-marketed consumption					Activity income
Commodities	Intermediate demand	Transaction costs			Private marketed consumption	Government consumption		Gross capital formation	Exports	Total demand
Factors	Value-added								Foreign transfers to factors	Factor income
Enterprises			Factor income to enterprises			Government transfers to enterprises			Foreign transfers to enterprises	Enterprise income
Households			Factor income to households	Enterprise transfers to households		Government transfers to households			Foreign transfers to households	Household income
Taxes	Taxes on producers	Taxes on products	Factor taxes	Corporate taxes	Household taxes					Tax income
Government				Enterprise transfers to government	Household transfers to government		Tax revenues paid to government		Foreign transfers to government	Government income
Savings				Enterprise savings	Household savings	Government savings			Foreign savings	Savings
Rest of the World		Imports	Factor payments abroad	Enterprise payments abroad	Household payments abroad	Government payments abroad				Foreign exchange outflow
Total	Activity expenditures	Total supply	Factor expenditures	Enterprise expenditures	Household expenditures	Government expenditures	Tax payments	Investment	Foreign exchange inflow	

A.4 Level of education in Niger is very low and does not improve in the SSP4 projections





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CHAPTER 2. FORCES GOVERNING LONG-RUN FOOD SECURITY IN RURAL AND URBAN NIGER

2.1 Introduction

Niger has a food insecurity situation that is categorized as serious based on the Global Hunger Index[19.] Its rapid population growth is occurring in the Sahel region, which is identified as one of the most climate change vulnerable regions due to its high exposure to heat and low adaptive capacity (Niang et al. 2014). This has left many observers wondering: How is Niger going to achieve its food security goals? The answer to this question depends on and will affect the stability of a country that is increasingly becoming a geographical strategic point in West Africa. A point of discussion is how much growth in agricultural productivity and economic development is going to be required to win the footrace with population growth in tackling food security challenges in Niger in an era of climate change.

To date there has been major debate but little quantitative analysis of this perfect storm. In its most recent national development plan (2017-21 Economic and Social Development Plan), Niger identified ensuring demographic transition, maintaining sustainable and inclusive economic growth, strengthening food and nutrition security, and adaptation of production systems to climate change among its eight major challenges. Specific targets have been set along each of the strategic axes addressing these challenges, such as reducing population growth to 3.06% by 2021, projecting GDP growth rate to an optimistic 6.2% from the current 5%. The importance of issues associated with population growth, economic development, climate change effects, and agricultural productivity at the national level are well recognized. However, their role in food security outcomes are typically analyzed separately, instead of as a group.

Against this backdrop, this chapter sheds light on i) the long-term consequences of climate change on the spread and depth of household food security through crop production and ii) the comparative strength of population growth, income growth, and agricultural productivity in driving food production and food security outcomes in Niger. This multifaceted approach is necessary to allow us to build a comprehensive view of future food security in Niger. This also provides a useful context for the evaluation of policy priorities (Chapter 3). This paper seeks to

[19] Niger's global hunger Index (GHI) in 2017 is 30.4. It ranks 99 among 199 countries. GHI scores are based on undernourishment, child wasting, stunting, and mortality levels.

answer three key questions. First, what are the likely impacts of climate change induced agricultural labor and crop productivity shocks on undernourishment in Niger in 2050? A second question is how will rural versus urban households be affected by these developments. Finally, the paper explores the relative importance and interactions between population growth, income growth, and agricultural productivity as drivers of household food security outcomes. Results from this study should be interpreted with consideration that the outcome indicators are not adequate reflections of diet quality, but of diet quantity only.

Given the paucity of data and the limited knowledge about economic parameters governing the food system in Niger, a relatively parsimonious partial equilibrium (PE) model of crop supply and demand in the agriculture sector called Simplified International Model of Crop Prices, Land Use and the Environment (SIMPLE model)[20] (Baldos and Hertel 2013) is used for this analysis. The model is paired with data from Nigerien household surveys. The standard model is modified to suit i) the Nigerien climate zones, ii) household consumption by rural and urban households and iii) the effect of food price on agricultural household income. The baseline year is 2009 and the model creates a scenario in 2050 considering population, income and total factor productivity (TFP) growth in future crop production and a range of climate change induced crop and labor productivity shocks.

This paper makes several contributions to the literature. First and most importantly, it fills a policy research gap in a high population growth, low productivity, climate change vulnerable country in the critical Sahel region by analyzing the comparative role of key drivers of food security outcomes. By supplying an integrated, quantitative analysis, it offers a framework for understanding the relative importance of the major drivers of food security i.e. growth in income, population, and agricultural productivity in the context of climate change. The analytical results of this paper can contribute to the discussion of building a coherent development plan, realistic targets, and identification of priority areas. To the best of our knowledge, no other paper has presented such analysis for Niger. Baldos and Hertel (2014) and Hertel and Baldos (2016) examine the effect of these drivers at the global level in 16 regions. Inferences for Niger can only be made from results from the entire Sub Saharan Africa region in their model -- which is insufficient for a country-level analysis. Montaud et al. (2017) conducts a static, economy-wide analysis to study

[20] 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

the changes in income, poverty levels, and food insecurity ratio, food access index, and food availability index in Niger strictly due to climate induced yield changes. However, Montaud et al. (2017) does not provide a prospective analysis of the outcomes based on the economic, climatic and demographic drivers analyzed in this paper, which are important to policy decision making.

Second, much of the literature focus on climate impacts in agriculture has been on crop productivity. However heat stress also affect agricultural labor productivity and Lima et al. (2019) finds welfare impacts due to heat stress related labor productivity shocks can be larger than impacts due crop related productivity shocks. Agricultural employers are hit twice: they need to hire more workers to get the same effort and second, they must pay the workers more. In places like Niger where 80% of the workforce is employed in agriculture and work outside where temperatures average 40 degree Celsius, the impacts can be significant. In this paper, these impacts are considered.

Third, there are several methodological contributions. The model is validated for Niger, looking back at history for the period of 1991-2009 to assess how well our model replicates observed changes in crop output growth and production input use. The value of projections lies in the scientific credibility of the underlying models which depends on model validation- an area in which most economic models of agriculture lag.

In most PE frameworks, income is treated as exogenous. For this reason, previous versions of SIMPLE did 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 paper by Hertel and Baldos (2016) does not disaggregate rural households and treats income as exogenous. This can be problematic, because there is an established link between crop prices, rural incomes, and poverty (Headey et al. 2014, Ravallion 1990). In this chapter, I model crop income as endogenously affecting rural household income.

Another methodological improvement is the analysis of crop supply and future yield projections at the grid cell level instead of national level. These gridded yield projections are aggregated to Niger’s distinct climate zones. It improves upon the yield impacts used in Montaud et al. (2017) which are downscaled from estimates for the entire region (Sahel or West Africa).

The rest of this chapter is structured as follows: Section 2.2 provides a background of Niger in the context of agricultural productivity, climate change, and undernourishment. Section 2.3

describes the SIMPLE model, the experimental design, and the data in relevant context. Section 2.4 presents the main findings from the experiments.

2.2 Historical background

Niger has been brought to the forefront of global news headlines over the past year, and not for the reasons it would wish. These headlines note the rising undocumented emigration through the desert in Agadez, in northern Niger to Libya onwards to Europe, as well as the increasing foreign military presence in the Sahara Desert, including a huge drone base. Concerns about transnational security have thrust a country that seldom receives international attention into the limelight. Missing from the discussion is the linkage between climate change, food security and population growth in the fight over security stability. As we look forward into 2050 in this paper, looking back at historical trends in the relevant context provides us with deeper insights into the future.

An increasingly harsher, unpredictable climate:

Niger is one of the hottest countries on the planet with temperatures in Niamey, the capital in the south, varying from 31 degrees Celsius (88 degrees Fahrenheit) in August to 41 degrees Celsius (106 degrees Fahrenheit) in April. More than 60% of the country's land area is in the Sahara Desert. Large parts of Niger where its dominant crop, millet, is grown are 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.

Regional climate analyses suggest a 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 one of the hotspots of climate change, and unprecedented climates are projected to occur earliest (late 2030s to early 2040s) in these regions (Mora et al. 2013).

Precipitation levels distinctly mark Niger's agro-ecological zones. The Sahara Desert (Saharienne zone) in the north receives less than 200 mm of rain per year. South of the Sahara Desert lies the central belt (200-400 mm rain per year) comprising the Saharo-Saheliene and Saheliene regions, where pastoralism is the main activity. Transhumant cattle herding (where the herd moves to green pastures after a short rainy season and back to dryland after harvest) dominates this zone. Most of the country's agricultural land falls within a narrow band in the south comprising the area north of the Nigerian border 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 350 mm of rain. Extensive farming of millet with mixed-stock keeping dominate the Sahelo-Sudanian zone. The Sudanian rain-fed zone (in 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.

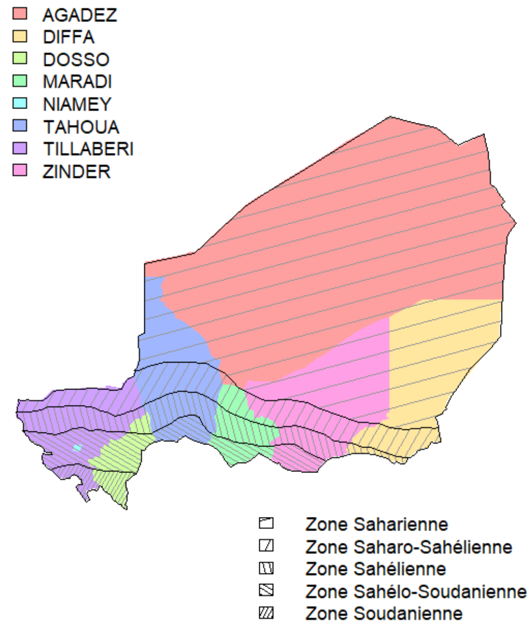

Figure 12: Niger admin regions and climate zones by isohytes

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 the lower isohyet lines (which are horizontal parallel lines on the map connecting points of similar rainfall range) moved southward from the 1950s to the 1980s, causing the most productive agricultural zones to shrink. The drying and desertification of the Sahel in recent decades appears to be in large part due to natural variability, but with a significant anthropogenic component (Gianni et al. 2008). The same isohyets moved northward again during 1988-1998. Although this looked promising, whether the trend will continue is debated. Moreover, even though rainfall may have increased, the rainy season has become shorter and there is more spatial and temporal variability with erratic and extreme rainfalls often leading to flooding along the Niger river. This presents significant challenges for farmers who thrive on predictable rainfall.

Low but improving agricultural productivity:

Estimates of the agricultural total factor productivity (TFP) growth rate in Niger and SSA in general differ widely but the general consensus is that productivity declined in the first two decades since its independence in 1961 and started improving from the 1980s. These studies are based on Food and Agriculture Organization (FAO) country level time series data on agricultural output and inputs[21].While the quality of the data may be questionable, this is the only repository of relevant cross-country time series data (Block 2013).

Table 5: Decadal growth rate (%) in agriculture (Niger) from Fuglie (2011)

	1961-70	**1971-80**	**1981-90**	**1991-00**	**2001-10**
Total Factor Productivity	-2.1	-0.3	0.7	2.2	1.9
Output	2.9	3.8	1.0	5.1	5.5
Input	5.0	4.1	0.3	3.0	3.5
	Land extensification Labor intensification Droughts		Research in high yielding varieties	Dissemination & adoption	Slow-down in release of high yielding varieties

The most recent work on TFP growth estimation in SSA is by Block (2013) and Fuglie (2012, 2011). The latter uses growth accounting method to calculate TFP growth rate with cost shares coming from a Cobb-Douglas production function regressed over inputs and finds an overall negative TFP growth rate over the 1961-2006 period in 28 SSA countries, including Niger. He attributes agricultural output growth in SSA mainly to land extensification. Block (2013) builds upon previous work and instead finds overall positive TFP growth rate (0.16 percent) for the 1960-2002 period, although negative for the Sahelian region (-1.17 percent). When decomposed by

[21] One of the limitations of the aggregated data in TFP growth estimation is the non-separability of agricultural inputs for crops and livestock and hence most of the studies (except Ludena et al. 2007) estimated agricultural TFP growth rate where output consists of both livestock products and crops.

decades both studies find negative growth in the first two decades and very low but positive TFP growth in the latter two decades.

Modern agricultural technologies, with few exceptions, were negligible in Niger until the 1990s. The focus of international research institutions on technological development for millet and sorghum were late in coming (Fuglie 2011). Even when there are inventions, given the diversity of soils in each agroecological zone in Niger, new technologies require local adaptation. While Nigeria and Senegal in West Africa have a long history of bilateral technical assistance programs, national millet and sorghum improvement programs did not start in Niger until the mid-1980s (Matlon 1990). Investments in cowpea, a cash crop intercropped with millet or sorghum is also lowest in Niger among cowpea producing countries. Extension services were also weak resulting in poor dissemination of promising materials. As a result, adoption rate has been low.

Ndjeunga et al. (2015) relied on GIS information and expert opinion surveys to summarize pearl millet, groundnut, and sorghum variety release and adoption in West and Central Africa. Along with Mali, Niger had by far the greatest number of releases in pearl millet (37)[22]. However, the adoption rate for millet[23] was among the lowest (11.5 percent of area under modern varieties compared to 31 percent in Mali). Adoption, is limited by slow release and a lack of promotion of released varieties (Ndjeunga et al. 2015), low human and financial investments, lack of desired traits, and lack of access to seed (Alene et al. 2015).

Modest levels of undernourishment, but very poor diet quality:

Niger's food insecurity situation is underestimated if one looks at only prevalence of undernourishment, which is more modest than the average for all of SSA (Figure 13). The picture is deceptive without looking at other indicators such as the high prevalence of wasting (above 15 percent – putting Niger in the very high category) and stunting (above 20 percent) among children under 5, and anemia among women (over 40 percent). The eastern region of Diffa is seriously affected by conflict and is highly food insecure.

[22] The study also noted dry spells in releasing new varieties between 1990 and 2010 and low turnover of crop varieties e.g. HKP released in 1975 is most popular pearl millet variety despite release of more high-yielding variation of HKP.
[23] Niger ranked lowest in a study of West African countries (Mali, Burkina Faso, Niger, Nigeria, and Senegal) in sorghum (7) and groundnut (13) variety releases, although, Similarly in the case of cowpeas, despite release of 15 improved varieties of cowpea since 1970s (comparable to average no of release in West and Central African countries except Nigeria), adoption rate is lowest among all countries (9% of total cultivated area in 2009)

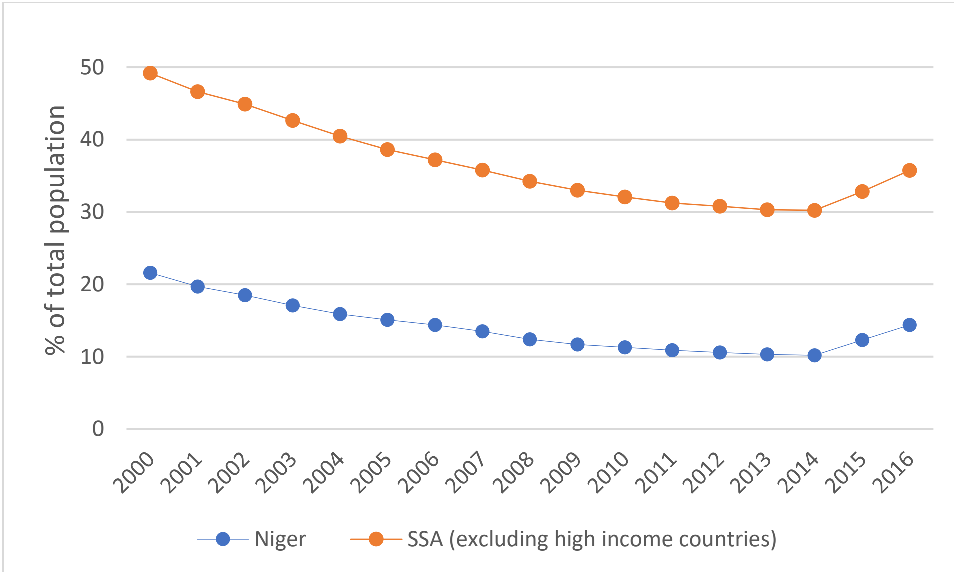

Figure 13: Prevalence of undernourishment in Niger and SSA

Source: https://data.worldbank.org/indicator

The Nigerien diet consists largely of carbohydrates, which explains the modest level of undernourishment but poorer diet quality leading to stunting and anemia. 72 percent of the dietary energy calorie (DEC) comes from carbohydrates, which is typical of least developed countries where households rely on cheap sources of starch for meeting energy requirements. As expected, rural households source more of their dietary energy from own produced food than urban households do (32 percent vs 4 percent) and consequently urban households have a larger share of purchased food in total food consumption in terms of monetary value (89 percent in urban vs 67 percent in rural).

As per capita income grows, individuals shift from a heavily starch-based diet to one that consists more of meat and dairy products (Gerbens-Leenes et al. 2010). With Niger's real per capita income 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 likely to be delayed, which means reliance on staple crops which are projected to be adversely affected by climate change will remain high.

2.3 The SIMPLE Model: A Framework for Food Security Projections

SIMPLE (a Simplified International Model of agricultural Prices Land use and the Environment) 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 model has been historically validated globally (Baldos and Hertel 2013), regionally (Hertel and Baldos 2016), and with respect to undernutrition (Baldos and Hertel 2014). It has been used in studies focusing on climate change mitigation and adaptation (Lobell et al. 2013), and climate change, trade and food security (Baldos and Hertel 2015).

This framework is selected for the study due to its parsimonious nature. We are not analyzing economy-wide effects and are focused on climatic impacts via the agriculture sector, and thus it is parsimonious to use a partial equilibrium model for the analysis. The advantage of the SIMPLE model for Nigerien agriculture is that the model is simple enough to be historically validated. Placing the agriculture sector in a general equilibrium (GE) model makes it challenging for validation and reduces the validation to a few key variables. Testing the model's ability to replicate the past 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 modified model was validated for Niger's crop output growth during 1991-2009 (Figure in Appendix). The parsimonious nature of the model also makes it well suited to the data scarce environment which we are confronted with in Niger.

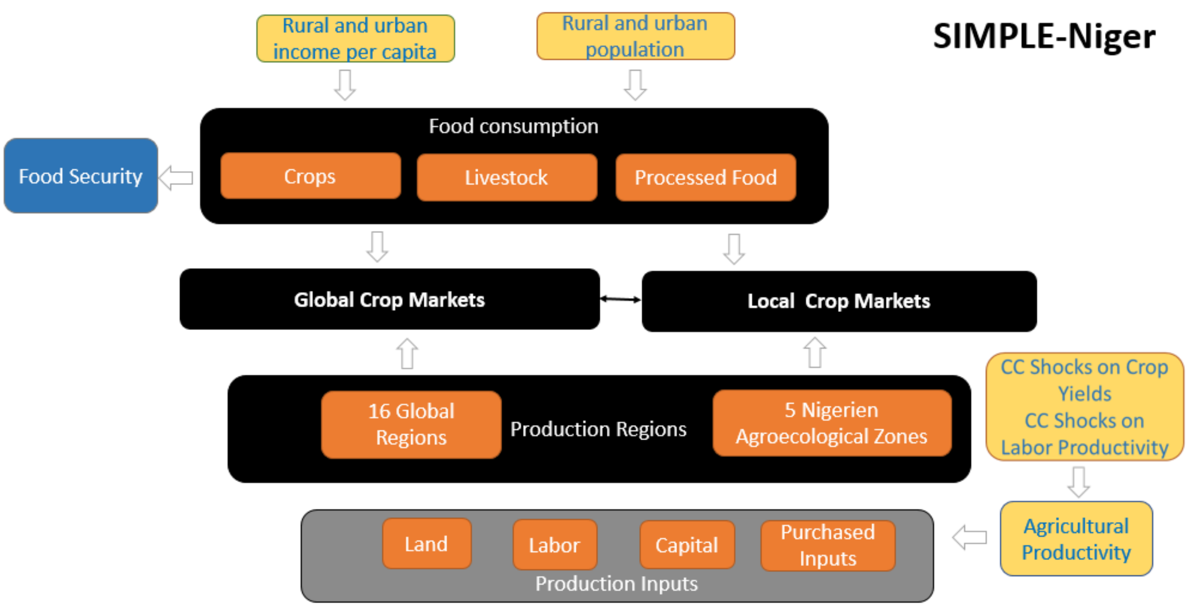

Figure 14: Structure of SIMPLE-Niger model

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). Crop demands for livestock and processed food sectors are derived demands, originating from the consumer demands for the products in these sectors.

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. As income rises, demand for food becomes less price- and income- sensitive (Muhammad et al.2011) and diets change to incorporate more of livestock and processed food, which are in general more expensive items.

On the supply side crop production is modeled via a Constant Elasticity of Substitution (CES) production function employing land and non-land inputs (for this study I disaggregate non-land inputs into labor, capital, and purchased inputs). Use of inputs is governed by the extensive and intensive margins of supply (Gohin and Hertel, 2003). 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. Yield growth through intensification is distinct from total factor productivity (TFP) growth – as it reflects 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.

Livestock and processed foods are value-added products, which are produced and consumed within each demand region using crop and non-crop inputs. Technological change and factor substitution in these sectors can alter the intensity of crop use in producing these food products. It is assumed that only the livestock sector has the ability to conserve on crop inputs (via input substitution or reduction of waste) in response to higher prices and this is captured by the elasticities of substitution between feed and non-feed inputs.

2.3.1 Food security module

I 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 are described in the paper and its supplementary material. Here I review the essentials.

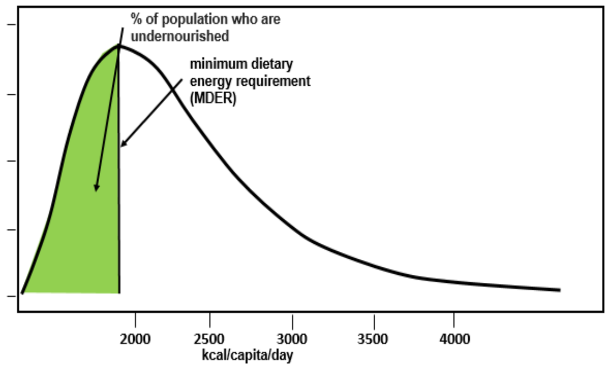

Figure 15: Log normal distribution of per capita food calorie intake, MDER and malnutrition incidence

Food security is measured by caloric consumption (caloric undernutrition) and indicators for the shortfall in caloric consumption (calorie gap)[24]. I concentrate on prevalence and incidence of undernourishment, and undernourishment gap. The undernourishment index (prevalence of undernourishment) is defined as the fraction of population whose daily dietary energy intake is below MDER (green area to the left) while the undernourishment gap represents the average dietary energy deficit that an undernourished person needs to close to satisfy the minimum requirement. The undernourishment gap is derived by integrating the caloric deficits of each malnourished person and dividing it by the undernourishment headcount. The undernourishment gap indicates the intensity of hunger.

The distribution of per capita caloric consumption is assumed to be log-normal which is consistent with the traditional assumption used by FAO regarding the dietary energy intake within a country (Neiken 2003). Changes in per capita food consumption are converted into changes in average caloric consumption. Shifts in the log-normal distribution of caloric consumption cause changes in the undernourishment index (as the fraction of population whose daily dietary energy intake is below the minimum requirement), undernourishment gap, and undernourishment headcount. Following equivalent terms in the poverty literature (poverty index and poverty gap). Baldos and Hertel (2014) uses growth elasticities of undernourishment index (ε_{MI}) and

[24] These indicators are limited to the caloric volume 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 emphasis on diet quality and it underestimates Niger's food insecurity situation. Stunting among children under 5, vitamin and micronutrient deficiency, diet diversity index are complementary measures of undernutrition. However, incorporation of these measures will require improved data.

undernourishment 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 and τ and π are the standard normal probability density and CDF.

Growth elasticities are the percentage change in these indices as the result 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.

2.3.2 Modifications to the SIMPLE model: SIMPLE-Niger

There are four modifications that are made to the model: i) including Niger as a single country region and disaggregating supply by agro-ecological zone, ii) disaggregating demand side by rural and urban households in Niger, iii) modeling rural income as an endogenous variable: linking changes in crop prices directly to rural household income, and iv) disaggregating the single composite non-land input in the model into labor, capital, and purchased inputs.

Disaggregation of geographical regions:

The current database for SIMPLE has 16 regions and the model has been historically validated for these regions – one of which is SSA, for 1960-2006 period. I disaggregated Niger from SSA, thereby making it the 17th region in the model and validated the model for the period of 1991-2009. The crop supply regions within Niger are further broken up into five agro-ecological zones cutting across its administration regions: Saharienne, Saharo-Saheliene, Saheliene, Sahelo-Soudaniene, and Soudaniene. The demand side is disaggregated into rural and urban households, where the income of rural households is affected by prices in the agriculture sector, and food commodity consumption pattern is by rural and urban households.

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 inputs are disaggregated into valued added (labor and capital), and other intermediate/purchased inputs. 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 are 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. 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. Crop price changes affect rural households' food security in two ways. The price change affects agricultural households' income from crop production and it affects their purchasing power of buying crop-based food.

For Niger rural income:

p_INC_PC = 0.33 * p_INC_PC_VLAND + 0.06 * p_INC_PC_VLAB + 0.61 * p_INC_PCd;

where, p_INC_PC is the % change in rural household income,

p_INC_PC_VLAND is the % change in income from value of crop land, which is linked to income from crop sales,

p_INC_PC_VLAB is the % change in income from value of labor, which is linked to change in agricultural labor wages and the quantity of labor demanded,

p_INC_PCd is the % change in non-crop income which changes exogenously.

The share of household income from different sources is estimated from Niger 2011 Living Standard Measurement Survey-Integrated Surveys on Agriculture (LSMS-ISA, also known as ECVMA[25]). The share of exogenous income (INC_PCd) in the household is any income that is not related to income from crop sales or agricultural wages, such as income from transfers, livestock and by products, non-agricultural wages, self-employment etc. I attributed all the share of household income from crop sales to land.

[25] The dataset is publicly available at http://surveys.worldbank.org/lsms/integrated-surveys-agriculture-ISA

Table 6: Sources of rural household income as share of total income, Niger, 2011

Sources	Share of rural household income (%)
Agricultural Wages	6
Non ag wages and self-employment	42
Crop Income	33
On farm income (crop, livestock and by products)	42
On farm income (without crop)	9
Transfers	11
Other Sources	0.1
Source: LSMS-ISA 2011 data processed by FAO and published in DATAPORTRAIT (http://www.fao.org/family-farming/countries/ner/en/)	

2.3.3 Data and Context

The details of the original SIMPLE model's database construction and parameters 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 Global Trade Analysis Project (GTAP) V.6 database (2006) while data on cropland cover and production, utilization and prices of crops are derived from FAOSTAT. In this section, I describe the additional database that had to be constructed for the modified model and in the context of Niger.

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 analysis, we concentrate on the 6 crops in Niger which together comprise of at least 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 aggregation to climate zones using available sub-national data (which is not available for all crops in the FAOSTAT database) and ii) using existing literature we can project yield changes due to climate change for these crops.

We combine data from FAOSTAT, FAO Country Stat, and Earth Stat (Ramankutty et al. 2008) to aggregate 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 the regional level. FAOSTAT provides data at national level. Country Stat 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[26] cut across horizontally through these regions. In order to aggregate to climate zones, we use grid cell level data from Earth Stat[27] (Ramankutty et al. 2008) 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 aggregate 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 price weights constructed from world crop prices and the world price of millet. The conversion approach is described in the Appendix.

Input cost shares in crop production from plot level agriculture survey:

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 using GTAP v.6 cost shares. The GTAP database, however, does not have Niger as a representative country. We use Niger 2011 Living Standard Measurement Survey-Integrated Survey of Agriculture (LSMS-ISA/ECVMA)28 and the Niger Social Accounting Matrix (SAM, provided by International Food Policy Research Institute) jointly to calculate shares of value added (land, labor, and capital) and other intermediate inputs in crop production in Niger. The 2011 LSMS-ISA 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 areas and rural areas. The survey was conducted in two phases, 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 the parcel level by

[26] The shapefiles for climate zones were collected from AGRHYMET regional office in Niamey.
[27] http://www.earthstat.org/
[28] The dataset is publicly available at http://surveys.worldbank.org/lsms/programs/integrated-surveys-agriculture-ISA/niger.

crop. The calculated cost shares using the Niger SAM matrix and the household survey are land (30%)[29], labor (48%)[30], capital (12%), and other intermediate inputs (10%).

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). Although land is relatively abundant in Niger compared to its East African counterparts, the land is very unfertile with high spatial and temporal intra-annual and inter-annual rainfall variability risk, thus rendering low productivity and comparatively low value of land. Farmers sow on more surface than they can manage to diversify risk (Abdoulaye and Sanders 2005).

Given the large size of farm households in Niger (on average around 7 people), farm labor employment is closely associated with size of household. Most workers are household members and 49% of surveyed farm households hired workers who did 10% of the total farm work (Dillon and Barrett 2017). This is also consistent with the minimal labor wage share in total income (3%).

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%. 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 only after exhausting traditional options (Abdoulaye and Lowenberg-DeBoer 2000). The traditional soil-fertility-maintenance technique is 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 remains very low[31]. 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.

Fixed capital such as farm machinery, tools, and structures also remain very low in SSA and Niger is no exception. The main asset is livestock. Unlike in South Asian countries where soil

[29] 80% of the cultivated land is farm household owned. Land rental market participation is (7-8.5% renting land in) (Dillon and Barrett 2017). 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).

[30] 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 lowest during harvest period and highest during preparation period.

[31] 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 2017).

is dense, livestock is not used for land preparation[32]. Manure from livestock is used as an input to crop production. 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 storage facilities.

Undernutrition data from household survey:

Consistent with the data source for input cost shares in crop production, we get our estimates on prevalence of undernutrition, diet composition, and dietary caloric intake from different food groups from the 2011 LSMS-ISA. 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. 2006). The approach in Baldos and Hertel (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 household surveys provide a more accurate picture of consumption, which are based on recorded household consumption patterns.

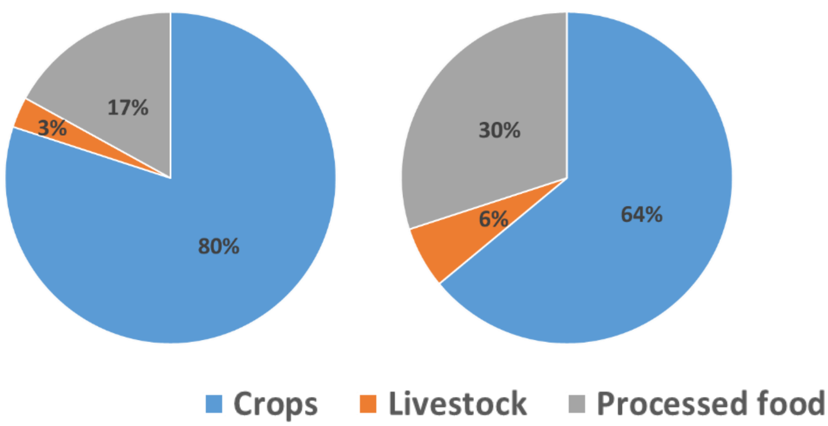

Figure 16: Share of caloric consumption from different food commodities in Niger
Source: Authors' estimation from Niger 2011 LSMS-ISA.ECMVA household survey

[32] The soil type in Sahel and Sudanian zones is loamy sandy, naturally low of phosphorous and nitrogen, and has low water holding capacity.

Table 7: Dietary energy consumption, MDER, and prevalence of undernourishment in Niger

	National	Urban	Rural	Unit
Average dietary energy intake	2381.4	2328	2394.2	kcal/capita/day
Minimum dietary energy requirement (MDER)	1682	1,759.5	1,663.7	kcal/capita/day
Prevalence of undernourishment	18.8	20	15.4	%
Depth of Food Deficit	124.1	139.2	314.6	Kcal/person/day

Source: Niger 2011 LSMS-ISA/ECMVA household survey

2.3.4 Establishing the 2050 scenario

To create the future baseline scenario, the farm and food system is projected from 2009 to 2050. The exogenous shocks to the system to create the scenario are population, per capita income, agricultural productivity growth, and climate change induced negative productivity shocks: on crops and on agricultural labor.

Population and income growth rates are based on the Shared Socio-economic Pathways (SSP) database, which provide alternative trends in socio-economic development (detailed discussion in Chapter 1). 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). Given the uncertainties in fertility rates, rural urban migration, and economic growth patterns, we make projections under three SSP scenarios.

Table 8: Annual growth rate assumptions, 2009-2050

		SSP 2	SSP 3	SSP 4
GDP	Niger	6.9	5.9	5.4
	Urban	8.5	6.8	7.6
	Rural	5.8	5.4	3.4
Population	Niger	3.1	3.6	3.6
	Urban	5.0	4.6	6.4
	Rural	2.5	3.3	2.3
Per capita GDP	Niger	3.7	2.2	1.8
	Urban	3.3	2.0	1.1
	Rural	3.3	2.0	1.1

Note: Historical growth rates are 5.5% (GDP 2001-2015), 1.4% (GDP per capita 2001-2015), 0.4% (GDP per capita 1991-2015)

The urbanization shares are from National Center for Atmospheric Research (NCAR) (Jiang and O'Neill 2012) which are used in the SSP scenarios to project rural and urban population in 2050. These urbanization scenarios are based on UN estimates of urbanization but modified by linking countries to reference countries, which are correlated to have experienced similar urbanization patterns in the past. The SSP2, SSP3 and SSP4 assume medium, slow and rapid urbanization rates for Niger (35%, 24%, and 50% respectively). The UN projects 28% of the population to be living in urban areas of Niger by 2050 (UNDESA 2017).

The SSPs provide GDP growth projections at national level but not for rural-urban level. To project GDP growth rates in rural and urban areas, I assume Niger's current urban premium (the ratio between per capita income in urban area and in rural area), which is 2.17, remains constant in 2050 for all SSP scenarios.

Agricultural productivity growth is difficult to measure, let alone forecast several decades into the future. Following Hertel and Baldos (2016), I 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 these rates apply in the future and across all regions.

2.3.5 Climate change induced productivity shocks

Predicting climate change impacts on crop yields is challenging. It involves the combination of crop models and climate models and uncertainties are grounded in both climate and agriculture literature. The biggest uncertainty in the crop models is the size of the effects of CO2 fertilization[33] (Moore et al. 2017). There are mainly two types of studies in 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 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. Christensen et al. (2007) predicts an increase of 1.5 and 4.7 degrees C in the minimum and maximum temperature in West Africa.

Schlenker and Lobell (2010) were one of the earliest studies, which focused on climate change impacts for crops specific to SSA, namely maize, sorghum, millet, groundnut, and cassava. They consider historical observations to discover a biophysical relationship between heat stress

[33] 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.

and average crop yield in low fertilizer use and high fertilizer use countries in Sub-Saharan Africa. 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 CO2 fertilization, as the crops under study are less sensitive[34] to it.

Baldos and Hertel (2015) and Hertel and Baldos (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 CO2 fertilization, and gridded production of 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. The general consensus is that the changing climate will have adverse effects on crop yields in Niger[35].

For data-poor regions like Niger, the use of country averages can amplify measurement error. Thus, our yield projections for maize are drawn from Haqiqi and Hertel (2018) who extend Schlenker and Roberts (2009) to estimate crops yield response functions for irrigated and non-irrigated crops at the global level. They employ NASA NEX-GDDP (Global Daily Downscaled Projections) conducted under CMIP5 and RCP 8.5 for future climate change 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 estimated coefficients of average temperature and precipitation on yields of these crops

[34] 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.

[35] 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 2º and 4º 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 (6º 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.

in SSA countries with low levels of fertilizer use from Schlenker and Lobell (2010) (Table A1 of Supplementary Files of their 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.

So, what we project is the yield penalty due to climate change. Now how do we know what the climate change is going to be? That comes from different climate change prediction models. In our case these are from Representative Concentration Pathway (RCP) 8.5 which is a greenhouse gas (GHG) emission trajectory. The RCPs set pathways for GHG emissions and effectively the amount of warming to be observed. Since Schlenker and Lobell's work was not specific to Niger, we had to re-do this projections by grid cell level for Niger. The yield projections can be used at -30% to +30% range at 90% confidence interval.

Table 9: Reduction in crop yields (%) in Niger's climate zones by 2050 due to future changes in 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

Note: 1. The grid level yield projections for each of these crops are aggregated to the climate zones in Niger *weighing them by cropland share*. 2. 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.

2.3.6 Heat Stress induced agricultural labor productivity shocks

While the literature has made progress in estimating the impact of climate change in agriculture by quantifying impact on crops, it has paid little attention to an important component of crop production: labor and the impact of global warming on agricultural labor. When the human body loses the ability to internally regulate heat balance, heat stress occurs; and with agricultural labor working outdoors the economic impact of this stress can be significant. Buzan (2018) finds with substantial warming (+4˚C), local summer agricultural labor productivity losses become catastrophic and parts of West Africa incur labor capacity loss of around 25%, one of the highest. Lima et al. (2019), uses the estimated impacts from Buzan (2018) to analyze the consequences of global warming for agricultural commodities and agricultural labor force capacity.

The labor productivity shock estimations for this essay is described briefly in appendix. The heat stress metric (the Enviromental Stress Index) that is used is appropriate for outdoor workplace environment; utilizes direct measurements of temperature, humidity, and solar radiation; and compatible with global circulation model output. Laborers are assumed to be following International Standards (ISO) for day and night time conditions (4x daily CMIP5 output), with appropriate outdoor clothing and scheduled breaks for heat stress. To that end, it is useful to stress that the labor stress impacts are on their lower bound, given that it can be safely stated laborers in Niger do not get to follow ISO standard for working outside.Due to heat stress, existing unskilled agricultural laborers are able to work only a fraction of the baseline hours. For the case of estimating climate change shocks on crop yields, we had used RCP 8.5 which indicates an increase of around 2.5c by 2050 in Niger. To be consistent, heat stress impacts on agricultural labor productivity is estimated for an increase in temperature by 2˚C) on labor capacity calculated for 1986-2005.

Table 10: Reduction in agricultural labor productivity (%) in Niger's climate zones by 2050 due to future changes in heat

	Zone Saharienne (NCZ1)	**Zone Saharo-Sahelienne (NCZ2)**	**Zone Sahelienne (NCZ3)**	**Zone Sahélo-Soudanienne (NCZ4)**	**Zone Soudanienne (NCZ5)**
Reduction in labor productivity (%)	-17.3	-10.6	-7.9	-8.2	-8.6

Note: The raw data about labor capacity is associated at climate zone level following the crop composition in each grid cell. See appendix for details.

2.4 Results

The results are presented for Niger and for rest of SSA (excludes Niger and South Africa) as a measure of comparison. 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.

Historically crop output growth was dominated by demand from a fast-growing population

Historically population growth has been the main demand driver behind crop output growth in most regions in the world except China (where the income growth effect was equally significant over the past two decades, even as population growth was suppressed) (Hertel and Baldos 2016). Productivity growth has been the key supply-side driver, allowing long run prices to fall, despite growing demand for food. In Niger, due to very low agricultural productivity in the past and negative income growth (GDP per capita), nearly all of the crop output growth between 1961 and 2009 can be explained by its rapid population growth, with negative income and productivity contribution Niger's agricultural productivity growth was estimated to be negative until the 1990s. This turned around at the turn of the century.

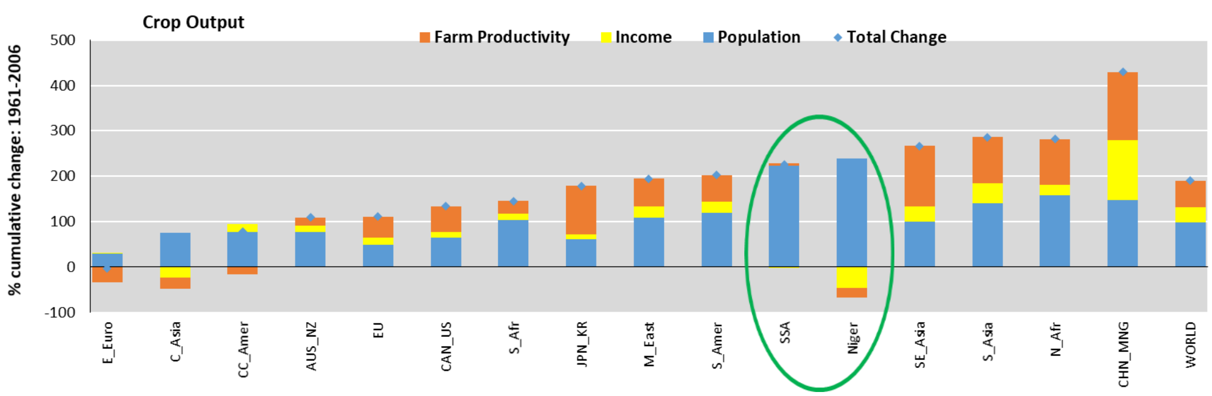

Figure 17: Historical drivers of crop out growth in the SIMPLE regions and Niger, 1961-2006
Source: Replicated from Hertel and Baldos, 2016 with Niger as an additional region

Population growth impacts are projected to be larger than climate impacts on agriculture

If the improvements in productivity growth rates from the past decade are to continue at the rate of rest of SSA, contribution of agricultural productivity in crop output growth will be larger than in the past. However, in contrast to the world as a whole, where income growth plays a key role, the projected Nigerien crop output in the future is expected to continue to be driven by population growth in the region. Population growth and associated increases in rural labor supply[36] are expected to explain nearly one-third of the crop output growth in Niger regardless of the socio-

[36] The labor endowment effect refers to the shift in labor supply due to population growth

economic scenario considered. Compared to that, climate impacts are relatively smaller on crop output growth.

The figures and table below show the decomposition results. Growth in population, agricultural productivity, and income within Niger and in rest of the world (RoW) has different impacts on crop output growth within Niger. For example, relatively higher productivity growth outside of Niger means growth within Niger will be smaller because subject to trade costs crop from RoW is then cheaper. Similarly, growth in population and income in RoW drives more crop output in Niger as the world in general then requires more crop (and they could be importing from Niger). From the results, it is evident that the biggest world driver for Niger is relative growth in agricultural productivity in other regions.

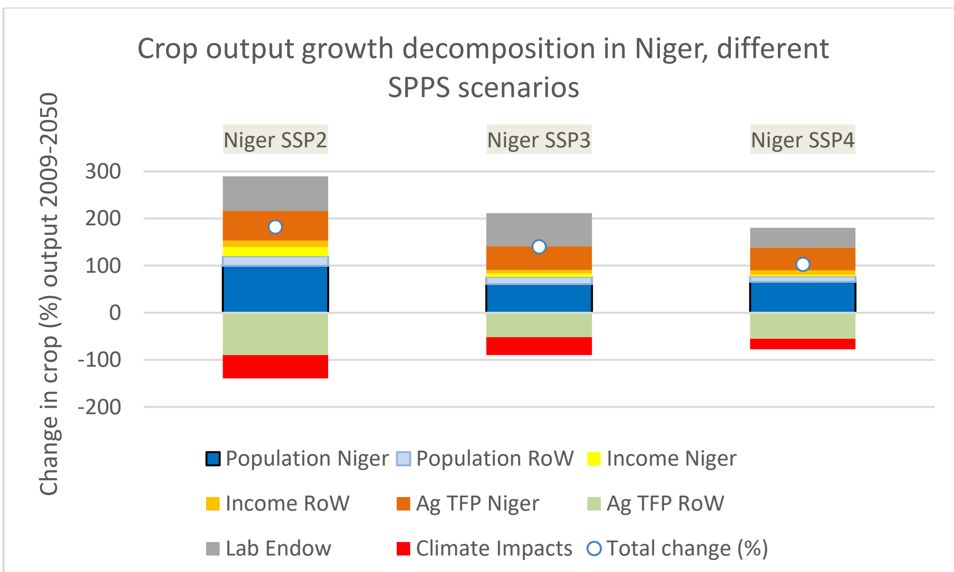

Figure 18: Drivers of future crop output growth in Niger and SSA from 2009 baseline to 2050

Table 11: Decomposition of change in crop output growth by key drivers

Crop Output Growth (%)	Total change, 2009-2050 (%)	Population Niger	Population RoW	Income Niger	Income RoW	Ag TFP Niger	Ag TFP RoW	Lab Endow	CC Impacts
Niger SSP2	182	100	21	20	13	64	-90	73	-49
Niger SSP3	140	61	15	8	8	50	-52	71	-38
Niger SSP4	103	65	12	4	9	48	-55	43	-22

Prevalence of undernourishment reduces but undernutrition headcount unlikely to decline

Despite forecasted growth in income and agricultural productivity, Niger is unlikely to see any reduction in the absolute numbers of undernourished people under these scenarios. The number of undernourished people is predicted to be stagnant in Niger as population growth outpaces productivity growth. However the prevalence of undernourishment (% of total population undernourished) is likely to be significantly reduced.

Table 12: Projected change in undernourishment count and index from 2009 to 2050 in Niger

		2009 Baseline	2050 Baseline	Difference
Undernourished count (in millions)				
SSP2	Niger	2.6	1.2	-1.4
SSP3	Niger	2.6	2.6	0.0
SSP4	Niger	2.6	5.7	3.1
Undernutrition index (% of population)				
SSP2	Niger	16.2	0.5	-15.7
SSP3	Niger	16.2	0.8	-15.4
SSP4	Niger	16.2	1.7	-14.5

Source: 2050 baseline-author's estimation from experiment
2009 baseline-Niger 2011 LSMS-ISA

Demands from a growing population increase crop prices. 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 drivers results in a higher crop price. The price increase, in absence of sufficient income increase, will make financial access to food, which is required to turn available food into utilized food in the household, more difficult. Hence the increase in household food insecurity.

Urban areas will suffer from increasing concentration of food insecurity

Disaggregation of the outcomes casts a picture of improvements in rural areas– primarily due to existing lower levels of undernourishment than in urban areas and rural households benefiting from an increase in food prices as they are net sellers - but an alarming level of food insecurity situation in urban areas.

Table 13: Projected change in food security outcomes from 2009 to 2050 by rural and urban Niger

		2009 Baseline	2050 Baseline	Difference
Undernourished count (in millions)				
SSP2	Niger	2.6	1.2	-1.3
	Rural	2.0	0.53	-1.5
	Urban	0.5	0.7	0.2
SSP3	Niger	2.6	2.7	0.2
	Rural	2.0	1.47	-0.6
	Urban	0.5	1.2	0.7
SSP4	Niger	2.6	6.0	3.4
	Rural	2.0	1.6	-0.5
	Urban	0.5	4.5	3.9
Undernutrition index (% of population)				
SSP2	Niger	16.2	0.5	-15.7
	Rural	15.4	1.48	-13.92
	Urban	20.0	3.6	-16.5
SSP3	Niger	16.2	0.8	-15.4
	Rural	15.4	2.9	-12.5
	Urban	20.0	7.5	-12.5
SSP4	Niger	16.2	1.8	-14.4
	Rural	15.4	4.6	-10.8
	Urban	20.0	13.0	-7.0
Undernutrition gap (kcal/cap/day)				
SSP2	Rural	231.8	161.0	-70.8
	Urban	237.8	161.9	-75.9
SSP3	Rural	231.8	174.5	-57.3
	Urban	237.8	184.6	-53.2
SSP4	Rural	231.8	186.0	-45.7
	Urban	237.8	209.3	-28.5

17% of the current population live in urban areas and undernourishment is more concentrated in urban areas (20% vs. 15.4% in rural areas in 2011). In urban areas impacts are driven mainly by growth in population, secondly by agricultural productivity and lastly by growth in income). Urban population growth occurs not just due to area urbanization and natural population growth but also due to increasing rural-urban migration. By 2050, 28-50% of the Nigerien population are projected to be living in urban areas and around 75% of the total undernourished population will be in urban areas (up from 20% in 2009).

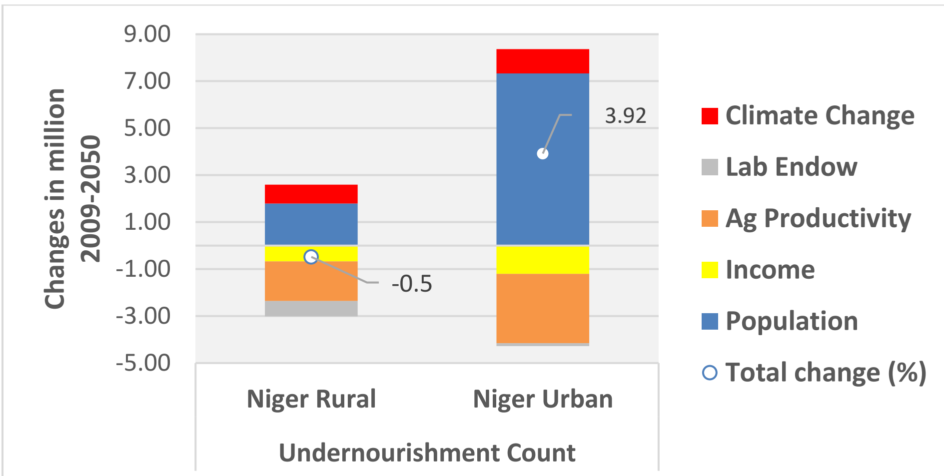

Figure 19: Decomposition of projected change in undernourishment count by key drivers

Even though agricultural productivity growth affects the supply side the same way, it affects the demand side differently. In our model, rural and urban demand regions face the same consumer price changes. A population driven crop output growth means prices can hike up in absence of adequate gains in productivity. Crop price increases affect rural households in two ways: i) their household income increases from higher selling price ii) they face higher food price. Depending on whether they are net seller or buyers, they may or may not benefit form the price increase. Urban households are almost always negatively hit by a food price hike as they usually do not have agricultural income and are net buyers of food.

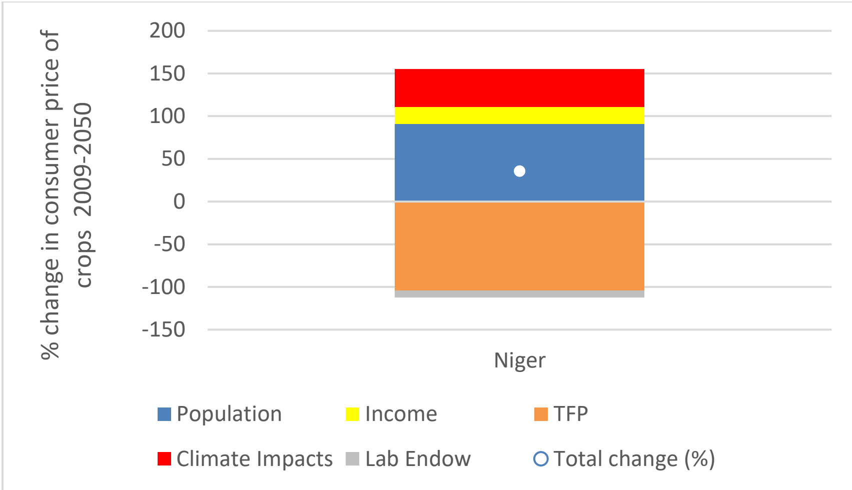

Figure 20: Decomposition of projected change in crop prices, 2009-2050

Differences in food security outcomes in rural and urban households arise also due to variation in diet composition in urban and rural households and changes in diet composition due to income growth. Ceteris paribus when income increases diets are diversified and shift towards livestock and processed food. Consumption also becomes less price and income sensitive with higher levels of per capita income. In rural Niger while per capita caloric consumption of crops is expected to rise, caloric intakes from livestock and processed food is expected to rise far greater in magnitude mainly due to growth in income. Among the urban population, being on average at an income level 2.17 times higher than the rural population, the diet shift due to income growth is less price and income sensitive.

Table 14: Changes in caloric intake (kcal/per/day), 2009-2050

	2009 baseline (kcal/cap/day)	2050 baseline (kcal/cap/day)	% change in kcal/cap/day	Due to Population growth in Niger	Due to Income growth in Niger	Due to TFP growth in Niger	Due to Climate impacts in Niger
Rural							
Crops	1872	2070	11	-4.18	4.44	4.59	-9.91
Livestock	70	124	76	27.43	32.18	19.79	1.03
Processed food	398	697	75	27.77	21.47	27.72	-1.54
Total	2341	2892	24				
Urban							
Crops	1331	1282	-4	-16.93	5.09	1.73	-9.4
Livestock	125	174	39	-5.26	31.70	10.70	-3.34
Processed food	624	841	35	-8.25	23.78	15.55	-5.57
Total	2080	2297	10				

Climate change will make things worse with differential impacts in rural and urban areas

A climate change induced contraction in output means there is less amount of crop produced for a given amount of inputs. With relatively price inelastic demand, the decrease in crop output due to reduced yield and labor productivity, result in strong consumer price increases for food commodities. As a result, all indicators of undernutrition outcomes i.e. count, index, and gap are negatively affected by climate change Although relative to population growth impacts, climate impacts on caloric intake are smaller in Niger; they are still substantial large. An additional 2 million Nigeriens (SSP4 scenario) are pushed into undernourishment solely due to climate impacts.

Negative climate impacts are not unexpected. What is noteworthy though is the difference in the magnitude of the effect in rural and urban Niger. The shocks have a greater relative effect among the drivers of food security outcomes in rural households than in urban households.

When climate change induced negative crop productivity shocks are felt, food commodity prices increase. With the largest increase in prices occurring to crops among the three food commodities, a larger share of rural households are negatively affected than urban households primarily because they have a larger share of caloric intake from crops than urban population has. This is predicted despite the fact that in rural crop price increases can have a positive effect on net sellers of food. The reliance on crops for caloric intake outweighs the gains in income among rural households due to increase in crops prices.

2.5 Concluding Remarks

Food security outcomes are largely driven by population growth in Niger. Climate change induced productivity shocks can push an additional 2 million people into undernourishment by mid-century. Inadequate production due to climate change can lead to increased dependence on imports that are itself volatile. Most of Niger's imports come from neighboring Sahelian countries which are also susceptible to climate shocks at the same time, which compromises the case of weather related shock resistance through trade with neighboring countries.

The results also highlight the differential impacts of climate change and socio-economic conditions on rural and urban households. Niger currently has a relatively small urban base but its concentration of undernourished population is higher in urban areas. Urbanization through rural-urban migration often means poor segments of the rural population migrating to urban areas in search of employment and living in dismal conditions. With expected urbanization, the country will have to pay attention to food access in urban areas along with rural areas and create appropriate policies addressing issues specific to urban living. For long-term development, policy makers can use these results to understand and address the different impacts and food security outcome among urban and rural population. An important question at this juncture is how to allocate scarce resources to achieve food security as well as other objectives. And on this note I build the motivation for the third chapter of this dissertation.

2.6 Appendix

A.1 Crop commodity conversion

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 ($e^{W}_{crop,year}$ (\$)) 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.

A.2 Agricultural Labor Productivity Shock

The perturbations to agricultural technologies used in the SIMPLE model are derived from a 3-step procedure. First, based on Monfreda et al. 2008 the crop composition by grid for each region/country is determined. Let *c* be a certain crop produced in grid *g* and region *r*. The following output weight for crop *c* is defined by:

$$outw_{c,g,r} = \frac{Y_{c,g,r}}{\sum_g Y_{c,g,r}}$$

where *Y* is the crop output following \cite{monfreda2008}. The second step determines the labor shock. The raw data about labor capacity is associated at regional/country level following the crop composition in each grid cell.

$$labor_{c,r} = \sum_{g} \left(outw_{c,g,r} \times rawlabor_g\right)$$

Finally, the crop composition underlying the SIMPLE model is used determine the final technology shocks for labor for each region/country *s* in the model. The weights to determine the crop composition are based on the value of production in the baseline year both for crop ($outv_{c,r}$) and region/country ($outv_{r,s}$).

$$SIMPLElabor_s = \sum_r \sum_c (outv_{c,r} \times outv_{r,s} \times labor_{c,r})$$

Where *s* is the regional aggregation in SIMPLE model.

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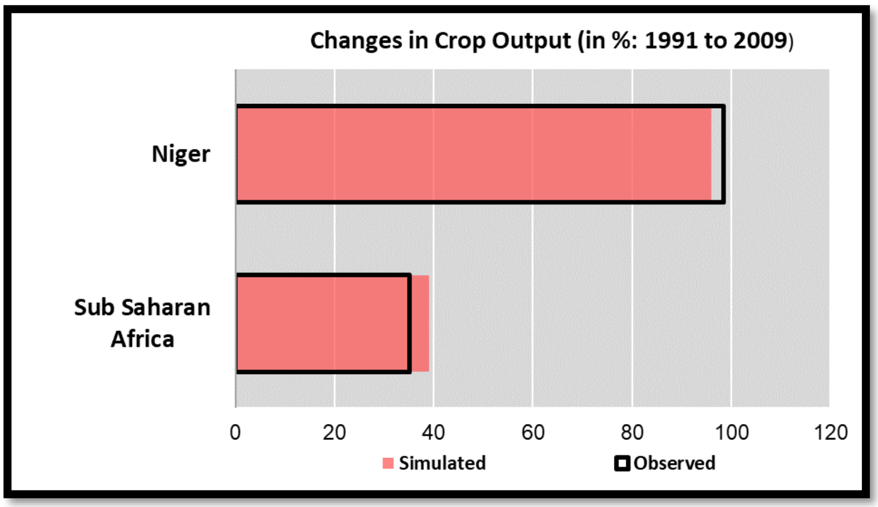
A.3: Historical Validation



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CHAPTER 3. FOOD SECURITY IN NIGER IN MID-CENTURY: WHAT IF…?

3.1 Introduction

In the previous chapter, we realize the roles population growth and agricultural productivity will play on food security outcomes in Niger. In 2012, the country put in place a sustainable food security and agricultural development strategy called the 3N Initiative ("Nigeriens Nourishing Nigeriens") in order to increase production from agropastoral and fishing activities and reduce the impact of droughts and other adverse weather events on the people of Niger and on their livelihoods. Although, the Nigerien government is emphasizing demographic transition and food and nutrition security in its development plan, budgetary allocation for security remains the priority. In the past four years conflict and insecurity in the region has crowded out funds from education, agriculture, and sexual and reproductive health which are crucial for long term sustainability and resilience to shocks[37]. With limited resources[38] (UNOWAS 2018) where should funds be directed? While two scenario experiments in this essay do not provide a definite answer based on cost-benefit analysis, it provides insights into quantitative and comparative measurements of outcome improvements through investments for i) agricultural research and dissemination and ii) sexual and reproductive health to make changes in agricultural productivity growth and population growth.

In addition in this paper, I also consider the implications of market integration for Niger which was not discussed in the previous chapter. Why is this important? Niger is entering the African Continental Free Trade Agreement (AfCFTA[39]) which will lead to greater market integration. Relative rates of agricultural productivity is one of the biggest drivers of crop output growth in Niger (chapter 2). And the level of influence of rest of the world drivers depends on the level of market integration among other things. A frequently postulated hypothesis is that global market integration is bad for food security. So what does market integration mean for household food

[37] Security related sending rose from 1.5 to 5.2 percent of GDP from 2011 to 2015.
[38] The public sector funding gap in the 10 Sahelian countries, on average, remain 32% of the required resources.
[39] The African Continental Free Trade Agreement (AfCFTA) is a trade agreement which was signed in 2018, with the goal of creating a single market followed by free movement and an African single-currency union. It is in force since May 30, 2019 between the 25 African Union member states who ratified it.

security outcomes in Niger? I explore this question in the context of a counter-factual situation: what would happen if markets were not at its current level of integration?

Thus I have three scenario experiments in this essay to evaluate their impact on household food security outcomes i.e. undernourishment levels in rural and urban Niger. These scenarios are first examined under the assumption that crop markets in Niger will perform in the mid-century under current level of market integration. I then turn to a counterfactual representation in which lower levels of market integration is assumed. In the second experiment considering the relatively slow productivity growth in Niger, I analyze the potential impacts of an increase in agricultural productivity growth through increased national spending on research and dissemination. Finally, I assume population growth rate will reduce to an optimistic 2.4% annually (close to the optimistic scenario in the 2017-21 ESDP) instead of 3.6% as assumed in 2050 baseline SSP4 scenario.

3.2 Materials, Methods and Context

3.2.1 Global market integration scenario

Market integration, price transmission, and import shares:

The premise of full price transmission and market integration correspond to those of the standard competition model, in a frictionless undistorted world, the Law of One Price (LOP) is supposed to regulate spatial price relations (Fackler and Goodwin 2001). Price transmission refers to the effect of prices in one market on prices in another market. If all producers have access to both international and domestic markets, then there is no market segmentation and there is only one price of crops. In the Armington specification[40], the initial extent of market penetration (the share of spending on international goods, in this case crops) also plays a central role in determining the degree to which the global and regional crop markets are linked.

The extent of market integration in the SIMPLE model is captured by the elasticities of substitution (ESUB) and transformation (ETRANS) between domestic and international goods and the initial shares of international goods in the consumption and production bundles (Hertel and

[40] A characteristic of real-world trading patterns is that countries often simultaneously import and export goods in the same product category. In the applied literature this is accommodated via the Armington assumption. In this approach, consumers are assumed to have a 'love of variety' that generates demand for both domestic and foreign produced products within a product category: a special case of the horizontal product differentiation.

Baldos 2016). When farmers are well integrated into the world market, a strong supply response to international prices is expected and the elasticity of transformation is high.

Market Integration and Spatial Price Transmission in Niger Grain Markets:

Few studies exist on price transmission from regional and global prices to Niger domestic food prices. Price transmission is generally measured in terms of the transmission elasticity, defined as the percentage change in the price in one market given a one percent change in the price in another market (Minot, 2011). Aker (2007, 2010) investigated Niger cereal market performance during food crises. Her findings revealed that Niger's millet market responds to supply rather than demand shocks, and neighboring country markets namely Benin and Nigeria have a significant effect on Niger domestic markets. Cornia et al. (2012) found that there are important short-term but not long-term effects of international cereal prices on the Niger domestic millet price. Zakari et al. (2014) investigates price transmission not only on millet market prices, but also for three other important grain crops, namely sorghum, maize and rice. They find a 10 percent change in prices of markets in Chad, Mali and Burkina Faso in the long run induce an adjustment of 2.98 per cent in Niger millet prices within one month. For sorghum the transmission rates vary from 15% to 39%. Maize and rice markets have high speed of adjustments to world prices compared to millet and sorghum markets because millet and sorghum are mainly domestically produced.

Experiment:

The absolute value of the trade elasticities (ESUB and ETRANS) for Niger are set to 6. It is estimated by calibrating the model at the baseline (2009) to reflect the price transmission levels in Niger from the recent literature. I project food security situations in Niger in 2050 under SSP4 scenario assuming that current level of integration continues in future (this 2050 scenario is termed as 2050+INT). And then the ESUB and ETRANS is set at 3 at 2009 baseline to reflect smaller price transmission and thus less market integration and projected into 2050 under the same SSP4 scenario (2050+Seg) The results from the two outcomes are then compared.

3.2.2 Accelerated Investments in Research and Dissemination Scenario

What is TFP? Total factor productivity reflects the technology and efficiency with which all inputs are transformed into outputs. Sources of crop output growth can be decomposed into coming from agricultural land expansion (extensification) and/or growth in yield per hectare (intensification). Yield growth itself can come through input intensification (i.e., more capital, labor, and fertilizer per hectare of land) and/or TFP growth. Growth in TFP can occur from research on productivity, economic policy reforms, growth in human capital of labor forces including its skill level and health status, infrastructure development etc (Fuglie and Rada 2013).

TFP growth, Technological Advances and Adoption in Niger: Most of the studies which have focused on crop output growth in Niger, or West Africa in general, highlight land extensification (Fuglie 2011) as the supply side means of growth. Estimates on TFP growth rate in Niger and in SSA in general differ widely (Table 1 in Appendix) but the general consensus is that productivity declined in the first two decades and started improving from the 1980s. One of the limitations of the aggregated data in TFP growth estimation is the non-separability of agricultural inputs for crops and livestock and hence most of the studies (except Ludena et al. 2007) estimated agricultural TFP growth rate where output consists of both livestock sector products and crops. The most recent work on TFP growth estimation in SSA is by Block (2013) and Fuglie (2011). Fuglie (2011) finds an overall negative growth in TFP over the 1961-2006 period in 28 SSA countries including Niger. He attributes agricultural production growth in SSA including Niger mainly to land extensification. When decomposed by decades both studies find the positive TFP growth in the latter two decades and negative growth in the first two decades.

Modern technical change, with few limited exceptions, have been negligible in Niger until the 1990s. Focus of international research institutions on technical development for millet and sorghum, crops particular to semi-arid tropics in SSA, were late in coming (Fuglie 2011). ICRISAT, which has modest impact in developing crop variety improvements in Niger, established it first research center in the SSA in Niamey in 1983. Even when there are inventions, given the diversity of soil in each agroecological zone in Niger, technologies require local adaptation. While Nigeria and Senegal in West Africa had a long history of bilateral technical assistance program, national millet and sorghum improvement programs did not start in Niger until the mid-1980s (Matlon 1990). Investments in cowpea, a cash crop intercropped with millet or sorghum is also lowest in Niger among cowpea producing countries. Extension services were also weak resulting in poor dissemination of promising materials. As a result adoption rate has also been low.

Ndjeunga et al. (2015) relied on GIS information and expert opinion survey to summarize pearl millet, groundnut, and sorghum variety release and adoption in West and Central Africa. They note most of the national level scientific strength is concentrated on breeding and mostly none in other disciplines such as pathology, agronomy, and seed production which are important in crop variety improvement. As a result, Niger ranked lowest in a study of West African countries (Mali, Burkina Faso, Niger, Nigeria, and Senegal) in sorghum (7) and groundnut (13) variety releases, although along with Mali it had by far the most number of releases in pearl millet (37)[41].

Dissemination and adoption of new varieties is low in Niger compared to its Sahelian neighbors and this means there is potential to achieve higher yields with existing varieties. Adoption rate of pearl millet was by far one of the lowest (11.5% of area under modern varieties compared to 31% in Mali). Adoption of groundnut and sorghum MVs were rather slightly higher than pearl millet MVs. The most successful has been the adoption of varieties which have improved local adaptation to farm level stresses such as early maturing P3 Kolo for millet (Matlon 1990). Adoption, among other things is limited by slow release and a lack of promotion of released varieties (Ndjeunga et al. 2015).

Similarly in the case of cowpeas, despite release of 15 improved varieties of cowpea since 1970s (comparable to average no of release in West and Central African countries except Nigeria), adoption rate is lowest among all countries (9% of total cultivated area in 2009) (Alene et al. 2015). The study reasons lack of adoption of cowpeas could be attributed to low human and financial investments, lack of desired traits, and lack of access to seed.

The case for Niger's TFP growth: Population density in the Southern part of the country, covering 25 percent of the territory and where 96 percent of Nigeriens live, average about 60 inhabitants per km^2, twice the average of West Africa (29 inhabitants per km^2) (OECD 2018). Rising rural land scarcity suggests that agricultural production growth, which has traditionally depended on land expansion more than productivity gains, may become difficult to maintain. The amount of agricultural land available for farming and grazing halved in rural per capita terms during 1990-2015 (from 4.9 to 2.7 hectares), and the amount of per capita arable crop land has also fallen (from 1.6 to 1.0 hectares). Even if agricultural land continues to expand at current rates, which is unlikely, it would still be outpaced by rural population growth (i.e., with crop land falling to 0.6 hectares per rural inhabitant by 2050.

[41] The study also noted dry spells in releasing new varieties between 1990 and 2010. Low turnover of crop varieties e.g. HKP released in 1975 is most popular pearl millet variety despite release of more high-yielding variation of HKP. Higher adoption of varieties released by ICRISAT.

While it has made progress in bringing out high-yielding, drought tolerant seed varieties; there is a large gap remaining between current yields and potential yields in Niger.

Productivity gains from R&D investments: TFP growth can be achieved through investments in R&D in national, international and private agricultural research. It takes several years for the knowledge generated from research to be fully incorporated into higher farm productivity and output (Alston, Norton, and Pardey, 1995). Thus investments in R&D materialize into TFP growth with a lag. TFP may continue to grow even without any growth in R&D spending if past R&D spending is still adding to R&D stock, due to the lag effects between R&D investment and R&D stock accumulation.

Each 1% increase in national agricultural research R&D stock raises TFP by 0.0394% in Sub-Saharan Africa, meaning if annual R&D spending If annual R&D spending is raised 1% and continued at this new level, then TFP will eventually increase by 0.0394% percent (Fuglie and Rada 2013). It raises by 0.0403% for the same investment in international research centers. National and international agricultural research are complementary. Stronger national research systems help achieve greater impact from CGIAR research by enabling more rapid diffusion of technologies

Experiment: This essay relies on heavily on the historical R&D spending and capital stocks data provided by Fuglie (2014) in estimating the cost of climate adaptation. Data on 5-year agricultural R&D expenditures is converted to agricultural R&D capital stocks using a lag structure. The length of the lag-structure is region-specific with shorter lags in developing regions including Niger (35-year lags) than in developed countries. The R&D capital stocks are converted to growth rates in agricultural total factor productivity via the R&D TFP elasticities.

I first establish the future baseline TFP growth in the crop sector by assuming that historical R&D spending rates will persist in Niger. Then I double the rate of annual spending growth and the associated TFP growth in 2050 is estimated. I assume that both national and CGIAR ag R&D increase by 6% a year in real terms. With this, Niger TFP grows by 0.39% per year (and from an index value of 100 in 2006 to 145 in 2050, or for an accumulated total growth of 45% by 2050).

The graphs below show the trend lines for national spending and associate TFP growth in Niger. Note that private R&D spending, which is, almost non-existent in Niger is excluded from these scenarios.

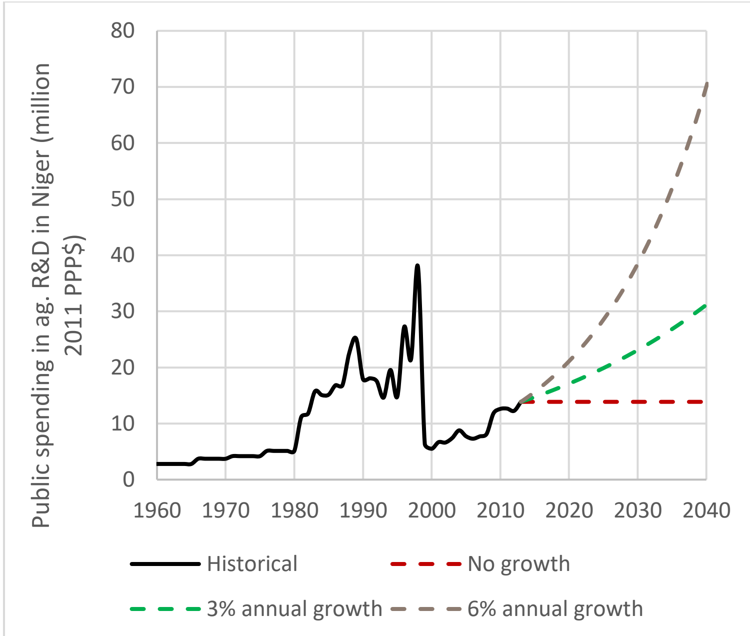

Figure 21: Historical and future trends: public spending in agricultural R&D in Niger (million 2011 PPP$); Source: Fuglie 2014

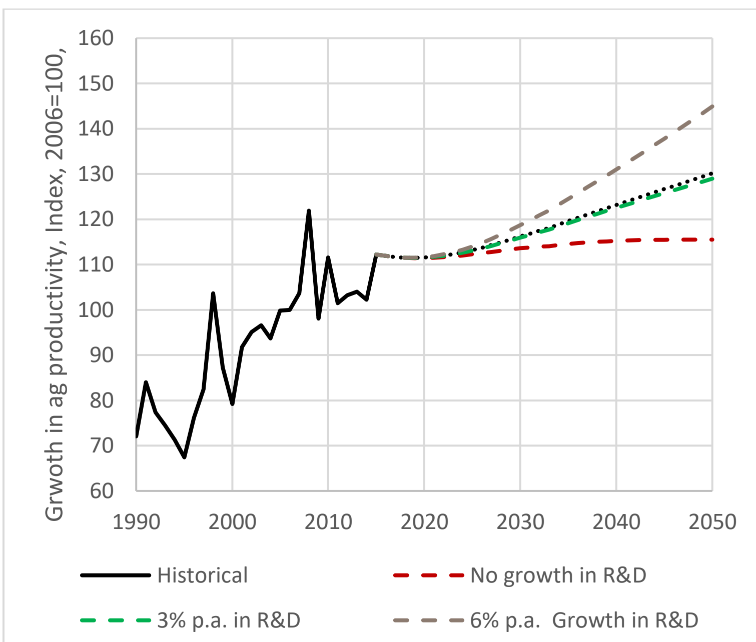

Figure 22: Historical TFP growth and future ag TFP growth associated with different growth rates of public spending for R&D in Niger. Source: Estimated from Fuglie 2014

3.2.3 Reduced Population Growth Scenario

Africa's fastest growing population (3.9 percent annually) has the highest fertility rate in the world and at the same time one of the highest infant mortality rate (81 infants per 1000 love births). The desired fertility rate in Niger is above the current estimated fertility rate (DHS 2015). The population more than quadrupled in less than 50 years from 3.3 million in 1960 to 14.1m in 2006. Niger is not an anomaly in the Sahel region which has the highest fertility rates in SSA, but while in recent years its neighbors have shown declining trends, the fertility rate in Niger remains more or less stable over the years.

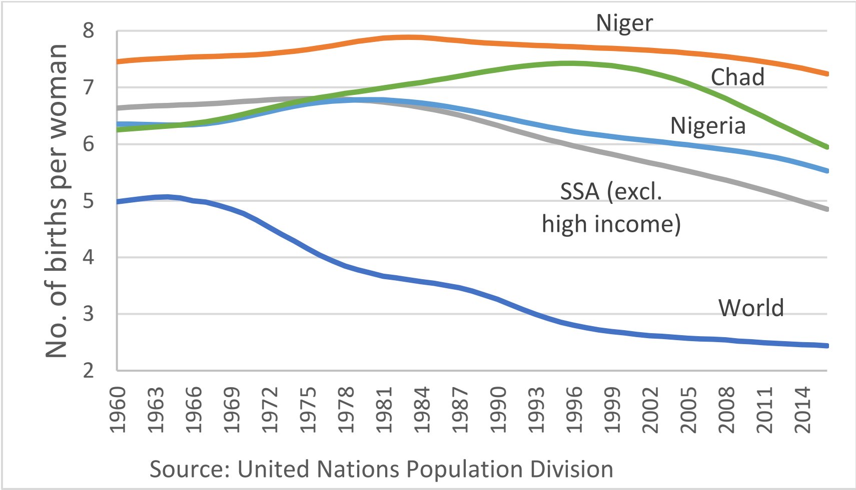

Figure 23: Trends in fertility rate, 1960-2016

The reasons behind the high fertility rates are complex. It is not only due to factors such as low child survival rates (replacement) or "supply side" economic factors such as unavailability of family planning services—but a deep desire to have large families which is an accumulation of own desire, family desire and social norms (DHS 2015, Canning et al. 2015). Qualitative analysis shows, even urban and educated respondents in DHS were very proud to have a large number of children – it was a measure of prestige, respect and honor that they held in society.

Experiment: In the 2017-21 Economic and Social Development Plan, the government targets a reduced population growth rate of 3.06% for 2021. I assume population growth rate will reduce to an optimistic 2.4% annually for 2050 (close to the most optimistic scenario in the 2017-21 ESDP) instead of 3.6% as assumed in 2050 baseline SSP4 scenario. GDP growth and urbanization shares are assumed to be same as the SSP4 scenario based on which the 2050 baseline is created. However since the population growth rate changes, the per capita GDP growth in Niger and in rural and urban Niger changes to be consistent with the unchanged GDP growth.

3.3 Results

Market integration: Does a more restricted market aid household food security situation in Niger in the long run considering the number of people involved in agriculture? From the household undernourishment point of view, the prevalence of undernourishment increases both in rural and urban Niger compared to baseline integration scenario (Figure). Not accounting for full extent of distributional effects, on average a more restricted market is not beneficial for household food security in Niger.

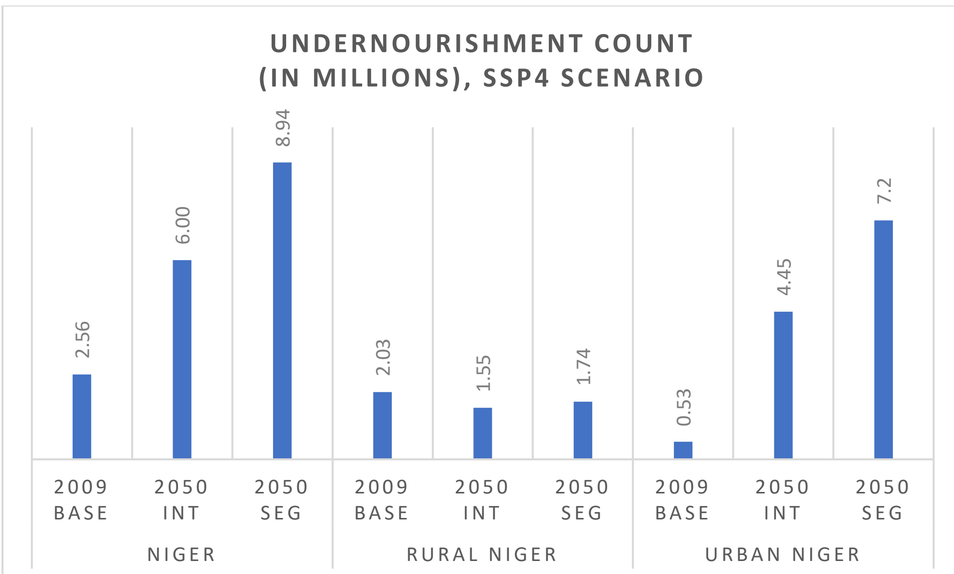

Figure 24: No. of people projected to be undernourished in 2050 in Niger. INT referes to 2009 market integration level. SEG refers to lower integration.

Source: 2009 baseline data ECVMA 2011, 2050 INT and SEG results based on simulations.

Recapping the results of 2nd essay, we saw an overall increase in the number of undernourished people in 2050 scenario with most of the increase occurring in urban areas and the rural areas experiencing a decline compared to 2009 baseline. The undernourishment index in rural Niger (15%) is less than in urban Niger (20%) to start with. In a less integrated scenario, despite food commodity prices hiking up and rural households benefitting from a larger agricultural income (Table), the net result on food security is negative in rural areas and more so in urban areas where household income do not benefit from crop price increases.

Table 15: Change in rural income and sources of income, 2009-2050, in integrated and segmented markets

Total Change (%) in Rural Income from 2009 to 2050	p_INC_PC	p_INC_PC_VLAND	p_INC_PC_VLAB
2050 Int	118	303	135
2050 Seg	193	775	359
Note: For Niger rural income: p_INC_PC = 0.33 * p_INC_PC_VLAND + 0.06 * p_INC_PC_VLAB + 0.61 * p_INC_PCd; where p_INC_PCd is the % change in non-crop income.			

Whether high or low food prices are bad for the poor depends largely on initial conditions. At household level, the impact of a change in food prices depends on the household's characteristics and one of them is how dependent it is on agricultural production and sales as a source of income. (Aksoy and Hoekman, 2010). Although around 80% of the labor force is employed in agriculture, it is one of the least productive sectors in Niger and share of household income from agriculture is low.

A less integrated market does push Niger to grow more local crops (9.7 m MT vs. 10. M MT millet equivalent), but overall results in no change in total crop availability and higher food prices. Ensuring food security is not only about food availability, but one of the premise is financial and physical access to food. With higher crop prices and in absence of accompanying rise in rural income, household food insecurity exacerbates.

An important point to note on the grounds of environmental sustainability is that in a less integrated market scenario, the expansion of local crop output growth comes at the cost of farther agricultural land expansion (by around 118% from 2009 to 2050 vs. 65% in a current integration scenario) . The model does not put a limit to land expansion, so the extent of land availability is at its upper bound. There is already evidence of land degradation, conflicts over land, and agricultural land pressure.

Finally, some net consumers may become net producers if prices rise. Assessing the impact of prices changes clearly requires empirical analysis. The only thing that can be said with confidence is that not everyone will gain or lose: there will be distributional effects.

Accelerated R&D investment:

An accelerated level of public spending in R&D is expected to aid in improving household food security situation. However an increase in national R&D spending growth rate from 3% to 6% in Niger which translates into annual TFP growth of 0.82% (rising from 0.55%), results in a small change compared to the 2050 baseline (2050 INT).

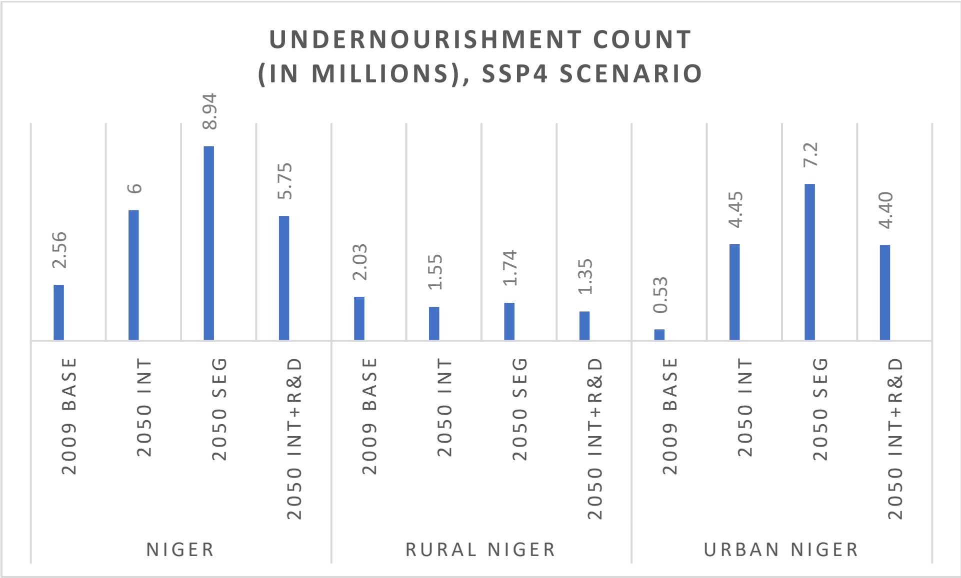

Figure 25: No. of people projected to be undernourished in 2050 in Niger
Source: 2009 baseline data from ECVMA 2011, 2050 results based on simulations

The current elasticities of transformation (R&D investment to TFP growth) are small in Niger and thus does not result in higher increases in TFP growth, which can subsequently affect household food security levels. These elasticities are based on average R&D elasticities estimated for the SSA region as a whole. It is possible that Niger has particular circumstances that will allow R&D to TFP transformation to grow faster than these projections.

Growth in TFP also occur other than through increased national public spending in R&D, it is not the only source of growth. For example, Niger could be benefitting from economic policy reforms. Or it might capture R&D spillovers from neighboring countries like Nigeria, or, perhaps the CGIAR is targeting relatively more attention to this country/region (with an ICRISAT station in the country, for example). NGO's might also be contributing – they have had an impact on developing small scale irrigation methods and zai pits & agroforestry innovations that have been widely adopted.

So what the model projections tell us is that given historical R&D transformation elasticities, increased spending in national R&D is not enough to tackle household food security. The R&D spending to TFP growth transformation can increase with a better R&D system.

Reduced Population Growth Scenario

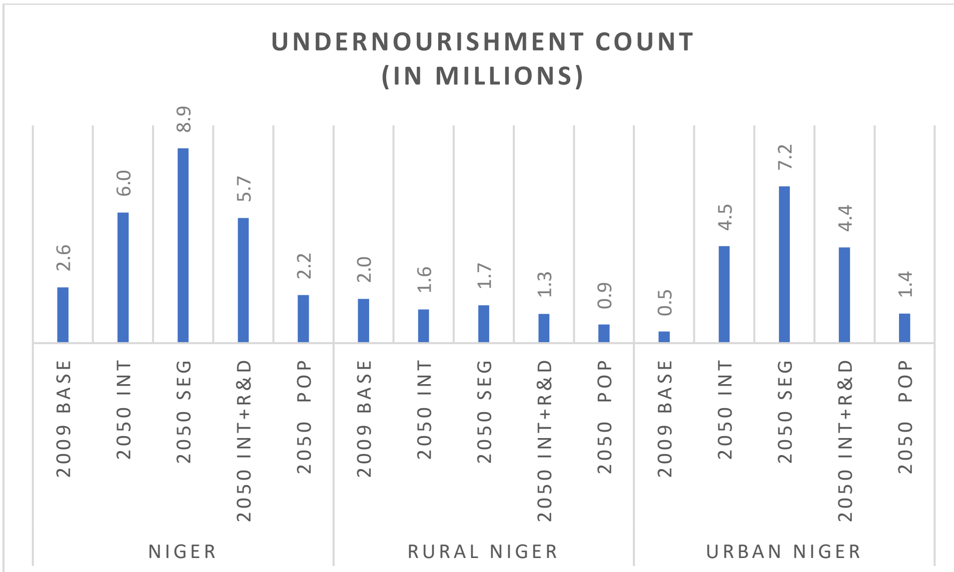

Figure 26: No. of people projected to be undernourished in 2050 in Niger

Source: 2009 baseline data from ECVMA 2011, 2050 results based on simulations

The reduced population growth rate scenario has the largest positive outcome on household food security in Niger. This is not surprising given our results from 2nd essay. Most results were driven mainly by growth in population. However, even during times of security stability, fund allocation for relatively less controversial issues like investments in agricultural productivities are easier to make than in family planning or sexual reproduction and health (Shiffman and Quissell 2012). Education and women's labor force participation is well known to reduce fertility rates. And it has also been shown that basic education of agricultural laborers is a key factor in agricultural production (Hayami and Ruttan 1971). Lutz et al. (2004) showed in their work for number of African countries that education can be a key determinant in reducing malnutrition and food security.

3.4 Concluding Remarks and Charting the Way Forward

The market integration simulation shows the overall positive outcomes of a more integrated market for food security in Niger. Both rural and urban household undernourishment levels improve, and there are positive environmental outcomes as well with less cropland expansion vs. when markets are less integrated. On the supply and demand side interventions, an intervention on the demand side (population growth scenario) has far greater impact on household food security in Niger than supply side intervention (investments in agricultural R&D). This is not surprising because food security outcomes are largely driven by population growth in Niger. And productivity of the national R&D institutions in Niger is relatively low, as reflected in a low output elasticity linking R&D spending to TFP growth in Niger. A limitation in the current analysis is that it is missing information on how much investment is required for the reduction in population growth which can make these two scenarios comparable.

Given the externalities of stagnant agricultural productivity growth or increasing population growth, or segmented markets; none of these policies are recommended to be implemented to the exclusion of the others. Against the backdrop of the AfCFTA, the scenario of market integration becomes even more important for Niger. This is an area of potential future research with specific focus on AfCFTA.

On the supply side, overall investment in agricultural research has remained low and increases in research capacity will likely be necessary to maintain, and possibly accelerate, its recent improvements in agricultural productivity growth. Total factor productivity improvements through investments in agricultural R&D can continue to contribute to mitigating the negative effects of climate change. There is potential for gains through two types of interventions in this frontier: accelerate TFP growth through more R&D investments, and through more efficiency gains in dollar to TFP growth conversion. This can be achieved by better extension work, research dissemination, and input market access.

With the current low base for agricultural productivity, advancements in food security will likely be outpaced by the rocketing population growth and setbacks by climate change. Despite the cultural taboos and the political challenges, Niger would benefit greatly from bringing sexual and reproductive health, and women empowerment through education and labor force participation into focus. On the other hand, it could also take the opportunity to turn its young population into a human capital base with education and training appropriate for semi-skilled to highly-skilled labor force.

Finally, although migration among Nigeriens is mostly limited to seasonal migration within West Africa, the conversation on outmigration through undocumented channels surfaces as Niger lies on the land migration route taken by many Africans heading to Europe. And so does the conversation on national and international security with recent instabilities in the region. Missing in the conversation is the connection between food security, climate change impacts, population growth, migration and national security. While funds are being diverted towards defense and security, it important to remember Investments in family planning and skill development will be key to long run stability and economic security in the region.

3.5 Appendix

A.1: Estimated TFP growth rates (%) in SSA and Niger from different sources

Paper	Approach	Coverage	TFP Change (%)		Efficiency change	Technical change
Block (2013)	CD-growth accounting	1960-2002 Africa divided into different regions	**Sahel including Niger:** -2.41 (1960-1984) 0.48 (1985-2002) **-1.17 (1960-2002)**			
Fuglie (2011)	CD-growth accounting	1961-2008, 48 SSA countries	**Niger: -0.21 (1961-2006); -0.002 (1961-2008)**			
Nin-Pratt and Yu (2008)	DEA	1964-2003 30 SSA countries (Niger not in sample) (growth rates shown for SSA excluding Nigeria)	1964-2003	-0.15		
			1964-83	-0.77	-0.90	0.14
			1984-2003	1.18	0.97	0.21
Ludena et al. (2007)	DEA	1960-2000, SSA and other regions for crops, ruminants and non-ruminants	1961-1981 (SSA Crop)	-0.15	-0.87	0.30
			1981-2000 (SSA Crop)	0.88	0.73	0.15
Fulginiti et al. (2004)	Semi-non parametric	1960-1999 41 SSA countries	-**0.43 (Niger)** 0.83 (SSA)			
Coelli and Rao (2003)	DEA	1980-2000 93 countries including 26 African countries	**0.998 (Niger)** 1.013 (Africa)		0.995 (Niger) 1.006 (Africa)	1.004 (Niger) 1.007 (Africa)
Lusigi and Thirtle (1997)	DEA	1961-1991 47 African countries	**1.493 (Niger)** 1.27 (Africa)		4.886 (Niger) 1.15 (Africa)	3.876 (Niger) 0.9 (Africa)
Frisvold and Ingram (1994)	CD	1973-1985 28 SSA countries divided into 4 ecological zones (Niger in semi-arid tropics)	1.48 (land productivity in semi-arid tropics)		Changes in conventional inputs: 0.97(labor), 0.31(livestock), 0.10 (fertilizer), 0.14 (tractors); Rest explained by changed in non-conventional inputs.	

A.2: Cumulative crop TFP growth in SIMPLE regions as used in the simulations. NCZs refers to Niger climate zones.

```
Shock p_AOCROPr("E_Euro")=71.3;
Shock p_AOCROPr("N_Afr")=64.9;
Shock p_AOCROPr("SSA")=28.8;
Shock p_AOCROPr("NCZ1")=39.9;
Shock p_AOCROPr("NCZ2")=39.9;
```

```
Shock p_AOCROPr("NCZ3")=39.9;
Shock p_AOCROPr("NCZ4")=39.9;
Shock p_AOCROPr("NCZ5")=39.9;
Shock p_AOCROPr("S_Amer")=70.9;
Shock p_AOCROPr("AUS_NZ")=39;
Shock p_AOCROPr("EU")=46.8;
Shock p_AOCROPr("S_Asia")=36.5;
Shock p_AOCROPr("CC_Amer")=70.2;
Shock p_AOCROPr("S_Afr")=59.3;
Shock p_AOCROPr("SE_Asia")=68.3;
Shock p_AOCROPr("CAN")=60.6;
Shock p_AOCROPr("US")=60.6;
Shock p_AOCROPr("CHN_MNG")=92.1;
Shock p_AOCROPr("M_East")=50.5;
Shock p_AOCROPr("JPN_KR")=68.3;
Shock p_AOCROPr("C_Asia")=71.3;
```

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APPENDIX A. SIMPLE-NIGER MODEL

```
!===========================================================
===================!
!  SIMPLE v2:                                          !
!      a Simplified International Model of agricultural Prices,           !
!        Land use and the Environment                                   !
!        by U. Baldos and T. Hertel                                 !
!        Department of Agricultural Economics                           !
!        Purdue University, IN, USA                                  !
!===========================================================
===================!
!Modified by Kayenat Kabir for Niger!
!Modifications: 1.Farm income endogenous!
!2.Non-land disaggregrated into labor, capital and purchased inputs!
!3.Supply zones: 5 climate zones!
!4.Demand zones: urban and rural!
!------------------------------------------
 Overview of SIMPLEv2 TAB file structure
 ------------------------------------------
     I. PRELIMINARIES

    II. CONSUMER DEMAND SYSTEM
       II.A  CONSUMER DEMAND DRIVERS, VARIABLES & ELASTICITIES
        II.A.1  Exogenous Drivers of Commodity Demand
        II.A.2  Sources of Industrial Demands for Crops
          II.A.2.1  Exogenous Driver of Crop Demand
          II.A.2.2  Sources of Crop Demand as Intermediate Inputs
        II.A.3  Variables Related to Commodity Demand
        II.A.4  Demand Elasticities [Ad hoc System]
       II.B  CROP USE ACCOUNTING SYSTEM
       II.C  CONSUMER DEMAND EQUATIONS
        II.C.1  Per Capita Commodity Demand
        II.C.2  Regional Commodity Demand

   III. PRODUCTION SYSTEM
      III.A  CROP PRODUCTION SYSTEM
        III.A.1  Coefficients & Variables Related to Crop Production
        III.A.2  Exogenous Shifters of Land Supply
        III.A.3  Coefficients & Variables Related to Land Demand/Supply
        III.A.4  Variables Related to Technical Change in Crop Production
        III.A.5  Key Equations on Land Demand/Supply & Crop Production
          III.A.5.1  Long Run Supply for Land
          III.A.5.2  Long Run Supply for Nonland Inputs
          III.A.5.3  Long Run Derived Demand Equation for Land
```

```
        III.A.5.4  Long Run Derived Demand Equation for Nonland Inputs
        III.A.5.5  Zero Profit Condition for Crop Producers
      III.B. GLOBAL MARKET CLEARING EQUATIONS FOR CROPS
      III.C  LIVESTOCK & PROCESSED FOOD PRODUCTION
       III.C.1  Coeff. & Var. Related to Livestock & Proc. Food Prod.
       III.C.2  Var. Related to Tech. Chg. in Lvstck & Proc. Food Prod.
       III.C.3  Key Equations in Livestock & Proc. Food Production
        III.C.3.1  Long Run Derived Dmd for Feed inputs
        III.C.3.2  Long Run Derived Dmd for Nonfeed Inputs
        III.C.3.3  Long Run Derived Dmd for Crop inputs in Proc. Food
        III.C.3.4  Long Run Drvd Dmd for Noncrop inputs used in Proc. Food
        III.C.3.5  Zero Profit Condition for Livestock Producers
        III.C.3.6  Zero Profit Condition for Processed Foods Producers

    V. APPPENDICIES
      Appendix A. Checks in the model
      Appendix B. Summary Statistics

!
!<
=====================================================================
===========
    I. PRELIMINARIES

=====================================================================
===========  >!
!  Declaration of sets. All the sets are read from the
   LANDSETS.HAR file located in the "in" folder                    !

File LANDDATA # file containing all base data #;
    LANDPARM # file containing all parameters #;
    LANDSETS # file containing all sets & each of their elements #;

Set REG     # world regions (17) #
        read elements from file LANDSETS header "H1";
![[! Edits !]]!
Set
   SREG    # world regions: Niger Climate Zones (21) #
        read elements from file LANDSETS header "SREG";
   DREG    # world regions: Niger Rural Urban (18) #
        read elements from file LANDSETS header "DREG";
   CONS_COMM # consumption commodities (4) #
        read elements from file LANDSETS header "AGGC";
   FOOD_COMM # food commodities (3): subset of consumption commodities #
        read elements from file LANDSETS header "AGGF";
        subset FOOD_COMM is subset of CONS_COMM;
```

```
Set NFOOD_COMM # non-food commodity: subset of consumption commodities #
        = CONS_COMM - FOOD_COMM;
Set COEF    # set of parameters from the demand elasticity regression #
        read elements from file LANDSETS header "COEF";

Set NRUREG # Niger Rural Region # (NRUR);
Subset NRUREG is subset of DREG;
Set OTHREG # Non-Niger Rural Region # = DREG - NRUREG;

!        Set mapping                           !
Mapping MP_SREG from SREG to REG;
     read (By_Elements) MP_SREG from file LANDSETS header "MAP1";
Mapping MP_DREG from DREG to REG;
     read (By_Elements) MP_DREG from file LANDSETS header "MAP2";

!  Declaration of slack variables (for advanced users only).          !
!Variable (all,i,CONS_COMM) (all,g,REG)               slack_q_pc(i,g)
   # slack variable for fixing per capita demand #;!
Variable                                     slack_acrpuse
   # slack variable for targeting global price from demand side # ;
Variable (all,g,REG)                         slack_crpfeed(g)
   # slack variable for allowing targeting of p_AFCRPFEED(y) # ;
Variable (all,g,REG)                         slack_crpfood(g)
   # slack variable for allowing targeting of p_AFCRPFOOD(y) # ;

!<
=================================================================
===========
   II. CONSUMER DEMAND SYSTEM

=================================================================
===========  >!
!< ------------------------------------------------------------------
   II.A  CONSUMER DEMAND DRIVERS, VARIABLES & ELASTICITIES
   -----------------------------------------------------------------  >!
!  ***********************************************************
   II.A.1  Exogenous Drivers of Commodity Demand
   ***********************************************************       !
!Variable (levels) (all,g,DREG)               INC_PCd(g)
   # per capita income (in 2005 USD) #;!
Variable (levels) (all,g,DREG)                POPd(g)
   # population (in Millions) #;

!  ***********************************************************
   II.A.2  Sources of Industrial Demands for Crops
   ***********************************************************       !
```

```
!   II.A.2.1  Exogenous Driver of Crop Demand
    ------------------------------------------------------------------  !
Variable (levels)                                   QCRPBIOF
   # global crop demand for biofuel use (in M MTs corn-equiv.) #;

!   II.A.2.2  Sources of Crop Demand as Intermediate Inputs
    ------------------------------------------------------------------  !
Variable (levels) (all,g,REG)                       QCRPFEED(g)
   # quant. of feeds used in livestock prod. (in M MT corn-equiv.) #;
Variable (levels) (all,g,REG)                       QCRPFOOD(g)
   # quant. of crops used in proc. food prod. (in M MT corn-equiv.) #;

!   ******************************************************************
    II.A.3  Variables Related to Commodity Demand
    ******************************************************************         !
Variable (levels) (all,g,DREG)                      INC_PCd(g)
   # per capita income (in 2005 USD) #;
Variable (all,g,NRUREG)                             p_INC_PC_VLAND(g)
   # per capita income from owned land (in 2005 USD) #;
Variable (all,g,NRUREG)                             p_INC_PC_VLAB(g)
   # per capita income from owned labor (in 2005 USD) #;
Variable (all,g,DREG)                               p_INC_PC(g)
   # per capita income from other sources (in 2005 USD) #;

!       Price & consumption variables                         !
Variable (levels) (all,i,CONS_COMM)(all,g,REG)                P(i,g)
  # commodity prices by income regions (in USD $2005 / MT)#;
Variable (levels) (all,i,CONS_COMM)(all,g,DREG)               Pd(i,g)
  # commodity prices by demand regions (in USD $2005 / MT)#;
Variable (levels) (all,i,CONS_COMM)(all,g,DREG)               QPCd(i,g)
  # per capita consumption of commodities by demand region #
    !(in USD $2005, in MT: 'Crops' only) !;
Variable (levels) (all,i,CONS_COMM)(all,g,DREG)         QCONSd(i,g)
  # consumption of each commodity by demand region #
    !(in M USD $2005, in M MT: 'Crops' only)!;
Variable (levels) (all,i,CONS_COMM)(all,g,DREG)         VCONSd(i,g)
  # value of consumption of each commodity by income region #
    !(in M USD $2005, in M MT: 'Crops' only)!;
Variable (levels) (all,i,CONS_COMM)(all,g,REG)        QCONS(i,g)
  # consumption of each commodity by income region #
    !(in M USD $2005, in M MT: 'Crops' only)!;
Variable (levels) (all,i,CONS_COMM)(all,g,REG)        VCONS(i,g)
  # value of consumption of each commodity by income region #
    !(in M USD $2005, in M MT: 'Crops' only)!;

    Read QCONSd  from file LANDDATA header "QCND";
```

```
        VCONSd  from file LANDDATA header "VCND";
        INC_PCd from file LANDDATA header "YPCD";
        POPd    from file LANDDATA header "POPD";
        QCONS  from file LANDDATA header "QCON";
        VCONS  from file LANDDATA header "VCON";
        !INC_PCd from file LANDDATA header "YPC";
        POPd    from file LANDDATA header "POP";!


!       Formulas for deriving prices & per capita consumption           !
   Formula (initial) (all,i,CONS_COMM)(all,g,DREG)      QPCd(i,g)
   = QCONSd(i,g) / POPd(g) ;
   Formula (initial) (all,g,REG)                    P("Livestock",g)
   = VCONS("Livestock",g) / QCONS("Livestock",g) ;
   Formula (initial) (all,g,REG)                    P("Proc_Food",g)
   = VCONS("Proc_Food",g) / QCONS("Proc_Food",g) ;

!       Formulas for deriving prices & per capita consumption           !
   Formula (initial) (all,i,CONS_COMM)(all,g,DREG)      QPCd(i,g)
   = QCONSd(i,g) / POPd(g) ;
   Formula (initial) (all,g,DREG)                   Pd("Livestock",g)
   = VCONSd("Livestock",g) / QCONSd("Livestock",g) ;
   Formula (initial) (all,g,DREG)                   Pd("Proc_Food",g)
   = VCONSd("Proc_Food",g) / QCONSd("Proc_Food",g) ;

!  ****************************************************************
   II.A.4  Demand Elasticities [Ad hoc System]
   ****************************************************************           !
!      Parameters from the linear regression of the demand elasticities   !
Coefficient (parameter) (all,i,CONS_COMM) (all,k,COEF)       EIY(i,k)
   # regression estimates of income elasticities & per capita incomes #;
Coefficient (parameter) (all,i,CONS_COMM) (all,k,COEF)       EIP(i,k)
   # regression estimates of own-price elasticities & per capita incomes #;
Coefficient (all,i,CONS_COMM) (all,g,DREG)            adhocEINCd(i,g)
   # predicted income elasticities of demand by comm. & inc. region #;
Coefficient (all,i,CONS_COMM) (all,g,DREG)            adhocEOPd(i,g)
   # predicted own-price elasticities of demand by comm. & inc. region #;

!      Consumption elasticities in the model                            !
Coefficient (all,i,CONS_COMM) (all,g,DREG)            EINCd(i,g)
   # income elasticity of demand for all commodities #;
Coefficient (all,i,CONS_COMM)(all,g,DREG)             EOPd(i,g)
   # own-price elasticities of demand for all commodities #;
!Coefficient (parameter) (all,i,CONS_COMM) (all,g,DREG)        addEIP(i,g)
   # own-price elasticities shifter for Niger #;
Coefficient (parameter)  (all,i,CONS_COMM) (all,g,DREG)        addEIY(i,g)
```

```
   # income elasticities shifter for Niger #;!

   Read EIP from file LANDPARM header "EIP";
       EIY from file LANDPARM header "EIY";
    !  addEIP from file LANDPARM header "SEIP";
       addEIY from file LANDPARM header "SEIY";
Note: The elasticity shifters were added for historical period!

!      Formulas Linking per capita income and the regression parameters   !
   Formula (all,i,CONS_COMM) (all,g,DREG)            adhocEINCd(i,g)
   = EIY(i,"INT") + EIY(i,"SLP") * loge(INC_PCd(g));
   Formula (all,i,CONS_COMM) (all,g,DREG)            adhocEOPd(i,g)
   = EIP(i,"INT") + EIP(i,"SLP") * loge(INC_PCd(g));

!      Linking demand elasticities to the predicted elasticities        !
   Formula (all,i,CONS_COMM) (all,g,DREG)            EINCd(i,g)
   = adhocEINCd(i,g);
   Formula (all,i,CONS_COMM)(all,g,DREG)             EOPd(i,g)
   = adhocEOPd(i,g);

!<  ----------------------------------------------------------------
    II.B  CROP USE ACCOUNTING SYSTEM
   ----------------------------------------------------------------   >!
!        Crop variables                                    !
Variable (levels) (all,g,REG)                  QCROPg(g)
   # crop production (in M MT corn-equiv.) #;
Variable (levels) (all,g,REG)                  VCROPg(g)
   # value of crop production (in M USD $2005) #;
Variable (levels) (all,g,REG)                  PCROPg(g)
   # regional crop price (in USD $2005) #;

Variable (levels) (all,s,SREG)                 QCROPs(s)
   # crop production (in M MT corn-equiv.) #;
Variable (levels) (all,s,SREG)                 VCROPs(s)
   # value of crop production (in M USD $2005) #;
Variable (levels) (all,s,SREG)                 PCROPs(s)
   # regional crop price (in USD $2005) #;

Variable (levels)                              PCROP
   # world crop price (in USD $2005) #;

!       Crop Allocation Shares                               !
Coefficient (all,g,REG)                        CRPSHRCONS(g)
   # crops allocated to direct food consumption #;
Coefficient (all,g,REG)                        CRPSHRFEED(g)
   # crops allocated to the livestock sector #;
```

```
Coefficient (all,g,REG)                          CRPSHRFOOD(g)
   # crops allocated to the processed food industry  #;


    Read VCROPs   from file LANDDATA header "VCPS";
        QCRPFEED from file LANDDATA header "QFD";
        QCRPFOOD from file LANDDATA header "QPR";
        QCROPs   from file LANDDATA header "QCPS";
        QCRPBIOF from file LANDDATA header "QBIO";

!       Formulas for calculating regional crop quantity and value       !
Formula&Equation E_QCROPg (all,g,REG)                         QCROPg(g)
      = sum(s, SREG: MP_SREG(s) EQ g, QCROPs(s));
Formula&Equation E_VCROPg (all,g,REG)                         VCROPg(g)
      = sum(s, SREG: MP_SREG(s) EQ g, VCROPs(s));

!       Formulas for calculating crop allocation shares                 !
    Formula (all,g,REG)                          CRPSHRCONS(g)
      = QCONS("Crops",g) / [sum(y, REG, QCRPFEED(y)
                    + QCRPFOOD(y) + QCONS("Crops",y)) + QCRPBIOF];
    Formula (all,g,REG)                          CRPSHRFEED(g)
      = QCRPFEED(g) / [sum(y, REG, QCRPFEED(y)
                    + QCRPFOOD(y) + QCONS("Crops",y)) + QCRPBIOF];
    Formula (all,g,REG)                          CRPSHRFOOD(g)
      = QCRPFOOD(g) / [sum(y, REG, QCRPFEED(y)
                    + QCRPFOOD(y) + QCONS("Crops",y)) + QCRPBIOF];

!       Formulas for reallocating global crop supply to global demand
        to initialize the crop demand data
        (ensures total crop demand = total crop supply)                 !
    Formula (initial) (all,g,REG)                QCONS("Crops",g)
      = CRPSHRCONS(g) * sum(y, REG, QCROPg(y));
    Formula (initial) (all,g,REG)                QCRPFEED(g)
      = CRPSHRFEED(g) * sum(y, REG, QCROPg(y));
    Formula (initial) (all,g,REG)                QCRPFOOD(g)
      = CRPSHRFOOD(g) * sum(y, REG, QCROPg(y));
    Formula (initial)                            PCROP
      = sum(g, REG, VCROPg(g))/sum(y, REG, QCROPg(y));

    Formula (initial) (all,g,REG)                P("Crops",g)
      = VCONS("Crops",g)/QCONS("Crops",g);
    Formula (initial) (all,g,DREG)               Pd("Crops",g)
      = VCONSd("Crops",g)/QCONSd("Crops",g);
    Formula (initial) (all,g,REG)                PCROPg(g)
      = VCROPg(g)/QCROPg(g);
```

```
   Formula (initial) (all,s,SREG)                    PCROPs(s)
     = VCROPs(s)/QCROPs(s);

! Linkages between consumption in Demand region to Region !
Equation (levels) E_QCONS (all,i,CONS_COMM)(all,g,REG)                    QCONS(i,g)
     = sum(s, DREG: MP_DREG(s) EQ g, QCONSd(i,s));
Equation (levels) E_VCONS (all,i,CONS_COMM)(all,g,REG)                    VCONS(i,g)
     = sum(s, DREG: MP_DREG(s) EQ g, VCONSd(i,s));

!< ------------------------------------------------------------
   II.C CONSUMER DEMAND EQUATIONS
  ------------------------------------------------------------  >!
Equation E_INC_PC_NRUR
  # per capita income equation in Niger Rural Region #
  (all,g,NRUREG)
  p_INC_PC(g) =   0.33 * p_INC_PC_VLAND(g) + 0.06 * p_INC_PC_VLAB(g)
              + 0.61 * p_INC_PCd(g);

Equation E_INC_PC_OTHRREG
  # per capita income equation in Other Region + Niger Urban Region #
  (all,g,OTHREG)
  p_INC_PC(g) = p_INC_PCd(g);

!   II.C.1 Per Capita Commodity Demand
  --------------------------------------------------------------  !
Equation E_QPC
  # determines the endo. price of per cap. demand for all commodities #
  (all,i,CONS_COMM) (all,g,DREG)
  p_QPCd(i,g) =   EOPd(i,g) * p_Pd(i,g)
             + EINCd(i,g) * p_INC_PC(g);
!             + slack_q_pcd(i,g);!

!   II.C.2 Regional Commodity Demand
  --------------------------------------------------------------  !
Equation E_CONS
  # determines the change in consumptions of all commodities #
  (all,i,CONS_COMM)(all,g,DREG)
  p_QCONSd(i,g) = p_QPCd(i,g) + p_POPd(g);

!      Equation of value of crop consumption                      !
   Equation E_VCONSd  (all,i,CONS_COMM)(all,g,DREG)     p_VCONSd(i,g)
   = p_Pd(i,g) + p_QCONSd(i,g);

   Equation E_Pd  (all,i,CONS_COMM)(all,g,DREG)     p_Pd(i,g)
   = p_P(i,MP_DREG(g));
```

```
!<
=================================================================
===========
  III. PRODUCTION SYSTEM

=================================================================
===========  >!
!< ----------------------------------------------------------------
  III.A  CROP PRODUCTION SYSTEM
  ----------------------------------------------------------------   >!
!  ***************************************************************
  III.A.1  Coefficients & Variables Related to Crop Production
  ***************************************************************        !
!        Elasticity of substitution between land & nonland inputs        !
Coefficient (Parameter) (all,s,SREG)              ECROPs(s)
  # global elasticity of subs. in prod. of crops #;

!  ***************************************************************
  III.A.3  Coefficients & Variables Related to Land Demand/Supply
  ***************************************************************        !
!        Price elasticities of crop input factors                  !
Coefficient (Parameter) (all,s,SREG)              ELANDs(s)
  # price elas. of cropland input #;
Coefficient (Parameter) (all,s,SREG)              ELABORs(s)
  # price elas. of labor input #;
Coefficient (Parameter) (all,s,SREG)              ECAPITALs(s)
  # price elas. of capital input #;
Coefficient (Parameter) (all,s,SREG)              EOTHERs(s)
  # price elas. of purchased inputs #;

!        Cost share of crop inputs                               !
Coefficient (all,s,SREG)                     SHRLANDs(s)
  # cost share of land inputs in crop production #;
Coefficient (all,s,SREG)                     SHRLABORs(s)
  # cost share of labor inputs in crop production #;
Coefficient (all,s,SREG)                     SHRCAPITALs(s)
  # cost share of capital inputs in crop production #;
Coefficient (all,s,SREG)                     SHROTHERs(s)
  # cost share of other inputs in crop production #;

!        Values, quantities and prices of land & nonland inputs
         used in crop production                                 !
Variable (levels) (all,s,SREG)                 QLANDs(s)
  # Cropland (in K ha: Harvested Area) #;
Variable (levels) (all,s,SREG)                 VLANDs(s)
```

```
   # Value of cropland inputs crop sector (in M USD $2005) #;
Variable (levels) (all,g,REG)                VLANDg(g)
   # Value of cropland inputs crop sector (in M USD $2005) #;
Variable (levels) (all,s,SREG)               PLANDs(s)
   # Land rents (in 1000 USD $2005 per hectare) #;

Variable (levels) (all,s,SREG)               QLABORs(s)
   # Value of labor inputs crop sector (in M USD $2005) #;
Variable (levels) (all,s,SREG)               VLABORs(s)
   # Value of labor inputs crop sector (in M USD $2005) #;
Variable (levels) (all,g,REG)                VLABORg(g)
   # Value of labor inputs crop sector (in M USD $2005) #;
Variable (levels) (all,s,SREG)               PLABORs(s)
   # Price index of labor inputs (1=Y2005) #;
Variable (change) (all,s,SREG)               slack_LABs(s)
   # slack variable for fixing labor supply #;

Variable (levels) (all,s,SREG)               QCAPITALs(s)
   # Value of capital inputs crop sector (in M USD $2005) #;
Variable (levels) (all,s,SREG)               VCAPITALs(s)
   # Value of capital inputs crop sector (in M USD $2005) #;
Variable (levels) (all,s,SREG)               PCAPITALs(s)
   # Price index of capital inputs (1=Y2005) #;
Variable (change) (all,s,SREG)               slack_CAPs(s)
   # slack variable for fixing capital supply #;


Variable (levels) (all,s,SREG)               QOTHERs(s)
   # Value of purchased inputs crop sector (in M USD $2005) #;
Variable (levels) (all,s,SREG)               VOTHERs(s)
   # Value of purchased inputs crop sector (in M USD $2005) #;
Variable (levels) (all,s,SREG)               POTHERs(s)
   # Price index of purchased inputs (1=Y2005) #;

!       Regional crop yields                          !
Variable (levels) (all,s,SREG)               YIELDs(s)
   # crop yields (in 1000s MTs corn-equiv. per hectare) #;

    Read QLANDs      from file LANDDATA header "QLDS";
       VLANDs      from file LANDDATA header "VLDS";
       VLABORs     from file LANDDATA header "VLBS";
       QLABORs     from file LANDDATA header "QLBS";
       VCAPITALs   from file LANDDATA header "VLCS";
       PCAPITALs   from file LANDDATA header "PLCS";
       VOTHERs     from file LANDDATA header "VOTS";
       POTHERs     from file LANDDATA header "POTS";
```

```
   ELANDs      from file LANDPARM header "ELN";
   ECAPITALs   from file LANDPARM header "ECAP";
   ELABORs     from file LANDPARM header "ELAB";
   EOTHERs     from file LANDPARM header "EOTH";
   ECROPs      from file LANDPARM header "ECRP";

!  Formulas and equation defining changes in the values and prices
   of land and nonland inputs                                  !
 Formula (initial) (all,s,SREG)                    PLANDs(s)
   = VLANDs(s)/QLANDs(s);

 Equation E_VLANDs (all,s,SREG)                    p_VLANDs(s)
   = p_PLANDs(s) + p_QLANDs(s);

 Formula & Equation E_VLANDg (all,g,REG)           VLANDg(g)
   = sum(s, SREG: MP_SREG(s) EQ g, VLANDs(s));

 Formula (initial) (all,s,SREG)                    PLABORs(s)
   = VLABORs(s)/QLABORs(s);

 Equation E_VLABORs (all,s,SREG)                   p_VLABORs(s)
   = p_PLABORs(s) + p_QLABORs(s);

 Formula & Equation E_VLABORg (all,g,REG)          VLABORg(g)
   = sum(s, SREG: MP_SREG(s) EQ g, VLABORs(s));

 Formula (initial) (all,s,SREG)                    QCAPITALs(s)
   = VCAPITALs(s)/PCAPITALs(s);
 Equation E_VCAPITALs (all,s,SREG)                 p_VCAPITALs(s)
   = p_PCAPITALs(s) + p_QCAPITALs(s);

 Formula (initial) (all,s,SREG)                    QOTHERs(s)
   = VOTHERs(s)/POTHERs(s);
 Equation E_VOTHERs (all,s,SREG)                   p_VOTHERs(s)
   = p_POTHERs(s) + p_QOTHERs(s);

!  Formulas and equations for deriving cost shares & definition of
   yields, value & technological change                        !
 Formula (all,s,SREG)                              SHRLANDs(s)
   = VLANDs(s) / ( VLANDs(s) + VLABORs(s) + VCAPITALs(s) + VOTHERs(s));
 Formula (all,s,SREG)                              SHRLABORs(s)
   = VLABORs(s) / ( VLANDs(s) + VLABORs(s) + VCAPITALs(s) + VOTHERs(s));
 Formula (all,s,SREG)                              SHRCAPITALs(s)
   = VCAPITALs(s) / ( VLANDs(s) + VLABORs(s) + VCAPITALs(s) + VOTHERs(s));
 Formula (all,s,SREG)                              SHROTHERs(s)
   = 1 - [SHRLANDs(s) + SHRLABORs(s) + SHRCAPITALs(s)];
```

```
   Equation E_VCROPs (all,s,SREG)                    p_VCROPs(s)
      = p_PCROPs(s) + p_QCROPs(s);
   Formula&Equation (levels) E_YIELDs (all,s,SREG)      YIELDs(s)
      = QCROPs(s) / QLANDs(s);

! ------ Endogenous Income Equation -------- !
Variable                                   slack_VLANDg;
Variable                                   slack_VLABORg;

   Equation E_INC_PC_VLAND (all,g,NRUREG)          p_INC_PC_VLAND(g)
      = p_VLANDg("Niger") + slack_VLANDg;

   Equation E_INC_PC_VLAB (all,g,NRUREG)           p_INC_PC_VLAB(g)
      = p_VLABORg("Niger") + slack_VLABORg;

!  *****************************************************************
   III.A.4  Variables Related to Technical Change in Crop Production
   *****************************************************************      !
Variable (levels) (all,s,SREG)                     AOCROPr(s)
   # Hicks-neutral eff. index in crop production #;
Variable (levels)                                  AOCROP
   # sub-comp. of Hicks-neutral eff. index: global #;
Variable (levels) (all,s,SREG)                     AOCROPs(s)
   # sub-comp. of Hicks-neutral eff. index: regional #;
Variable (levels) (all,s,SREG)                     AOCROPr_cc(s)
   # sub-comp. of Hicks-neutral eff. index: climate change #;
Variable (levels) (all,s,SREG)                     AFLANDr(s)
   # land-biased eff. index in crop production #;
Variable (levels)                                  AFLAND
   # sub-comp. of land-biased eff. index: global #;
Variable (levels) (all,s,SREG)                     AFLANDs(s)
   # sub-comp. of land-biased eff. index: regional #;
Variable (levels) (all,s,SREG)                     AFLABORr(s)
   # labor biased eff. index in crop production #;
Variable (levels)                                  AFLABOR
   # sub-comp. of labor biased eff. index: global #;
Variable (levels) (all,s,SREG)                     AFLABORs(s)
   # sub-comp. of labor biased eff. index: regional #;
Variable (levels) (all,s,SREG)                     AFCAPITALr(s)
   # capital biased eff. index in crop production #;
Variable (levels)                                  AFCAPITAL
   # sub-comp. of capital biased eff. index: global #;
Variable (levels) (all,s,SREG)                     AFCAPITALs(s)
   # sub-comp. of capital biased eff. index: regional #;
```

```
Variable (levels) (all,s,SREG)                AFOTHERr(s)
   # purchased inputs biased eff. index in crop production #;
Variable (levels)                             AFOTHER
   # sub-comp. of purchased inputs biased eff. index: global #;
Variable (levels) (all,s,SREG)                AFOTHERs(s)
   # sub-comp. of purchased inputs biased eff. index: regional #;

!   Formulas initializing values of tech. change variables          !
    Formula (initial)                 AOCROP       = 1;
    Formula (initial) (all,s,SREG)    AOCROPr(s)    = 1;
    Formula (initial) (all,s,SREG)    AOCROPs(s)    = 1;
    Formula (initial) (all,s,SREG)    AOCROPr_cc(s)  = 1;

    Formula (initial)                 AFLAND       = 1;
    Formula (initial) (all,s,SREG)    AFLANDs(s)    = 1;
    Formula (initial) (all,s,SREG)    AFLANDr(s)    = 1;

    Formula (initial)                 AFLABOR      = 1;
    Formula (initial) (all,s,SREG)    AFLABORs(s)   = 1;
    Formula (initial) (all,s,SREG)    AFLABORr(s)   = 1;

    Formula (initial)                 AFCAPITAL     = 1;
    Formula (initial) (all,s,SREG)    AFCAPITALs(s)  = 1;
    Formula (initial) (all,s,SREG)    AFCAPITALr(s)  = 1;

    Formula (initial)                 AFOTHER      = 1;
    Formula (initial) (all,s,SREG)    AFOTHERs(s)   = 1;
    Formula (initial) (all,s,SREG)    AFOTHERr(s)   = 1;

    Equation E_AOCROPs (all,s,SREG)              p_AOCROPs(s)
    = p_AOCROPr(s) + p_AOCROP + p_AOCROPr_cc(s);
    Equation E_AFLANDs (all,s,SREG)              p_AFLANDs(s)
    = p_AFLANDr(s) + p_AFLAND ;
    Equation E_AFLABORs (all,s,SREG)             p_AFLABORs(s)
    = p_AFLABORr(s) + p_AFLABOR ;
    Equation E_AFCAPITALs (all,s,SREG)           p_AFCAPITALs(s)
    = p_AFCAPITALr(s) + p_AFCAPITAL ;
    Equation E_AFOTHERs (all,s,SREG)             p_AFOTHERs(s)
    = p_AFOTHERr(s) + p_AFOTHER ;

!<  ************************************************************
   III.A.5  Key Equations on Land Demand/Supply & Crop Production
   ************************************************************      >!
!  *************************************************************
   Exogenous Shifters of Land Supply
   *************************************************************      !
```

```
Variable (all,s,SREG)                    p_QURBLANDs(s)
   # Supply shifter: land demand due to urbanization (in 1000s hectares) #;
Variable (all,s,SREG)                    p_QENVLANDs(s)
   # Supply shifter: land demand for envtl. services (in 1000s hectares) #;

!  III.A.5.X  Long Run Supply for Land
   -------------------------------------------------------------------  !
Equation E_PLANDs
   # determines the endogenous price of land in crop production #
   (all,S,SREG)
   p_QLANDs(s) = ELANDs(s) * p_PLANDs(s)
                       - p_QENVLANDs(s)
                       - p_QURBLANDs(s);

!  III.A.5.X  Long Run Supply for LABOR
   -------------------------------------------------------------------  !
Equation E_PLABORs
   # determines the endogenous price of labor in crop production #
   (all,S,SREG)
   p_QLABORs(s) = ELABORs(s) * p_PLABORs(s) + slack_LABs(s);

!  III.A.5.X  Long Run Supply for CAPITAL
   -------------------------------------------------------------------  !
Equation E_PCAPITALs
   # determines the endogenous price of capital in crop production #
   (all,S,SREG)
   p_QCAPITALs(s) = ECAPITALs(s) * p_PCAPITALs(s) + slack_CAPs(s);

!  III.A.5.X  Long Run Supply for OTHER
   -------------------------------------------------------------------  !
Equation E_POTHERs
   # determines the endogenous price of purchased inputs in crop production #
   (all,S,SREG)
   p_QOTHERs(s) = EOTHERs(s) * p_POTHERs(s);

!  III.A.5.X  Long Run Derived Demand Equation for Land
   -------------------------------------------------------------------  !
Equation E_QLANDs
   # determines the endogenous use of croplands #
   (all,s,SREG)
   p_QLANDs(s) + p_AFLANDs(s)  =  p_QCROPs(s) - p_AOCROPs(s)
    - ECROPs(s) * [p_PLANDs(s) - p_AFLANDs(s) - p_PCROPs(s) - p_AOCROPs(s)];

!  III.A.5.X  Long Run Derived Demand Equation for labor
   -------------------------------------------------------------------  !
Equation E_QLABORs
```

```
   # determines the endogenous use of labor #
   (all,s,SREG)
   p_QLABORs(s) + p_AFLABORs(s)  =  p_QCROPs(s) - p_AOCROPs(s)
    - ECROPs(s) * [p_PLABORs(s) - p_AFLABORs(s) - p_PCROPs(s) - p_AOCROPs(s)];

!  III.A.5.X  Long Run Derived Demand Equation for capital
   -------------------------------------------------------------------  !
Equation E_QCAPITALs
   # determines the endogenous use of capital #
   (all,s,SREG)
   p_QCAPITALs(s) + p_AFCAPITALs(s)  =  p_QCROPs(s) - p_AOCROPs(s)
    - ECROPs(s) * [p_PCAPITALs(s) - p_AFCAPITALs(s) - p_PCROPs(s) - p_AOCROPs(s)];

!  III.A.5.X  Long Run Derived Demand Equation for OTHER
   -------------------------------------------------------------------  !
Equation E_QOTHERs
   # determines the endogenous use of purchased inputs #
   (all,s,SREG)
   p_QOTHERs(s) + p_AFOTHERs(s)  =  p_QCROPs(s) - p_AOCROPs(s)
    - ECROPs(s) * [p_POTHERs(s) - p_AFOTHERs(s) - p_PCROPs(s) - p_AOCROPs(s)];

!  III.A.5.X  Zero Profit Condition for Crop Producers
   -------------------------------------------------------------------  !
Equation E_QCROPs
   # determines the endogenous output of ag. commodites #
   (all,s,SREG)
   p_PCROPs(s) + p_AOCROPs(s) =
              [SHRLANDs(s)] * [p_PLANDs(s) - p_AFLANDs(s)] +
              [SHRLABORs(s)] * [p_PLABORs(s) - p_AFLABORs(s)] +
              [SHRCAPITALs(s)] * [p_PCAPITALs(s) - p_AFCAPITALs(s)] +
              [SHROTHERs(s)] * [p_POTHERs(s) - p_AFOTHERs(s)];

!  III.A.5.X  Price linkages for Crop Producers
   -------------------------------------------------------------------  !
Equation E_PCROPs
   # determines the endogenous output of ag. commodites #
   (all,s,SREG)
   p_PCROPs(s) = p_PCROPg(MP_SREG(s));

![[! End of Edits !]]!
!<  -------------------------------------------------------------------
   III.B. GLOBAL MARKET CLEARING EQUATIONS FOR CROPS
  -------------------------------------------------------------------    >!
Set MKT # set of crop markets (local, global) #
          read elements from file LANDSETS header "MKT";
```

```
Coefficient (parameter)
    (all,g,REG)                                  ESUBg(g)
    # substitution elasticity between local and global crops #;
     Read ESUBg   from file LANDPARM header "ESUB";

Coefficient (parameter)
    (all,g,REG)                                  ETRANSg(g)
    # transformation elasticity between local and global crops #;
     Read ETRANSg   from file LANDPARM header "ETRA";

Variable (levels) (all,g,REG) (all,i,FOOD_COMM) (all,m,MKT)     QDCROPg(g,i,m)
    # regional crop demand by use and by source #;
     Read QDCROPg   from file LANDDATA header "QDCP";

Variable (levels) (all,g,REG) (all,m,MKT)                  QSCROPg(g,m)
    # regional crop supply and by source #;
     Read QSCROPg   from file LANDDATA header "QSCP";

Variable (all,g,REG)                               p_PCROP_loc(g)
   # "local" crop prices #;

Equation E_QCONS_CRP_LOC
   # derived demand for local crops for direct consumption #
   (all,g,REG)
   p_QDCROPg(g,"Crops","local") =
       p_QCONS("Crops",g) - ESUBg(g) * [p_PCROP_loc(g) - p_P("Crops",g)] ;

Equation E_QCONS_CRP_GLB
   # derived demand for global crops for direct consumption #
   (all,g,REG)
   p_QDCROPg(g,"Crops","global") =
       p_QCONS("Crops",g) - ESUBg(g) * [p_PCROP - p_P("Crops",g)] ;

Equation E_QCRPFEED_LOC
   # derived demand for local crops for feed use #
   (all,g,REG)
   p_QDCROPg(g,"Livestock","local") =
       p_QCRPFEED(g) - ESUBg(g) * [p_PCROP_loc(g) - p_P("Crops",g)] ;

Equation E_QCRPFEED_GLB
   # derived demand for global crops for feed use #
   (all,g,REG)
   p_QDCROPg(g,"Livestock","global") =
       p_QCRPFEED(g) - ESUBg(g) * [p_PCROP - p_P("Crops",g)] ;

Equation E_QCRPFOOD_LOC
```

```
   # derived demand for local crops for use in the proc. food sector #
   (all,g,REG)
   p_QDCROPg(g,"Proc_Food","local") =
       p_QCRPFOOD(g) - ESUBg(g) * [p_PCROP_loc(g) - p_P("Crops",g)] ;

Equation E_QCRPFOOD_GLB
   # derived demand for global crops for use in the proc. food sector #
   (all,g,REG)
   p_QDCROPg(g,"Proc_Food","global") =
       p_QCRPFOOD(g) - ESUBg(g) * [p_PCROP - p_P("Crops",g)] ;

! Composite price for demanded crops from the local and global markets !

![[! Purchase shares between local and global for all crop use are
        the same so there is only one composite price equation for each
        region !]]!

Coefficient  (all,g,REG) (all,m,MKT)                    SHRQDCROPg(g,m)
   # share of crop demand by source #;
   Formula (all,g,REG) (all,m,MKT)                      SHRQDCROPg(g,m)
   = sum(i, FOOD_COMM, QDCROPg(g,i,m)) /
           sum(j, FOOD_COMM, sum(k, MKT, QDCROPg(g,j,k)));

Equation E_P
  # regional crop price faced by consumers: mix of local & global prices  #
   (all,g,REG)
   p_P("Crops",g) =
        SHRQDCROPg(g,"local")  * p_PCROP_loc(g)  +
        SHRQDCROPg(g,"global") * p_PCROP ;

! Here are the crop supply functions for local and global via CET !

![[! Same as above. Producer price as the composite price for crops supplied
       locally and globally                              !]]!

Equation E_QSCROP_LOC
   # supply of crops in the local market #
   (all,g,REG)
     p_QSCROPg(g,"local") = p_QCROPg(g)
           + ETRANSg(g) * [p_PCROP_loc(g) - p_PCROPg(g)] ;

Equation E_QSCROP_GLB
   # supply of crops in the global market #
   (all,g,REG)
       p_QSCROPg(g,"global") = p_QCROPg(g)
           + ETRANSg(g) * [p_PCROP - p_PCROPg(g)] ;
```

```
Coefficient (all,g,REG) (all,m,MKT)                    SHRQSCROPg(g,m)
   # share of crop supply by source #;
   Formula (all,g,REG) (all,m,MKT)                     SHRQSCROPg(g,m)
   = QSCROPg(g,m) / sum(k, MKT, QSCROPg(g,k));

Equation E_PCROPg
   # regional crop price faced by producers: mix of local & global  #
   (all,g,REG)
   p_PCROPg(g) =
        SHRQSCROPg(g,"local")  * p_PCROP_loc(g)  +
        SHRQSCROPg(g,"global") * p_PCROP ;

! Regional market clearing condition determines
     crop prices faced by producers !
Equation (levels) E_PCROP_loc
   # local crop demand and supply balance #
   (all,g,REG)
    QSCROPg(g,"local")
        = sum(i, FOOD_COMM, QDCROPg(g,i,"local"));

! Global market clearing condition determines
     the global crop price !
Equation (levels) E_PCROP
   # crop demand and supply balance in the global market #
   sum(g, REG, QSCROPg(g,"global")) =
   sum(i, FOOD_COMM, sum(g, REG, QDCROPg(g,i,"global"))) + QCRPBIOF;

! Average consumer prices (This should replace p_PCROP) when reporting
        global changes !
Variable (levels)                              PCROP_QS
    # global average producer crop price #;
   Formula&Equation (levels) E_PCROP_QS
   PCROP_QS = sum(g, REG, VCROPg(g))/sum(g, REG, QCROPg(g));

Variable (levels)                              PCROP_QD
    # global average consumer crop price #;
   Formula&Equation (levels) E_PCROP_QD
   PCROP_QD = sum(g, REG, VCONS("Crops",g))/sum(g, REG, QCONS("Crops",g));

! Net trade flow in regional crop markets !
Variable (levels) (all,g,REG)                           QCRPTRADEg(g)
    # regional crop trade balance exports less imports #;
   Formula&Equation (levels) E_QCRPTRADEg
   (all,g,REG)
   QCRPTRADEg(g) =  QSCROPg(g,"global")  -
```

```
            sum(i, FOOD_COMM, QDCROPg(g,i,"global"))
       + 0.0000001 ; ! need to add small number to prevent singularity !

!<  ------------------------------------------------------------------
   III.C  LIVESTOCK & PROCESSED FOOD PRODUCTION
  ------------------------------------------------------------------   >!
!<  **************************************************************
   III.C.1  Coeff. & Var. Related to Livestock & Proc. Food Prod.
   **************************************************************      >!
!        Prices and quantities of non-crop inputs                    !
Variable (levels) (all,g,REG)                  QNCRPFEED(g)
   # quantity of non-feed inputs used in livestock production #
   ! (in M USD $2005) ! ;
Variable (levels) (all,g,REG)                  QNCRPFOOD(g)
   # quant. of non-crop inputs used in processed food production #
   ! (in M USD $2005) !;
Variable (levels) (all,g,REG)                  PNCRPFEED(g)
   # price index of non-feed inputs (1=Y2005) #;
Variable (levels) (all,g,REG)                  PNCRPFOOD(g)
   # price index of non-crop inputs used in proc. food prod. (1=Y2005) #;

!        Elasticities of substitution                    !
Coefficient (Parameter)                         ECRPFEED
   # global elasticity of subs. in prod. of livestock #;
Coefficient (Parameter)                         ECRPFOOD
   # global elasticity of subs. in prod. of proc. foods #;

!        Cost Shares                              !
Coefficient (all,g,REG)                        SHRCRPFEED(g)
   # cost share of feed inputs in the livestock industry #;
Coefficient (all,g,REG)                        SHRNCRPFEED(g)
   # cost share of non-feed inputs in the livestock industry #;
Coefficient (all,g,REG)                        SHRCRPFOOD(g)
   # cost share of crop inputs in the processed food industry #;
Coefficient (all,g,REG)                        SHRNCRPFOOD(g)
   # cost share of non-crop inputs in the processed food industry #;

   Read PNCRPFEED   from file LANDDATA header "PNF";
      PNCRPFOOD   from file LANDDATA header "PNPR";
      ECRPFEED    from file LANDPARM header "EFED";
      ECRPFOOD    from file LANDPARM header "EFOD";

!        Formulas for calculating QNCRPFEED & QNCRPFOOD                !
    Formula (initial) (all,g,REG)               QNCRPFEED(g)
      = VCONS("Livestock",g) - QCRPFEED(g) * P("Crops",g) ;
    Formula (initial) (all,g,REG)               QNCRPFOOD(g)
```

```
      = VCONS("Proc_Food",g) - QCRPFOOD(g) * P("Crops",g) ;

!       Formulas for calculating SHRNCRPFEED,
              SHRNCRPFOOD & SHRCRPFEED, SHRCRPFOOD                    !
   Formula (all,g,REG)                         SHRCRPFEED(g)
      =  QCRPFEED(g) * P("Crops",g) / VCONS("Livestock",g);
   Formula (all,g,REG)                         SHRNCRPFEED(g)
      = 1 - SHRCRPFEED(g) ;
   Formula (all,g,REG)                         SHRCRPFOOD(g)
      =  QCRPFOOD(g) * P("Crops",g) / VCONS("Proc_Food",g);
   Formula (all,g,REG)                         SHRNCRPFOOD(g)
      = 1 - SHRCRPFOOD(g) ;

!<  *************************************************************
  III.C.2  Var. Related to Tech. Chg. in Lvstck & Proc. Food Prod.
  *************************************************************      >!
Variable (levels) (all,g,REG)                    AFCRPFEED(g)
  # feed eff. index #;
Variable (levels)                            AFCRPFEEDW
  # sub-comp. of the feed eff. index: global #;
Variable (levels) (all,g,REG)                    AFCRPFEEDr(g)
  # sub-comp. of the feed eff. index: regional #;

Variable (levels) (all,g,REG)                    AFNCRPFEED(g)
  # non-feed eff. index #;
Variable (levels)                            AFNCRPFEEDW
  # sub-comp. of the non-feed eff. index: global #;
Variable (levels) (all,g,REG)                    AFNCRPFEEDr(g)
  # sub-comp. of the non-feed eff. index: regional #;

Variable (levels) (all,g,REG)                    AFCRPFOOD(g)
  # eff. index of crops in proc. food prod. #;
Variable (levels)                            AFCRPFOODW
  # sub-comp. of crops in proc. food prod. index: global #;
Variable (levels) (all,g,REG)                    AFCRPFOODr(g)
  # sub-comp. of crops in proc. food prod. index: regional #;

Variable (levels) (all,g,REG)                    AFNCRPFOOD(g)
  # eff. index of non-crop inputs in proc. food prod.#;
Variable (levels)                            AFNCRPFOODW
  # sub-comp. of the non-crop eff. index: global #;
Variable (levels) (all,g,REG)                    AFNCRPFOODr(g)
  # sub-comp. of the non-crop eff. index: regional #;

Variable (levels) (all,g,REG)                    AOCRPFEED(g)
  # hicks-neutral eff. index in livestock prod. #;
```

```
Variable (levels) (all,g,REG)                    AOCRPFOOD(g)
   # hicks-neutral eff. index in proc. food prod. #;

!        Formulas initializing values of tech. change variables           !
    Formula (initial) (all,g,REG)    AOCRPFEED(g)   = 1;
    Formula (initial) (all,g,REG)    AOCRPFOOD(g)   = 1;
    Formula (initial) (all,g,REG)    AFCRPFEED(g)   = 1;
    Formula (initial) (all,g,REG)    AFCRPFOOD(g)   = 1;
    Formula (initial) (all,g,REG)    AFNCRPFEED(g)  = 1;
    Formula (initial) (all,g,REG)    AFNCRPFOOD(g)  = 1;
    Formula (initial)             AFCRPFEEDW     = 1;
    Formula (initial)             AFCRPFOODW     = 1;
    Formula (initial)             AFNCRPFEEDW    = 1;
    Formula (initial)             AFNCRPFOODW    = 1;
    Formula (initial) (all,g,REG)    AFCRPFEEDr(g)  = 1;
    Formula (initial) (all,g,REG)    AFCRPFOODr(g)  = 1;
    Formula (initial) (all,g,REG)    AFNCRPFEEDr(g) = 1;
    Formula (initial) (all,g,REG)    AFNCRPFOODr(g) = 1;

    Equation E_AFNCRPFEED (all,g,REG)                p_AFNCRPFEED(g)
      = p_AFNCRPFEEDW + p_AFNCRPFEEDr(g);
    Equation E_AFNCRPFOOD (all,g,REG)                p_AFNCRPFOOD(g)
      = p_AFNCRPFOODW + p_AFNCRPFOODr(g);
    Equation E_AFCRPFEED (all,g,REG)                 p_AFCRPFEED(g)
      = p_AFCRPFEEDW  + p_AFCRPFEEDr(g);
    Equation E_AFCRPFOOD (all,g,REG)                 p_AFCRPFOOD(g)
      = p_AFCRPFOODW  + p_AFCRPFOODr(g);

!< ***************************************************************
   III.C.3  Key Equations in Livestock & Proc. Food Production
   ***************************************************************      >!

!  III.C.3.1  Long Run Derived Demand for Feed inputs
   ------------------------------------------------------------------    !
Equation E_QCRPFEED
   # determines the endogenous use of feed in livestock production #
   (all,g,REG)
   p_QCRPFEED(g) + p_AFCRPFEED(g) =
      p_QCONS("Livestock",g) - p_AOCRPFEED(g)
      - ECRPFEED * [p_P("Crops",g) - p_AFCRPFEED(g)
      - p_P("Livestock",g) - p_AOCRPFEED(g)];

!  III.C.3.2  Long Run Derived Demand for Nonfeed Inputs
   ------------------------------------------------------------------    !
Equation E_QNCRPFEED
   # determines the endogenous use of nonfeed in livestock production #
```

```
   (all,g,REG)
   p_QNCRPFEED(g) + p_AFNCRPFEED(g) =
    p_QCONS("Livestock",g) - p_AOCRPFEED(g)
     - ECRPFEED * [p_PNCRPFEED(g) - p_AFNCRPFEED(g)
     - p_P("Livestock",g) - p_AOCRPFEED(g)];

!  III.C.3.3  Long Run Derived Demand for Crop inputs in Proc. Food
   -------------------------------------------------------------------    !
Equation E_QCRPFOOD
   # determines the endogenous use of crop inputs in proc. food #
   (all,g,REG)
   p_QCRPFOOD(g) + p_AFCRPFOOD(g)  =
      p_QCONS("Proc_Food",g) - p_AOCRPFOOD(g)
       - ECRPFOOD * [p_P("Crops",g) - p_AFCRPFOOD(g)
       - p_P("Proc_Food",g) - p_AOCRPFOOD(g)];

!  III.C.3.4  Long Run Derived Demand for Noncrop inputs used in Proc. Food
   -------------------------------------------------------------------    !
Equation E_QNCRPFOOD
   # determines the endogenous use of non-crop inputs in proc. food #
   (all,g,REG)
   p_QNCRPFOOD(g) + p_AFNCRPFOOD(g)  =
    p_QCONS("Proc_Food",g) - p_AOCRPFOOD(g)
     - ECRPFOOD * [p_PNCRPFOOD(g) - p_AFNCRPFOOD(g)
     - p_P("Proc_Food",g) - p_AOCRPFOOD(g)];

!  III.C.3.5  Zero Profit Condition for Livestock Producers
   -------------------------------------------------------------------    !
Equation E_QCONS_LIVESTOCK
   # determines the endogenous output of ag. commodites #
   (all,g,REG)
    p_P("Livestock",g) + p_AOCRPFEED(g) =
           [SHRCRPFEED(g)] * [p_P("Crops",g) - p_AFCRPFEED(g)] +
           [SHRNCRPFEED(g)] * [p_PNCRPFEED(g) - p_AFNCRPFEED(g)];

!  III.C.3.6  Zero Profit Condition for Processed Foods Producers
   -------------------------------------------------------------------    !
Equation E_QCONS_PRCFOOD
   # determines the endogenous output of ag. commodites #
   (all,g,REG)
   p_P("Proc_Food",g) + p_AOCRPFOOD(g) =
             [SHRCRPFOOD(g)] * [p_P("Crops",g) - p_AFCRPFOOD(g)] +
            [SHRNCRPFOOD(g)] * [p_PNCRPFOOD(g) - p_AFNCRPFOOD(g)];

!  Option to endo. tech chg. in lvstck & proc. food (for advanced users)
   -------------------------------------------------------------------    !
```

```
!<  In order to target commodity price from the demand side, we can swap
    crpfeedslack with p_AFCRPFEED and similarly for food, then acrpuse
    becomes an instrument for targeting price.                       >!

  Equation E_AFCRPFEED_slack
   # endogenizes tech change in the livestock industry #
   (all,g,REG)                              p_AFCRPFEED(g)
   = slack_acrpuse + slack_crpfeed(g) ;

  Equation E_AFCRPFOOD_slack
   # endogenizes tech change in the processed food industry #
   (all,g,REG)                              p_AFCRPFOOD(g)
   = slack_acrpuse + slack_crpfood(g) ;

!<
==================================================================
==============
     V. APPPENDICIES

==================================================================
============== >!

!<  ***********************************
    Appendix A. Data checks in the model
    ***********************************                                >!
Coefficient                                  QCROPCHK
  # Clearing of crop demand & supply - should be near 0 #;
  Formula                                    QCROPCHK
  = - sum(g, REG, QCROPg(g)) +  sum(g,REG, QCRPFEED(g)
              + QCRPFOOD(g) + QCONS("Crops",g)) + QCRPBIOF;
Coefficient (all,s,SREG)                      VCROPCHK(s)
   # Zero profit condition for crop sector - should be near 0 #;
   Formula (all,s,SREG)                       VCROPCHK(s)
   = VCROPs(s) - [VLANDs(s) + VLABORs(s) + VCAPITALs(s) + VOTHERs(s)];
Coefficient (all,g,REG)                       VLVSTCKCHK(g)
   # Zero profit condition for livestock sector - should be near 0 #;
   Formula (all,g,REG)                        VLVSTCKCHK(g)
   = VCONS("Livestock",g)
     - [QCRPFEED(g) * P("Crops",g) + QNCRPFEED(g) * PNCRPFEED(g)];
Coefficient (all,g,REG)                       VPRCFCHK(g)
   # Zero profit condition for proc. food sector - should be near 0 #;
   Formula (all,g,REG)                        VPRCFCHK(g)
   = VCONS("Proc_Food",g)
    - [QCRPFOOD(g) * P("Crops",g) + QNCRPFOOD(g) * PNCRPFOOD(g)];

!<  ******************************
```

```
   Appendix B. Summary Statistics
   *****************************                                  >!
![[! Edits !]]!
!          Index of TFP                              !
Variable (levels) (all,s,SREG)                     TFP_CROP(s)
   # TFP for crop sector (regional) #;
   Formula&Equation (levels) E_TFP_CROP (all,s,SREG)    TFP_CROP(s)
   = AOCROPs(s) * [({VLANDs(s)}/ {VCROPs(s)}) * AFLANDs(s) +
             ({VLABORs(s)}/ {VCROPs(s)}) * AFLABORs(s) +
             ({VCAPITALs(s)}/ {VCROPs(s)}) * AFCAPITALs(s) +
             ({VOTHERs(s)}/ {VCROPs(s)}) * AFOTHERs(s)];

Variable (levels)                                 TFP_CROPW
   # TFP for crop sector (global) #;
   Formula&Equation (levels) E_TFP_CROPW                TFP_CROPW
   = sum(s, SREG, [VCROPs(s)/sum(y, SREG, VCROPs(y))]
       * TFP_CROP(s));

Variable (levels) (all,g,REG)                      TFP_LVSTOCK(g)
   # TFP for livestock sectors (regional) #;
   Formula&Equation (levels) E_TFP_LVSTOCK (all,g,REG) TFP_LVSTOCK(g)
   = AOCRPFEED(g) * [({P("Crops",g) * QCRPFEED(g)}
    /{VCONS("livestock",g)}) * AFCRPFEED(g) + ({PNCRPFEED(g)
    * QNCRPFEED(g)}/{VCONS("livestock",g)}) * AFNCRPFEED(g)];

Variable (levels) (all,g,REG)                      TFP_PROC_FD(g)
   # TFP for proc. food sectors (regional) #;
   Formula&Equation (levels) E_TFP_PROC_FD (all,g,REG) TFP_PROC_FD(g)
   = AOCRPFOOD(g) * [({P("Crops",g) * QCRPFOOD(g)}/
      {VCONS("proc_food",g)}) * AFCRPFOOD(g) + ({PNCRPFOOD(g)
      * QNCRPFOOD(g)}/{VCONS("proc_food",g)}) * AFNCRPFOOD(g)];

Variable (levels)                                 TFP_LVSTOCKW
   # TFP for livestock sectors (global) #;
   Formula&Equation (levels) E_TFP_LVSTOCKW             TFP_LVSTOCKW
   = sum(g, REG, [VCONS("livestock",g)
        /sum(k, REG, VCONS("livestock",k))]
        * TFP_LVSTOCK(g));

Variable (levels)                                 TFP_PROC_FDW
   # TFP for proc. food sectors (global) #;
   Formula&Equation (levels) E_TFP_PROC_FDW             TFP_PROC_FDW
   = sum(g, REG, [VCONS("Proc_Food",g)
        /sum(k, REG, VCONS("Proc_Food",k))]
        * TFP_PROC_FD(g));
```

Variable (**levels**) YIELDW
 # crop yields (global) #;
Formula&**Equation** (**levels**) E_YIELDW YIELDW
= **sum**(s, SREG, QCROPs(s))/**sum**(s,SREG, QLANDs(s));

Variable (**levels**) QLANDW
 # cropland use (global) #;
Formula&**Equation** (**levels**) E_QLANDW QLANDW
= **sum**(s, SREG, QLANDs(s));

Variable (**levels**) VLANDW
 # value of cropland use (global) #;
Formula&**Equation** (**levels**) E_VLANDW VLANDW
= **sum**(s, SREG, VLANDs(s));

Variable (**levels**) PLANDW
 # land rent (global) #;
Formula&**Equation** (**levels**) E_PLANDW PLANDW
= **sum**(s, SREG, VLANDs(s))/**sum**(s, SREG, QLANDs(s));

Variable (**levels**) QCROPW
 # crop production (global) #;
Formula&**Equation** (**levels**) E_QCROPW QCROPW
= **sum**(s, SREG, QCROPs(s));

Variable (**levels**) VCROPW
 # value of crop production (global) #;
Formula&**Equation** (**levels**) E_VCROPW VCROPW
= **sum**(s, SREG, VCROPs(s));

Variable (**levels**) (**all**,i,CONS_COMM) QCONSW(i)
 # Comm. consumption (global) #;
Formula&**Equation** (**levels**) E_QCONSW (**all**,i,CONS_COMM) QCONSW(i)
= **sum**(g, REG, QCONS(i,g));

Variable (**levels**) QCRPFEEDW
 # Feed use (global) #;
Formula&**Equation** (**levels**) E_QCRPFEEDW QCRPFEEDW
= **sum**(g, REG, QCRPFEED(g));

Variable (**levels**) QNCRPFEEDW
 # Nonfeed use (global) #;
Formula&**Equation** (**levels**) E_QNCRPFEEDW QNCRPFEEDW
= **sum**(g,REG, QNCRPFEED(g));

Variable (**levels**) QCRPFOODW

```
   # Crop input use in proc. food. sector (global) #;
Formula&Equation (levels) E_QCRPFOODW                    QCRPFOODW
   = sum(g,REG, QCRPFOOD(g));

Variable (levels)                               QCRPCONSW
   # Direct Food Use (global) #;
   Formula&Equation (levels) E_QCRPCONSW                 QCRPCONSW
   = sum(g, REG, QCONS("Crops",g));

Variable (levels)                               QNCRPFOODW
   # Noncrop input use in proc. food. sector (global) #;
Formula&Equation (levels) E_QNCRPFOODW                    QNCRPFOODW
  = sum(g,REG, QNCRPFOOD(g));

!<  *****************************************************************
   MODULE   IV. Food Security Module
   *****************************************************************   >!
!   This module captures the changes in per capita caloric consumption and
   caloric distribution. Specifically, this module is divided in ff parts:
   1) Westernization of diets
       regression of per capita incomes and nutrient content of food
   2) Changes in food security measures
       growth elasticity approach, assumes that per capita caloric
       consumption fits the log-normal distribution.
   3) Summary variables at global level

   Data on calories consumption are taken from FAO ESS Food
   Security Data. Data on distributional parameters are taken from
   2010 FAO Statistical Yearbook while key equations on elasticities of
   malnutrition and malnutrition gaps are taken from Bourguinon (2003)
   "The Growth Elasticity of Poverty Reduction:
   Explaining Heterogeneity across Countries and Time Periods".          !

!-------------------------------------------------------------------------!
!   PART 1. WESTERNIZATION OF DIETS                                 !
!-------------------------------------------------------------------------!
!   Define developing regions, these will be the focus of this module       !
Set OECDREG # OECD regions: excluded in the food sec module #
         (S_Afr,AUS_NZ,EU,CAN,US,JPN_KR);
Subset OECDREG is subset of DREG;
Set LDREG # Least developing regions #
         = DREG - OECDREG;

!   Parameters which influence nutrient content of commodities
   -------------------------------------------------------              !
Coefficient (parameter) (all,i,FOOD_COMM) (all,k,COEF)      ECAL(i,k)
```

```
   # regression estimates of comm. caloric content and per capita incomes #;
   read ECAL      from file LANDPARM header "ECAL";

!  Variables which are included in Sub-module 1)
   ---------------------------------------------------                    !
Variable (levels) (all,i,FOOD_COMM)(all,g,DREG)         CAL_COMMd(i,g)
   # Caloric content of commodity i consumed in region y #
   ! (in kilocalories per gram) !;
   read CAL_COMMd     from file LANDDATA header "CALD" ;

Variable (levels) (all,i,FOOD_COMM)(all,g,DREG)       tmp_CAL_COMM(i,g)
   # Predicted caloric content of commodity (% chg. is linked to CAL_COMM) #
   ! (in kilocalories per gram) !;

Variable (levels) (all,i,FOOD_COMM)(all,g,DREG)         slack_cal(i,g)
   # slack variable to prevent changes in tmp_cal_comm #;

!  Initialize values but make them very small !
   Formula
   (initial)(all,i,FOOD_COMM)(all,g,DREG)    slack_cal(i,g) = 0.0000001;

!  Equations used to predict nutrient content given chg. in per cap. inc.
   ----------------------------------------------------------------------!
Formula & Equation E_tmp_CAL_COMM
   (all,i,FOOD_COMM)(all,g,DREG)                      tmp_CAL_COMM(i,g)
   = ECAL(i,"INT") + ECAL(i,"SLP") * loge(INC_PCd(g))
     + slack_cal(i,g);

!  Link between % chg. in predicted nutrient content to
   % chg. in actual nutrient content
   ----------------------------------------------------------------------!
   Equation E_CAL_COMM  (all,i,FOOD_COMM)(all,g,DREG)
   p_CAL_COMMd(i,g) = p_tmp_CAL_COMM(i,g);

!------------------------------------------------------------------------!
!  PART 2. CHANGING FOOD SECURITY MEASURES: GROWTH ELASTICITY
APPROACH     !
!------------------------------------------------------------------------!
!  Parameters which influence caloric distribution
   ---------------------------------------------------                   !
Coefficient (parameter) (all,g,DREG)                SDEV_CALd(g)
   ! standard deviation of log normal distribution
     of per capita caloric consumption               !;
   read SDEV_CALd      from file LANDPARM header "SDVD";

!  Variables which influence caloric consumption and distribution
```

```
   -----------------------------------------------------------          !
Variable (levels) (all,k,FOOD_COMM)(all,g,DREG)         QCONS_GRAMd(k,g)
   # food consumption (in grams per capita per day) # ;
Variable (levels) (all,g,DREG)                     MAL_INDEXd(g)
   # malnutrition index (% of population below the min. caloric cons.) #;
Variable (levels) (all,g,DREG)                     MAL_GAP_INDd(g)
   # malnutrition gap index: (% of min. caloric consumption) #;
Variable (levels) (all,g,DREG)                     MAL_GAPd(g)
   # malnutrition gap: ave. cal. deficit of the malnourished (kcal/cap/day) #;
Variable (levels) (all,g,DREG)                     MAL_COUNTd(g)
   # malnutrition count (in M persons) - income region #;
Variable (levels) (all,g,DREG)                     CALORIC_GAPd(g)
   # total caloric deficit (kcal/day) - regional #;
Variable (levels) (all,g,DREG)                       MIN_CALd(g)
   # minimum caloric consumption per capita in region y #
   ! (in kilocalories per day) !;
  read  MIN_CALd      from file LANDDATA header "MCLD";
      QCONS_GRAMd   from file LANDDATA header "COND";
      MAL_INDEXd    from file LANDDATA header "MIXD";
      MAL_GAP_INDd  from file LANDDATA header "MGID";

   Formula & Equation E_MAL_COUNT (all,g,DREG)           MAL_COUNTd(g)
   = MAL_INDEXd(g) * POPd(g)/100;
   Formula & Equation E_MAL_GAP (all,g,DREG)             MAL_GAPd(g)
   = [MAL_GAP_INDd(g)/100] * MIN_CALd(g) / [MAL_INDEXd(g)/100];
   Formula & Equation E_CALORIC_GAP (all,g,DREG)         CALORIC_GAPd(g)
   = MAL_GAPd(g) * MAL_COUNTd(g);

Variable (levels) (all,k,FOOD_COMM)(all,g,DREG)          QPC_GRAMd(k,g)
   # grams per capita per day of commodity k consumed in region g # ;
   Formula (initial) (all,k,FOOD_COMM)(all,g,DREG)       QPC_GRAMd(k,g)
   = QCONS_GRAMd(k,g) / POPd(g);

Variable (levels) (all,k,FOOD_COMM)                      QPC_GRAMW(k)
  # grams per capita per day of commodity k consumed: global #;
   Formula & Equation E_QPC_GRAMW (all,k,FOOD_COMM)       QPC_GRAMW(k)
   = sum(g, DREG, QCONS_GRAMd(k,g)) / sum(g, DREG, POPd(g));

Variable (levels) (all,k,FOOD_COMM)(all,g,DREG)          QPC_CALd(k,g)
   # kcal per capita per day of commodity k consumed in region g # ;
   Formula & Equation E_QPC_CAL (all,k,FOOD_COMM)
                        (all,g,DREG)             QPC_CALd(k,g)
   = CAL_COMMd(k,g) * QPC_GRAMd(k,g);

Variable (levels) (all,k,FOOD_COMM)                      QPC_CALW(k)
  # kcal per capita per day of commodity k consumed: global #;
```

```
   Formula & Equation E_QPC_CALW (all,k,FOOD_COMM)        QPC_CALW(k)
   = sum(j, DREG, QPC_CALd(k,j) * POPd(j)) / sum(g, DREG, POPd(g));

Variable (levels) (all,g,DREG)                          CALORIES(g)
   # total caloric consumption per capita in region y (kcal/cap/day) #;
   Formula & Equation (levels) E_CALORIES
   (all,g,DREG)                                    CALORIES(g)
    = sum{k, FOOD_COMM, CAL_COMMd(k,g) * QPC_GRAMd(k,g)};

!   Equations linking results from SIMPLE to Food Security Module
   -------------------------------------------------------------          !
Equation E_QCONS_GRAM
   # grams per day of commodity k consumed in region y #
   (all,k,FOOD_COMM)(all,g,DREG)                   p_QCONS_GRAMd(k,g)
   = p_QPC_GRAMd(k,g) + p_POPd(g);
Equation E_QPC_GRAMS
   # linkage between calorie supply to per capita consumption #
   (all,i,FOOD_COMM)(all,g,DREG)                  p_QPC_GRAMd(i,g)
   = p_QPCd(i,g) ;

!   Elasticities of malnutrition count & malnutrition gap
   ----------------------------------------------------                !
Coefficient (all,g,DREG)                          MIN_RATIO(g)
   # ratio of minimum caloric intake and per capita caloric intake #;
   Formula (all,g,DREG)                          MIN_RATIO(g)
   = MIN_CALd(g)/CALORIES(g);

Coefficient (all,g,DREG)                          FACTOR_1(g)
   ! The expression inside the hazard rate - i.e. ratio of density &
     cumulative function of the standard normal distribution
     (see Eq. 3, pp 12 in Bourguinon (2003)). This also appears in the
     elasticity of malnutrition gap (denominator in Eq. 4, pp 14) !;
   Formula (all,g,DREG)                          FACTOR_1(g)
   = LOGE{MIN_RATIO(g)}/SDEV_CALd(g) + [SDEV_CALd(g)/2] ;

Coefficient (all,g,DREG)                          FACTOR_2(g)
   ! The expression in the numerator in Eq. 4, pp 14 in Bourguinon (2003)
     This also appears in the denominator !;
   Formula (all,g,DREG)                          FACTOR_2(g)
   = LOGE{MIN_RATIO(g)}/SDEV_CALd(g) - [SDEV_CALd(g)/2];

Coefficient (all,g,DREG)                          EM_INDEX(g)
   # elasticity of malnutrition index #;
   ! see Eq. 3, pp 12 in Bourguinon (2003) !
   Formula (all,g,DREG)                          EM_INDEX(g)
   = [1/SDEV_CALd(g)] * [NORMAL(FACTOR_1(g))/CUMNORMAL(FACTOR_1(g))];
```

```
Coefficient (all,g,DREG)                              EM_GAP(g)
   # Elasticity of malnutrition gap index#;
   ! see Eq. 4, pp 14 in Bourguinon (2003). The negative sign in the orig
     equation is added in the E_MAL_GAP and E_MAL_GAPW !
   Formula (all,g,DREG)                               EM_GAP(g)
   = CUMNORMAL(FACTOR_2(g)) /
     [MIN_RATIO(g) * CUMNORMAL(FACTOR_1(g)) - CUMNORMAL(FACTOR_2(g)) ];

!   Equations used to track changes in malnutrition count and gap
   ------------------------------------------------------------          !
Equation E_MAL_INDEX # change in malnutrition index #
   (all,g,LDREG) p_MAL_INDEXd(g) = - EM_INDEX(g) * p_CALORIES(g);

Equation E_MAL_GAP_IND # change in malnutrition gap index #
   (all,g,LDREG) p_MAL_GAP_INDd(g)   = - EM_GAP(g) * p_CALORIES(g);

Equation E_MAL_INDEX_OECD # change in malnutrition index #
   (all,g,OECDREG) p_MAL_INDEXd(g) = 0;

Equation E_MAL_GAP_IND_OECD # change in malnutrition gap index #
   (all,g,OECDREG) p_MAL_GAP_INDd(g)   = 0;

!-----------------------------------------------------------------------------!
!   PART 4. SUMMARY VARIABLES AT GLOBAL AND GEOGRAPHIC LEVELS               !
!-----------------------------------------------------------------------------!

!   Variable for reporting food security at global level
   ---------------------------------------------------                  !
Variable (levels)                                     CALORIESW
   # total caloric consumption per capita (global) #;
  Formula & Equation (levels) E_CALORIESW                  CALORIESW
  = sum{g, LDREG, CALORIES(g) * POPd(g)}/sum{g, LDREG, POPd(g)};
Variable (levels)                                     MIN_CALW
   # minimum caloric consumption per capita (global) #;
   Formula & Equation E_MIN_CALW                          MIN_CALW
   = sum{g, LDREG, MIN_CALd(g) * POPd(g)}/sum{g, LDREG, POPd(g)};
Variable (levels)                                     MAL_INDEXW
   # malnutrition index (global) #;
   Formula & Equation E_MAL_INDEXW                         MAL_INDEXW
   = sum{g, LDREG, MAL_COUNTd(g)} / sum{g, LDREG, POPd(g)} * 100;
Variable (levels)                                     CALORIC_GAPW
   # total caloric deficit (kcal/day) - global #;
   Formula & Equation E_CALORIC_GAPW                       CALORIC_GAPW
   = sum(g, LDREG, CALORIC_GAPd(g));
Variable (levels)                                     MAL_COUNTW
```

 # malnutrition count (in M persons) - global #;
Formula & Equation E_MAL_COUNTW MAL_COUNTW
= **sum{**g, LDREG, MAL_COUNTd(g)**}**;
Variable (**levels**) MAL_GAP_INDW
 # malnutrition gap index: % of min. caloric consumption - global#;
Formula & Equation E_MAL_GAP_INDW MAL_GAP_INDW
= **sum{**g, LDREG, POPd(g)* **[**MAL_GAP_INDd(g)**]}**
/**sum{**g, LDREG, POPd(g)**}**;
Variable (**levels**) MAL_GAPW
 # malnutrition gap: ave. cal. deficit of the malnourished - global#;
! (in kcal/cap/day) !
Formula & Equation E_MAL_GAPW MAL_GAPW
= **sum{**g, LDREG, MAL_COUNTd(g)* **[**MAL_GAPd(g)**]}**
/**sum{**g, LDREG, MAL_COUNTd(g)**}**;
!]]!

APPENDIX B. MODEL PARAMETERS AND DATA SOURCE

B.1 Table of main parameters and values in SIMPLE-Niger Model

Elasticity	Description	Value	Note
ELAND	Price elasticity of land supply	0.5	For all agro-ecological zones in Niger, value is same as for SSA in Baldos and Hertel (2013)
EOTHER	Price elasticity of purchased inputs	1.34	Same as for price elasticity of non-land inputs in SSA in Baldos and Hertel (2013)
ELABOR	Price elasticity of labor inputs	1.34	Same as above
ECAPITAL	Price elasticity of capital inputs	1.34	Same as above
ECROP	Elasticity of substitution in production of crops	0.5	Assumption: ECROP is assumed to be half the value for SSA
ESUB	Elasticity of substitution between domestic and imported crops	6	Calibrated to fit the rate of price transmission of crops
ETRANS	Elasticity of transformation between domestic and imported crops	6	Calibrated to fit the rate of price transmission of crops
SDEV_CAL (NRUR)	Standard deviation of log normal dist. of per capita caloric consumption	0.31	Estimated from ECVMA 2011 (household survey)
SDEV_CAL (NURB)	Standard deviation of log normal dist. of per capita caloric consumption	0.285	Estimated from ECVMA 2012

B.2 Main Data Sources for Baseline

- Cropland area and crop production quantity
    - Sub-national level 2009 data (Ministry of Agriculture and FAO)
    - 2000 grid level data (EarthStat)
- Cost shares of land, labor, capital, and purchased inputs
    - Plot-level production data: Niger Living Standard Measurement Survey-Integrated Survey of Agriculture 2011
    - Niger Social Accounting Matrix (SAM) provided by IFPRI
- Share of crop use (direct consumption, processed food, livestock sector)
    - Calculated from Niger SAM
- Food security module (undernourishment prevalence, SD of caloric intake, MDER, share of food groups)
    - Niger LSMS 2011/ECVMA
- Income
    - World Development Indicators
    - Niger rural-urban income disaggregation: LSMS-ISA 2011/ECVMA, Niger SAM
- Population: United Nations Population Division
- Agricultural Employment: International Labor Organization (ILO)