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Climate change and adaptation: the case of Nigerian agriculture

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SUMMARY The present research offers an economic assessment of climate change impacts on the four major crop families characterizing Nigerian agriculture, covering more than 80% of agricultural value added. The evaluation is performed shocking land productivity in a computable general equilibrium model tailored to replicate Nigerian economic development until the mid of this century. The detail of land uses in the model has been also increased differentiating land types per agro ecological zones. Uncertainty on future climate is captured, using, as input, yield changes computed by a crop model, covering the whole range of variability produced by an envelope of one RCM and tem GCM runs. Climate change turns to be unambiguously negative for Nigeria in the medium term with production losses, increase in crop prices, higher food dependency on foreign imports and GDP losses in all the simulations after 2025. In a second part of the paper a cost effectiveness analysis of adaptation in Nigeria agriculture is conducted. Adaptation practices considered are a mix of cheaper "soft measures" and more costly "hard" irrigation expansion. The main result is that cost effectiveness of the whole package crucially depends on the possibility to implement adaptation exploiting low cost opportunities. In this case all climate change damages can be offset with a benefit cost ration larger than one in all the climate regimes. Expensive irrigation expansion should however be applied on a much more limited acreage compared with soft measures. If adaptation costs are those of the high end estimates, full adaptation ceases to be cost/effective. This points out the need of a careful planning and implementation of adaptation, irrespectively on the type, looking for measures apt to control its unit cost.

Keywords: climate change, impact, adaptation, agriculture, CGE modelling

JEL: C68, Q51, Q54, Q15

1. Introduction

Developing regions, and in particular Sub-Saharan Africa, are among the most vulnerable areas to climate change. This derives from an explosive mix of high exposure (higher temperature increase and climatic impacts), high sensitivity (higher dependence on climate sensitive sectors like agriculture) and low adaptive capacity (IPCC, 2007; Fisher et al., 2002; Parry, 2009). At the same time, some countries in the area, rich in raw materials and energy sources, experiencing massive GDP growth rates and rapid structural social-economic transformation are increasingly aware of the necessity to carefully plan and govern these transitions. And, against a common wisdom, according to which environmental concerns is an issue for the richer, they are increasingly perceiving climate change as a challenge for their development.

A topical example is Nigeria. In the last decade the country experienced a yearly GDP growth rate of the 5% reaching the 7% in 2009. In that very same year the Federal Government of Nigeria produced the "Nigeria Vision 2020" an ambitious policy document establishing a set of social economic targets aiming to place the country in the top 20 largest world economies within a decade. At the same time adverse climate change impacts can threaten the capacity of many sectors of Nigerian economy to support this development. In this context agriculture is strategic: in 2010 it built up the 42% of Nigeria value added and was almost completely rain-fed (99%) thus particularly sensitive to climatic conditions. Assessing climate change impacts on agriculture can thus offer good insights on the more general relevance of climate change for the country.

The tool used for this investigation is ICES a recursive-dynamic general equilibrium model for the world economy tailored to replicate Nigerian economic development goals until the mid of this century. Peculiar of the exercise is the representation of land use dynamics through the Agro Ecological Zoning approach (FAO-IIASA 2000), introducing land heterogeneity. Furthermore, the model represents as separate agricultural industries yam and cassava, which are the most important food crops in Nigeria. Input to the economic model are land productivity changes mimicking yield changes computed by a crop model, covering the whole range of variability produced by an envelope of one high resolution Regional Climate Model and ten Global Climate Model runs processing the A1B IPCC SRES scenario. Output of the model are effects on agricultural production, prices, imports, land prices, and ultimately on Nigeria GDP performance.

A second more explorative part of the paper describes a possible methodology for a cost effectiveness evaluation of adaptation measures in the agricultural sector using the CGE approach.

In what follows, section 2 presents the model used, section 3 its future baseline, section 4 describes the input used, section 5 introduces the results, section 6 discusses adaptation and section 7 concludes.

2. The ICES model

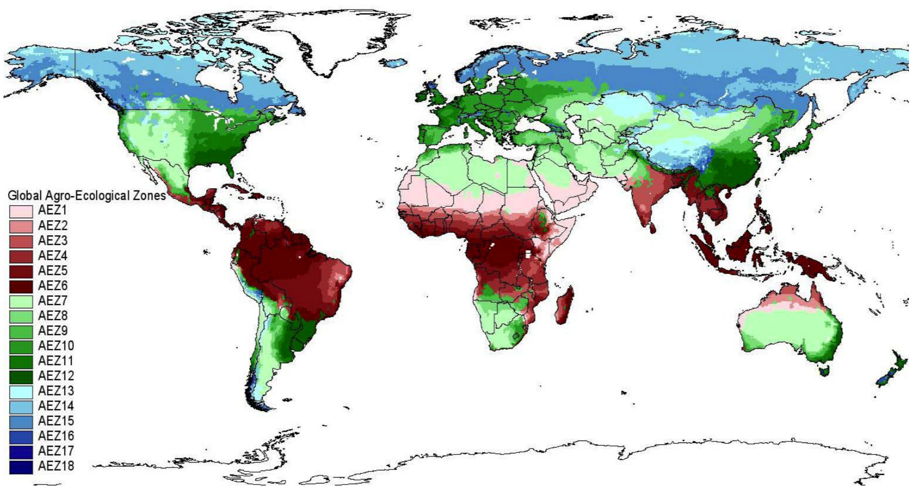
In this study we use ICES, a recursive-dynamic CGE model for the world economy, developed at the CMCC. The model is grounded on GTAP 7 database with 2004 as calibration year (Narayanan and Walmsley, 2008) and shares the core structure of the GTAP-E model (Burniaux and Troung, 2002), on its turn, an extension of the basic GTAP model (Hertel, 1997). The simulation period is 2004 – 2050 resolved in one-year time steps.

Given the agricultural-sector focus of the study, more realism in land allocation dynamics has been added by adopting the Agro Ecological Zone (AEZ) approach (FAO and IIASA, 2000).

In its standard version, the GTAP model proposes an undifferentiated land input. Land is then allocated to different crops responding to changes in crop prices. Frictions in land switching are captured by an elasticity of transformation parameter that summarizes all the economic, geo-bio-chemical constraints determining imperfect land substitutability. The AEZ methodology improves upon this very simplified representation. It introduces land heterogeneity - presently land types can be 18 - depending on climatic characteristics, moisture levels and length of growth period characterizing the different AEZs (see Figure 1). Now (imperfect) land substitutability is allowed within, but not between AEZs. The main consequence is that a crop cannot be grown everywhere within a country, but only in those AEZs where the land is geographically and bio chemically suitable to its cultivation.

Another non negligible advantage is offered by AEZs: the richer detail that can be used as input data. The main driver of economic effects here considered, are indeed changes in land productivity (crop yiels) induced by changing climatic conditions. The possibility to differentiate these by land type and areas within a country is an obvious increase in the realism of the subsequent impact assessment.

Figure 1: AEZ classification in the GTAP/ICES database



Source: Monfreda et al. (2009)

AEZ specificities are contained in the GTAP-AEZ database (Avetisyan et al. 2011) that was linked to the ICES (GTAP 7) database. GTAP-AEZ details production of 175 crops, in 18 AEZs in 113 countries/regions. In the present analysis only 8 AEZs are in fact considered, the 6 characterizing the Nigerian environment, and other 2 gathering all the remaining ones.

A further improvement, concerns the sectoral representation of Nigerian agricultural sector. The original GTAP 7 database considers 8 different crop families. These have been grouped into 6 major crop categories singling out those – rice, cereals, cassava and yams - which are characteristic of the Nigerian agricultural production (according to the last available information (Nwafor et al. 2010) they built the 80% of total Nigerian agricultural value added in 2006). Cassava and yams in particular, constituting respectively the 17.46% and 15.77% in the model calibration year, which in the original data base were part of the larger aggregate "vegetable and fruits", have been represented separately.

All other kinds of agricultural productions have been grouped into two residual aggregates.

Table 1 left reports the final sectoral and macro-sectoral specification of the model including non agricultural industries.

Table 1: Sectoral (left) and regional (right) detail of the ICES mode

Rice	Agriculture
Cereal Crops	
Cassava	
Yams	
Vegetable and Fruits	
Other Crops	
Livestock and Fishing	
Timber	
Coal	Mining
Oil	
Gas	
Mining	
Electricity	Manufacturing
Oil Products	
Other Industries	
Private Services	Services
Public Services	

USA	USA
EUROPE	Europe
FSU	Former Soviet Union
RoA1	Rest of Annex 1
MENA	Middle East and North Africa
NIGERIA	Nigeria
SSA	Sub Saharan Africa
ASIA	Asia
LACA	Latin and Central America

Even though the current assessment is focused on Nigeria, ICES is a world CGE model and the rest of the world needs to be considered. The chosen regional detail (Table 1 right) has been decided considering the need to simplify, but at the same time to keep a reasonable equilibrium between the regions' sizes to avoid unbalanced effects on international trade patterns.

3. The baseline scenario

Preliminary to the impact assessment, is the construction of the social-economic baseline capturing potential economic development in Nigeria up to 2050. This baseline represents the counterfactual "without climate change" against which the impacts of climate change on crops productivity will be imposed and the consequent effects on Nigerian GDP and sectoral performance will be evaluated.

Up to 2025 this baseline is shaped by the "prudential interpretation" of the "Nigeria Vision 2020" This policy document, produced by the Federal Government of Nigeria, sets ambitious development targets for the country in 2020. Its original formulation has been then revised, as judged too ambitious, during subsequent analyses (e.g. the Nigeria Climate Change Assessment 2010) basically shifting the goals of 2020 to 2025 and in particular correcting some assumptions concerning the evolution of national composition of macro sectoral value added. The ICES baseline is now calibrated on the following official mid-term policy targets: an average yearly GDP growth rate of the 9% in the period 2010-2025; a value added share of the 21% (slightly less than half of the 2010 figure); the 18%, the 15% and the 46% for agriculture, mining, industry and services respectively in 2025; a six-fold increase in agricultural productivity between 2010-2025. Nigeria population evolves according to United Nations world population prospects in the medium fertility variant scenario (UN, 2009).

Figure 2 and Table 2 summarize the benchmark targets and the model performance in their matching. After 2025 there are no information on macro-economic indicators. It is thus assumed that GDP growth rates remain sustained, but decrease to an average 5.7% in the period 2025-2050, and that sectoral value added shares stabilize at the 2025 levels.

A last set of assumptions concern specifically the agricultural sector: cropland extension remains constant at the 2010 values, furthermore irrigated land which in the calibration year in Nigeria is negligible (lower than 1% of total cultivated area) is assumed to reach 5% of total cropland in 2025 and 20% in 2050 consistently with the Country irrigation master plan (JICA 1999)[1]. This last information is important notwithstanding the current ICES model version does not differentiate between irrigated and rain-fed land. Indeed the two types of land differ, both in term of productivity and of reaction to climate-change pressures, therefore assumption on the share of irrigation is essential to compute correctly the net climatic impacts on crops productivity.

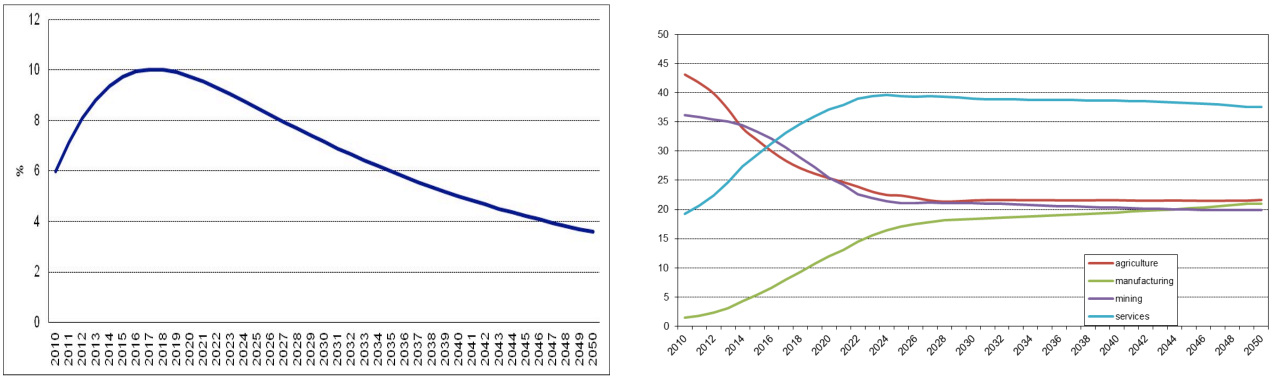
Population and GDP growth rates within the 2010-2050 period for non-Nigerian macro-regions derive respectively from UN (2009) and the A1B IPCC SRES (Nakicenowic et al. 2000).

Table 2: Baseline assumption on Nigeria main macronomic indicators

Average Nigerian yearly GDP growth rates		
	Target	Simulated
2010-2025	9.0%	9.0%
2025-2050	5.7%	5.7%
Average Nigerian yearly population growth rates		
	Target	Simulated
2010-2025	--	1.9%
2025-2050	--	1.3%
Composition of Nigerian macro-sectoral value added in 2025		
Agriculture	21%	23%
Manufacturing	18%	17%
Mining	15%	21%
Services	46%	39%
Crop productivity		
2010-18	3-fold increase	2.5-fold increase
2010-25	6-fold increase	5.3-fold increase

[1] The information on future irrigated land per crop and AEZ is not available. The study therefore assumes its uniform development.

Figure 2: Baseline assumptions for Nigerian yearly GDP growth rates (%) (left) and macro sectoral composition of value added (% over total) (right)



4. Climate–related shocks on the agricultural sector

The input information for the ICES CGE model on changes in crop yields under climate change derive from the DSSAT-CSM crop model (Mereu and Spano, 2011). The reference climate scenario is the A1B IPCC SRES (IPCC 2000) and, to account for the potential variability in climate and in crops responses, the crop model has been run using as input precipitations, temperature and solar radiation produced by a high (about 8 km horizontal) resolution regional climate model (RCM) and by its perturbation on an envelope of 10 different global circulation models (GCMs)[2].

Economic results reported in this paper, refer to three crop model runs: that using the RCM input and that of the National Center of Atmospheric Research (NCAR) and of the Global Fluid Dynamic Lab (GFDL) GCMs, which present respectively the less and the most pessimistic 2050 yield changes, across the whole range of perturbed climate model runs.

Two further notes on the data transfer process between DSSAT-CSM and ICES are in order:

(i) The crops analyzed by the DSSAT-CSM model are: cassava, yam, rice, millet, maize and sorghum. Therefore (see Table 1), a one to one correspondence with ICES exists just for the first three crops. Yield changes for the ICES "other cereals" aggregate have been thus computed as a weighted average of the yield changes of maize, millet and sorghum. Given to the unavailable data, no yield changes are on the contrary imposed on the last two ICES crop aggregates: "other crops" and "vegetable and fruits"[3].

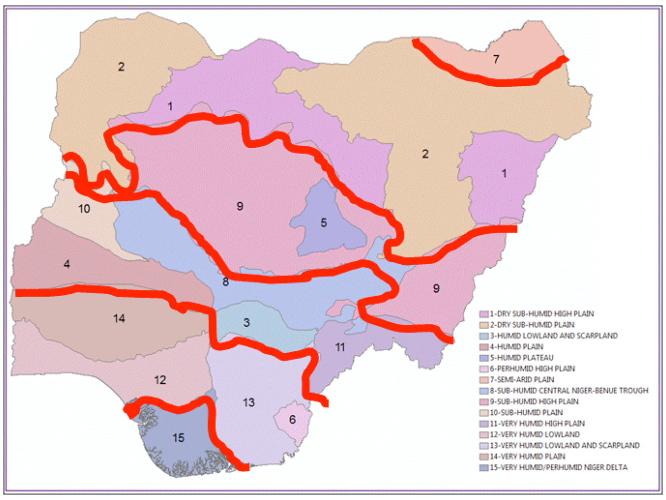
(ii) The agro-ecological zoning used by the DSSAT-CSM model is more detailed than that available in the ICES-AEZ database: Nigeria is detailed into 15 rather than 6 AEZs (Figure 3). Therefore an aggregation

[2] This approach to capture uncertainty is motivated by the common observation in the literature (Olesen et al. 2007; Lionello et al. 2012) that in the medium term the uncertainty stemming from the choice of climate models is larger than the one associated with emission scenarios, which become more important in the long term.

[3]Nonetheless, for completeness of information, production changes of these crops are also reported. But they depend upon changes in relative prices and are not directly imputable to climate-induced yield changes .

procedure had to be applied to DSSAT-CSM output to get consistency across the two different geographical resolutions.

Figure 3. Correspondence in Agro-ecological zoning across ICES and DSSAT-CSM



ICES-AEZ	***DSSAT-CSM AEZ***
AEZ 1	AEZ 7
AEZ 2	AEZ 1 and AEZ 2
AEZ 3	AEZ 9 and AEZ 5
AEZ 4	AEZs 10, 8, 11, 4, 3
AEZ 5	AEZs 14, 12, 13, 6
AEZ 6	AEZ 15

Tables 3 and 4 report respectively crops’ production per AEZ in Nigeria, and the contribution of each crop to the total value of production in each AEZ in 2004. This to provide also some characterization of the different zones, useful for result interpretations.

Table 3. Quantity of production: share per crop of each AEZ (2004)

	Rice	CerCrops	Cassava	Yams	VegFruits	OthCrops
AEZ1	0	2	0	0	2	0
AEZ2	10	36	1	0	14	12
AEZ3	9	31	2	2	13	14
AEZ4	24	18	18	25	23	10
AEZ5	52	12	59	62	38	11
AEZ6	5	2	20	11	10	53
TOT	100	100	100	100	100	100

Source: Our elaboration from GTAP-AEZ database

Table 4. Value of production: shares per AEZ of each crop (2004)

	Rice	CerCrops	Cassava	Yam	VegFruits	OthCrops	TOT
AEZ1	2.2*	23.3*	0.8*	0.0*	68.8*	5.0*	100
AEZ2	4.1	40.4	1.5*	0.0*	43.7	10.2	100
AEZ3	4.1	37.8	3.7*	3.2*	41.8	9.4	100
AEZ4	5.2	11.3	16.8	21.2	39.5	6.0	100
AEZ5	5.7	3.9	27.7	26.5	29.1	7.1	100
AEZ6	2.5	2.5*	44.2	20.8	27.1	3.0	100

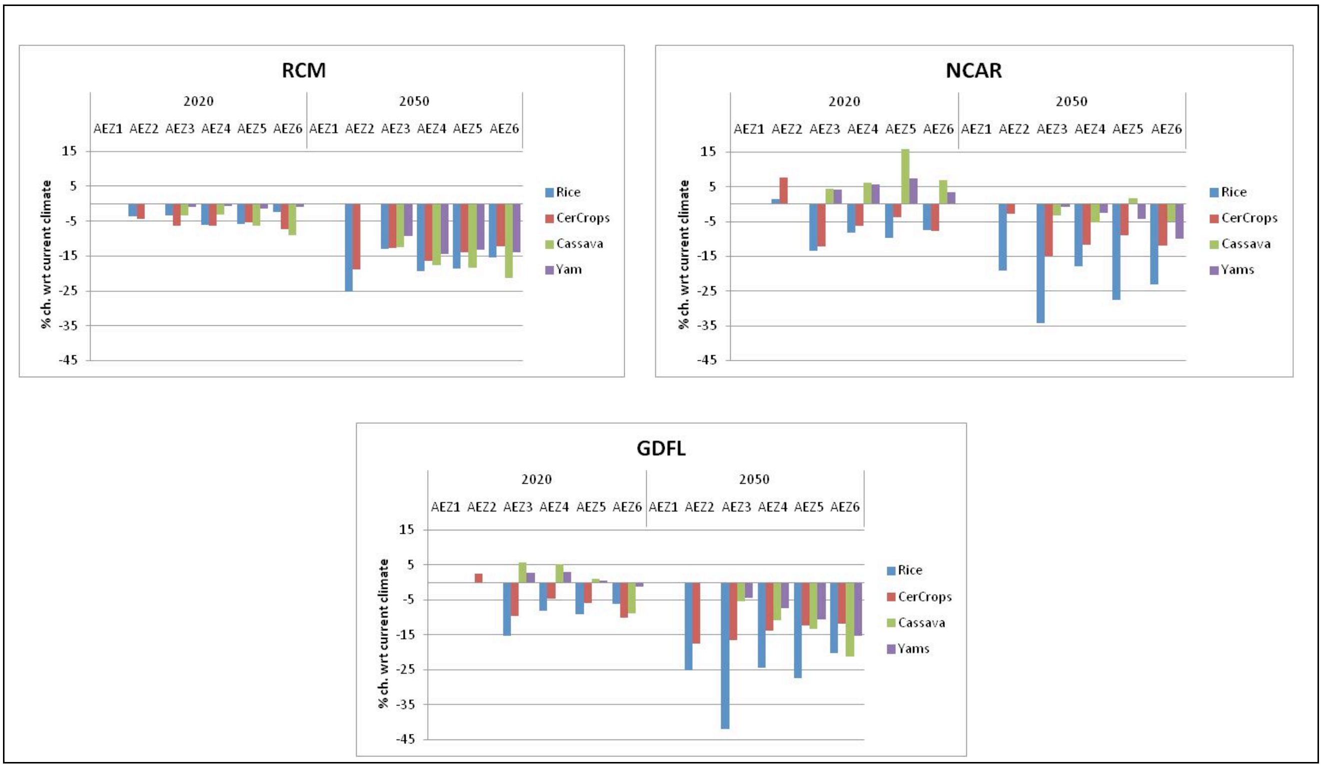
* Negligible presence of the crop in the AEZ (<= 2% of the national total)

It is thus evident that AEZ 1 provides a negligible contribution to Nigerian agricultural production being poorly endowed of any crop. The AEZ 2 and 3 are the most important producers of “cereals”, but are particularly poor of “cassava” and “yam”. These crops are concentrated in AEZ 5, 4 and 6. The AEZs 4 and 5, finally, are fundamental for “rice” and “vegetable and fruits” productions.

It is worth to notice that in the AEZ 4, 5 and 6, where “rice”, “cassava” and “yam” productions are concentrated, “rice” contributes only marginally (around 6%) to the agricultural value added, instead “cassava”, “yam”, and other “vegetable and fruits” play a major role.

Figure 4, finally, presents the shock on crop yields used as input to the CGE model.

Figure 4. Climate change impacts on Nigerian crop yields (% change wrt current climate) per Agro-ecological zones (A1B SRES)



Source: DSSAT-CSM model

According to the crop model RCM run, the generalized decrease in crop productivity in Nigeria is particularly pronounced for yam in AEZs 4 and 6 (-14.5 and -14.0% w.r.t baseline in 2050), cassava in AEZ 6 (-21.3% w.r.t. baseline in 2050), rice and “cereal crops” in AEZ 2 (respectively -25.3% and -18% w.r.t baseline in 2050). The major difference of RCM with the GCM perturbations is in the medium term. According to the latter, cassava and yam in fact increase their yield, while, at the same time, productivity losses are higher for other crop aggregates. In the long term, the GCM runs highlight a general decline in yields with GFDL more pessimistic than NCAR, and both more optimistic than RCM on cassava and yam.

5. Results

Here we present a selection of ICES model results, focusing on economic impacts determined in the RCM climate model run. Furthermore, we give an overview of outcomes of the NCAR and the GFDL runs, which represent the uncertainty range of our impact assessment. Finally, we perform an adaptation analysis for the three scenarios, computing the cost of a strategy mix able to offset climate change-driven yield loss, and its effect on GDP.

5.1 The RCM scenario

The direct effect of yield losses is a generalised decline of national agricultural production (Table 5). The major contraction concerns the “cereal crops” aggregate (-14.1% w.r.t baseline 2050) followed by smaller, but non negligible reduction in the output of rice, cassava, and yam (-6.0%, -4.0and -3.8% w.r.t baseline in 2050)[4].

Table 5: Crop production. RCM scenario (% change wrt baseline)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Rice	0.0	-1.2	-1.3	-1.9	-2.7	-3.4	-4.5	-5.2	-6.0
CerCrops	0.0	-2.4	-3.3	-4.9	-6.7	-8.3	-10.5	-12.3	-14.1
Cassava	0.0	-1.0	-1.0	-1.3	-1.8	-2.3	-3.0	-3.5	-4.0
Yams	0.0	-0.8	-0.7	-1.1	-1.6	-2.0	-2.7	-3.3	-3.8
VegFruits	0.0	-0.6	-0.6	-0.9	-1.3	-1.6	-2.2	-2.6	-3.2
OthCrops	0.0	-1.3	-1.3	-1.7	-2.4	-3.0	-3.7	-4.2	-4.8

Note: In the bold square those crops directly affected by yield changes

In 2050, the total shrinking of Nigerian crop production amounts to -7.2% w.r.t. baseline, but it is not uniform across AEZs denoting a worsening of the situation moving Northward (Table 6). The northern AEZ 2 is the most adversely affected (-13.6% w.r.t. baseline) due to its dedication to and high concentration of “cereal crops” and rice cultivations which also experience high yield declines. A lower, but still relevant production loss is registered in central Nigeria (AEZs 3 and 4 with respectively 8.7 and 7.1% production drop w.r.t. baseline) that again can be attributable to impacts on “rice” and “cereal crops” yields. The production performance of AEZ6 is strongly influenced by the “cassava” and “other crops” losses (-6.1 and -5.5% w.r.t. baseline).

[4] Note that the drop of production affects also the other two crop aggregates, “vegetable and fruits” and “other crops” which are not directly concerned by the yield decline. This is due to a general contraction of the Nigerian economy in the climate change scenario. See further on this below.

Table 6. Crop production in 2050 per AEZ. RCM scenario (% change wrt baseline)

	Rice	CerCrops	Cassava	Yam	VegFruits	OthCrops	Total
AEZ1	8.8*	-1.2*	16.5*	0.0*	-1.7*	-2.6*	-1.7*
AEZ2	-11.0	-16.9	15.0*	0.0*	-2.8	-4.3	-13.6
AEZ3	-2.0	-11.7	2.2*	0.7*	-2.3	-3.5	-8.7
AEZ4	-6.3	-14.7	-3.1	-4.7	-3.0	-4.4	-7.1
AEZ5	-6.0	-13.5	-4.0	-3.6	-3.7	-5.5	-5.7
AEZ6	-3.7*	-12.2*	-6.1	-4.0	-3.7	-5.5	-4.9
Total	-6.0	-14.1	-4.0	-3.8	-3.2	-4.8	-7.2

Note: In the bold square those crops directly affected by yield changes

* Negligible presence of the crop in the AEZ (<= 2% of the national total)

This picture is mirrored by increase in the price of agricultural commodities (Table 7 left) which in 2050 peaks to +47.2% (w.r.t. baseline) for rice. Cassava shows the second highest increase (+21.4% w.r.t. baseline), then followed by cereals and yam.

By comparing Tables 5 and 7-left, it is also possible to trace some interesting demand-side effects. Note for instance rice showing a lower drop in production than "other cereals", but the highest price increase across all crops. This witnesses a higher rigidity in demand which depends on the shift towards rice of part of the declined demand for other cereals and yam. On the contrary, the substitution away from cassava is more difficult, as highlighted by the relatively moderate decline in production and the high price increase.

Table 7. Crops prices (left) and land prices (right). RCM scenario (% change wrt baseline)

	2020	2050
Rice	7.0	47.2
CerCrops	2.9	14.3
Cassava	7.7	21.4
Yams	2.2	15.2
VegFruits	0.3	-1.8
OthCrops	-0.1	-0.9

	2020	2050
AEZ1	-4.2	-23.5
AEZ2	-0.8	5.7
AEZ3	0.3	-9.8
AEZ4	1.6	3.6
AEZ5	8.1	30.4
AEZ6	11.0	24.4

Note: In the bold square those crops directly affected by yield changes

The lower domestic crop production and the higher prices boost net imports of food commodities worsening Nigerian agricultural trade balance (Table 8), highlighting a potential stress on food dependency. Rice and cassava are the most affected, followed by cereal crops, while, in the case of yam, net imports decline. The case of cassava and yam need to be interpreted correctly though. In fact, imports of those two goods are basically zero in the baseline and accordingly remain negligible in the climate change scenarios. Therefore, the figures reported for these two crops reflect in fact changes in export flows. Those of cassava decline: a higher share of the declined production is addressed to satisfy domestic rather than international demand. On the contrary yam exports increase. Higher prices reduce domestic demand of yam which readdresses to rice and this make room for an expansion of international demand.

Table 8: Net-Imports of agricultural commodities. RCM scenario (% change wrt baseline)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Rice	0.0	4.7	6.2	10.0	15.9	23.1	29.5	36.1	43.7
CerCrops	0.0	0.3	2.4	5.4	6.9	8.0	9.3	11.3	13.7
Cassava*	0.0	13.0	12.9	15.2	20.2	27.0	31.0	33.2	35.2
Yams*	0.0	-9.4	-7.6	-11.8	-18.9	-26.7	-31.5	-34.6	-37.1
VegFruits	0.0	-0.4	-0.9	-2.6	-3.2	-4.3	-5.8	-7.6	-9.6
OthCrops	0.0	-1.7	-1.6	-2.2	-2.9	-3.9	-5.0	-5.9	-6.7

Note: In the bold square those crops directly affected by yield changes

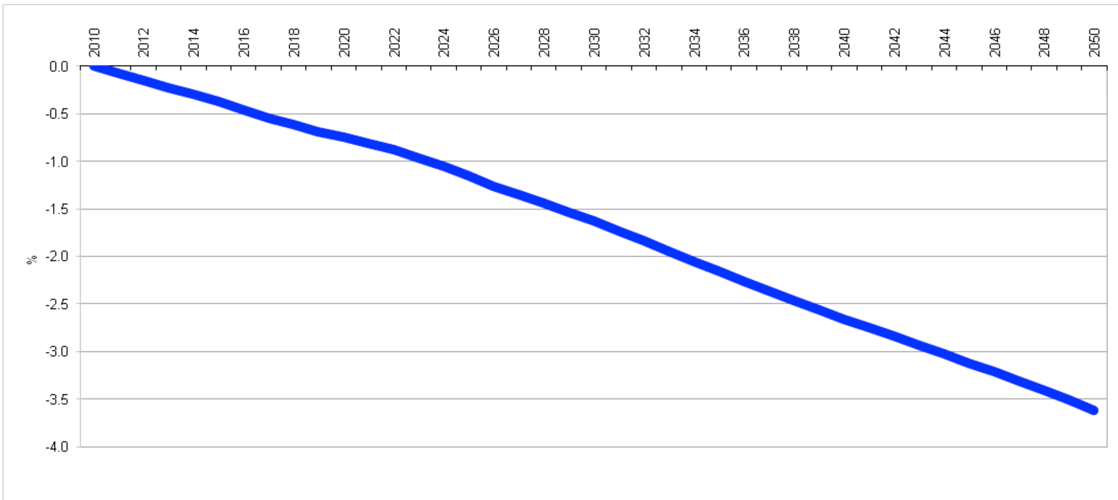
* Negligible quantity imported in the base year

Land prices are also affected (Table 7-left). In this case especially, model outcomes need to be taken *cum granu salis* as the institutional, regulatory, administrative, even cultural factors determining the definition of land property rights in Nigeria are not captured by the model mathematical structure. Nonetheless they are still indicative of the pressures that climate change may exert on the land endowment.

It can thus be noticed that the land value increases across different AEZs, tend to derive from a combination of crop price increases and dominance of the specific crop in the value of production in the AEZ. This applies for instance to the southern part of the country (AEZs 5 and 6) where the spike in land prices is motivated by the relatively high increase in cassava and yam prices and by the fact that those crops represent 55% and 70% of production value in those AEZs respectively. On the contrary, land price variations are moderate in the central AEZs 2 and 4, where "cereal crops", showing the lowest price increase, and especially vegetable and fruits whose price decline, are more important. Finally, AEZs 1 and 3 are experiencing a drop in land prices. This is due to relatively higher predominance of the "vegetables and fruits" aggregate whose prices are declining. Accordingly, climate change, albeit negative for the consumer, redistribute some gains in term of higher land rents to landowner especially in the southern part of the country. This welfare reallocation through endogenous price adjustment is a typical effect of climate change that the CGE analysis captures.

The net impact on the country, as approximated by the GDP performance, is nonetheless negative with a GDP loss that reaches the -3.6% compared to the baseline in 2050 (Figure 5).

Figure 5: Nigerian GDP. RCM scenario (% change wrt baseline)



5.2. Robustness analysis accounting for impact uncertainty.

To account for impact uncertainty, the economic analysis evaluates two further sets of yield changes. Those produced by the crop model processing the climatic data stemming from the NCAR and the GFDL GCM simulations. As said, these two particular runs roughly span the whole range of variability produced by the 10 GCMs envelope.

Both GFDL and NCAR runs register lower production losses than RCM in the medium term, with NCAR showing slight increases in rice, cassava and yam production (Table 9). Interestingly GFDL highlights declines in cassava and yam production notwithstanding their increased productivity. This is the effect of the aggregated demand decline on its turn driven by the GDP decline (Figure 6). In the longer term all scenarios depict decreasing production (-4.8% for NCAR and -7.4% for GFDL in 2050) with NCAR less pessimistic and GDFL more pessimistic than RCM.

Table 9. Crop production. RCM, NCAR and GFDL scenarios (% ch. wrt baseline**)**

	2020			2050		
	RCM	NCAR	GFDL	RCM	NCAR	GFDL
Rice	-1.3	0.2	-1.0	-6.0	-5.9	-8.2
CerCrops	-3.3	-1.6	-2.5	-14.1	-9.7	-15.7
Cassava	-1.0	1.0	-0.3	-4.0	-3.0	-4.8
Yams	-0.7	0.9	-0.2	-3.8	-3.1	-4.7
VegFruits	-0.6	0.5	-0.2	-3.2	-2.8	-4.1
OthCrops	-1.3	1.2	-0.5	-4.8	-4.5	-6.4
Total	-1.4	0.5	-0.6	-7.2	-4.8	-7.4

Note: In the bold square those crops with a change in yield exogenously imposed

In the long term, consistently with trends in crop productions, all crops increase their prices (Table 10). Again rice is the most severely affected followed by cereal crops. Cassava and yam prices are lower than in the RCM simulation, moreover in 2020 they decline. This is particularly evident in the GDFL run where higher yields are coupled with lower demand.

Table 10. Crop prices. RCM, NCAR and GFDL scenarios (% ch. w.r.t. baseline)

	2020			2050		
	RCM	NCAR	GFDL	RCM	NCAR	GFDL
Rice	7.0	10.2	8.1	47.2	91.2	73.2
CerCrops	2.9	2.5	3.1	14.3	14.5	7.7
Cassava	7.7	0.9	-10.4	21.4	14.6	1.8
Yams	2.2	-0.8	-7.2	15.2	10.0	4.6
VegFruits	0.3	-0.2	-0.9	-1.8	-2.3	-1.3
OthCrops	-0.1	-0.4	-0.6	-0.9	-1.1	-0.5

Note: In the bold square those crops with a change in yield exogenously imposed

The net-import flows (Table 11) confirm the increased dependence on foreign agricultural products especially in the GFDL run and especially for rice.

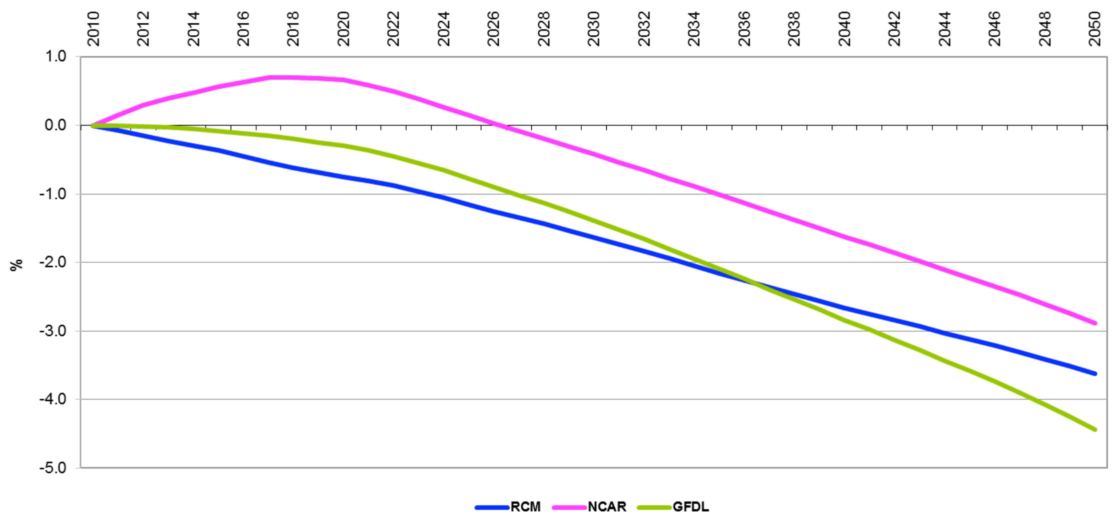
Table 11. Net Imports of agricultural commodities. RCM, NCAR and GFDL scenarios (% ch. w.r.t baseline)

	2020			2050		
	RCM	NCAR	GFDL	RCM	NCAR	GFDL
Rice	6.2	9.1	10.0	43.7	71.9	86.9
CerCrops	2.4	4.0	2.4	13.7	5.8	12.3
Cassava*	12.9	-17.6	0.9	35.2	-1.7	19.2
Yams*	-7.6	30.1	2.8	-37.1	-13.6	-26.8
VegFruits	-0.9	-1.1	-1.2	-9.6	-8.1	-12.5
OthCrops	-1.6	-0.2	-1.3	-6.7	-5.6	-8.7

Note: In the bold square those crops with a change in yield exogenously imposed

In term of GDP, Nigeria is expected unambiguously to lose since 2025 (Figure 6). In 2050 the loss ranges between the 3% and 4.4% of GDP. In the medium term however, the two GCM runs highlight a smaller downturn in the economic activity respect to the RCM simulation, with the NCAR one, projecting increases in cassava and yam production, even predicting a potential maximum GDP gain of about 0.7% in 2017.

Figure 6. Nigerian GDP. RCM, NCAR and GFDL scenarios (% ch. w.r.t. baseline)



Concluding: climate change can be surely considered a problem for the country in the medium-long term. More questionable is the fact that it entails relevant losses in the short-medium term (they remain lower than the 1% until 2020 also in the most adverse case) and jeopardize for instance Nigerian development goals. However, many considerations suggest caution in interpreting too positively these short-term outcomes as the quantified negative economic impacts are probably underestimated. Indeed: only a subset, although relevant, of crops have been examined, negative consequences can be higher when all the crops characterizing Nigeria agricultural production were considered. More importantly, only the agricultural sector is analyzed, while it is well recognized that climate change affects many more dimensions relevant for social and economic development. Furthermore, all the adjustments in demand and supply described by the model, factor and good substitution across markets, occur at no cost and without any friction. This also contributes to represent lower costs than in the reality. Finally, acting in anticipation is often cheaper than acting in reaction. All this strongly supports proactive actions against climate change. Some, will be discussed in the next section.

6. Adaptation

This more explorative part of the research describes a possible methodology for a cost effectiveness evaluation of adaptation measures in the agricultural sector using the CGE approach.

The exercise applies to the agricultural sector an idea proposed by Deke et al. (2001) and Darwin and Tol (2001) to estimate the general equilibrium effects of adaptation against sea-level rise. In our case the first step of the assessment consists in quantifying the total direct cost needed to completely offset projected yield decline through different adaptation practices (see Box 1). Then, interpreting this as an investment expenditure falling within the more general category of "adaptation", in adjusting consequently the capital accumulation process driving the model recursive dynamics. In practice, the ICES model is run without imposing the negative shocks on yields, but subtracting period by period the quantified adaptation costs from the Nigerian capital stock. This implicitly assumes that adaptation investment crowds out other forms of investment thus reducing capital (services) available to produce all other goods and services in the model production function[5]. The higher order cost of adaptation investment is the quantified difference between Nigeria GDP performance in this case and in the baseline. The economic effectiveness of adaptation, with which it is compared, is instead measured by the avoided GDP loss entailed by full adaptation, which thus coincides with the values reported in Figure 6 and replicated in Table 12.

BOX 1: Adaptation options for Nigerian agriculture

The estimation of direct adaptation costs derives from a detailed ad hoc study conducted within the World Bank "Nigerian Climate Risk Analysis" consulting report prepared by the Italian Euro-Mediterranean Center on Climate Change (CMCC). Extended results will be shortly available in the forthcoming World Bank report n. 69027 (Cervigni et al. forthcoming), to which the interested reader is addressed.

The adaptation strategy considered is a mix of "soft" and "hard" measures. The first are a combination of: shift of the sowing/planting dates, manure management to complement nutrient provision, increase of ordinary fertilisation. The second consist in the expansion of irrigated land through large and small scale irrigation plants. The analysis has therefore been conducted with regard to a range defined by a low unit cost case, and a high unit cost case.

The cost per hectare of soft measures varies across climate model runs depending on the yield loss to recover, the crop type and the measure. Sources of information used are FAO (2012), Bationo (2004), Bationo et al. (2011), Mutiro and Murwira (2004), Kamiri et al. (2011).

The lowest average minimum and maximum unit costs of adaptation are obtained in the NCAR run (roughly US $20-US $100). RCM and GFDL average costs per hectares are higher and quite similar ranging from roughly US $250 and US $1,100.

Turning to irrigation, large scale plants require an initial investment costs ranging between US $3,700/ha and $20,000/ha for newly irrigated land plus an annual operation and maintenance (O&M) cost of US $30/ha. For small scale plants initial required investment is between US $2,200/ha and $5,000/ha plus an annual O&M cost of US $40/ha (You et al. (2009), integrated with country expert personal communications).

The assumptions on the deployment of adaptation strategy are then as follow: first non irrigation practices are applied to all cropland, and then, if these are still insufficient to recover the production gap, irrigation expansion is used. This would occur trough substitution of irrigated for rain-fed land and with a combination of large scale (55%) and small scale (45%) irrigation.

This proportion is derived from You et al. (2009) reporting the economically viable irrigation potential of Nigeria for the two different irrigation schemes.

[5] Bosello et al. (2007) noted that this procedure represents adaptation as a pure cost, neglecting the potential multiplicative effects of adaptation investment on the economy. They thus propose to trade off adaptation investment with consumption rather than with other investments. We are testing this alternative formulation in a subsequent paper.

Table B1. Production Gap Eliminated by non irrigation options, by Year and Climate Model (Percent)

	2020			2050		
	RCM	NCAR	GFDL	RCM	NCAR	GFDL
Cassava	100	100	100	92.2	100	100
Maize	100	100	100	99.1	100	99.9
Millet	95.1	100	100	78.3	100	82.6
Rice	100	100	100	89.0	100	89.2
Sorghum	100	100	100	93.9	100	94.0
Yams	100	100	100	92.3	100	97.4

Table B2. Area of Adaptation Application by Climate Model (ha, millions)

	2020			2050		
	RCM	NCAR	GFDL	RCM	NCAR	GFDL
Farm practices in rain-fed areas	1.11	0.59	0.77	17.98	14.26	16.15
Additional Irrigation	0.02	0.00	0.00	1.67	0.00	1.49
Total	1.13	0.59	0.77	19.65	14.26	17.65

According to the adaptation analysis, in the long term, "soft" measures suffice to completely offset climate change yield decline in the NCAR run and almost completely, with the partial exception of millet and rice, in the other runs (Table B1). From 14 to 18 million hectares have to be treated with soft adaptation, whereas irrigation need to be applied to 1.7, 1.5 additional million hectares in the RCM and GFDL runs respectively (Table B2).

The result of the cost effectiveness analysis are summarized by Table 12.

Table 12. Adaptation cost effectiveness

	RCM	**NCAR**	**GFDL**
GDP loss induced by climate change in 2050 (economic gains from full adaptation)	3.6%	2.9%	4.5%
Direct cost of adaptation 2010-2050 total undiscounted (US$ billions)			
Low unit cost case	10	0.4	9
High unit cost case	45	1.3	40
GDP "cost" of full adaptation in 2050:			
Low unit cost case	2.6%	0.1%	2.3%
High unit cost case	14.3% (6.8% due to soft measures, 7.2% due to irrigation)	0.3%	12.7% (5.8% due to soft measures, 6.9% due to irrigation)
Benefit cost ratio:			
Low unit cost case	1.38	29	1.96
High unit cost case	0.25 (0.47 w/o irrigation)	9.6	0.35 (0.70 w/o irrigation)

All over the simulation period, using costs per hectare and hectares to be treated in Box 1, total direct adaptation costs can range from US \$0.4 to US \$45 billion (Table 12, 4th and 5th rows). Once computed the related GDP loss (Table 12, 7th and 8th rows) and compared with those induced by climate change (Table 12 2nd row), soft adaptation results unambiguously cost effective highlighting benefit-cost ratios much larger than one irrespectively upon the assumption on unit costs, in the NCAR run (Table 12, 10th and 11th rows). However soft measures may not be sufficient for a full recovery of production gaps as for instance with reference to the climate replicated by the RCM and GFDL climate models. In this case irrigation expansion can play a role. However, due to its particularly high costs, irrigation should be kept as a residual option (i.e. on a much more limited acreage compared with soft measures), and used when its costs are those of, or can be kept reasonably close to, the lower range of values proposed by the literature. In this case the adaptation mix still demonstrates a benefit cost ration larger than one in all the three runs. If costs are those of the high end estimates, full adaptation ceases to be cost/effective. Major responsible of the outcome is irrigation, however, also giving up the costly irrigation expansion, leaving anyway remaining adaptation measures to offset roughly 90% of damages, would not be enough to turn the benefit cost ratios above one. The main message is that it cannot be taken for granted that "any" adaptation is cost effective: in our specific case not only irrigation expansion, but also the much cheaper soft adaptation measures, should be carefully applied minimizing implementation cost. Even though the more technical aspects are out of the scope of the present analysis, it is worth stressing that, in addition to be cheaper, soft adaptation measures have anyway another advantage compared with irrigation: the flexibility in implementation. On the contrary, especially large irrigation infrastructure, needs anticipatory planning and, once the investment is immobilized in irrigation programs, it can be hardly reversible. This should put additional caveat in the use of irrigation expansion in the present context of climate uncertainty (in the NCAR scenario irrigation is for instance not necessary). A final aspect worth to consider descends from the evidence that, according to a cost-effective decision framework, a given degree of residual damage has to be accepted. This does not mean that its level and distributional implication across the society are acceptable under different criteria. This is when policy decision making is called upon to move.

7. Conclusions

The present research offers an economic assessment of climate change impacts on the four major crop families of Nigerian agriculture covering more than 80% of national production. The evaluation is performed shocking land productivity in a computable general equilibrium model tailored to replicate Nigerian economic development until the mid of this century. The detail of land uses in the model has been also increased differentiating land types per agro ecological zones. Uncertainty on future climate is captured, using, as input, yield changes computed by a crop model, covering the whole range of variability produced by an envelope of one RCM and tem GCM runs.

Climate change turn to be unambiguously negative for Nigeria in the medium term with production losses, increase in crop prices, higher food dependency on foreign imports and GDP losses in all the simulations after 2025. Compared to the baseline, in 2050, when negative impacts are the highest, total agricultural production declines between the 4.8% and the 7.4%, with northern Nigerian regions and cereal cultivation more penalized; crop prices increase on average between the 17% and the 32% (with a peak of 90% for rice); net imports of agricultural commodities increase on average between the 13% and the 23%.

Partial good news for landowner is the potential increase in land rents in the southern and central part of the country driven by the increased value of cassava and yam cultivations. Nonetheless, the projected GDP loss ranges between the 3% and the 4.4%. Considering that only a subset, although relevant, of crops is examined, that only the agricultural sector is analyzed, and that all the adjustments in demand and supply described by the model are assumed to occur at no cost and without any friction, it can be concluded that climate change can definitely entail higher costs for Nigeria, and can likely dampen its development potential especially during the second quarter of the century. This thus justifies proactive action to contrast adverse climate change impacts.

Against this background, the second part of the research develops a cost effectiveness analysis of adaptation in Nigeria agriculture by comparing the GDP implication of adaptation expenditure/investment with the avoided GDP loss induced by climate change. Adaptation practices considered are a mix of cheaper "soft measures" and more costly "hard" irrigation expansion. The main result is that cost effectiveness of the whole package crucially depends on the possibility to implement adaptation exploiting low cost opportunities. In this case all climate change damages can be offset with a benefit cost ration larger than one in all the climate regimes. Expensive irrigation expansion should however be applied on a much more limited acreage compared with soft measures. If adaptation costs are those of the high end estimates, full adaptation ceases to be cost/effective. This finding does not change even though only cheaper soft measures were used. This points out the need of a careful planning and implementation of adaptation, irrespectively on the type, looking for measures apt to control its unit cost. This said, it is worth stressing that hard measures, like irrigation, are less flexible than soft interventions. In a context of climatic uncertainty, this calls for additional caution in their use.

There are many limitations of the current research. Firstly, climate change is assumed to affect only agriculture in Nigeria. Negative effects on crops productivity outside the country may well reduce competitiveness loss of Nigerian food commodities, but can also increase further their price with a more adverse effect on Nigerian consumers. Aggregate effects on GDP can also differ from those highlighted. Another limitation is surely the very aggregated and stylized representation of adaptation which appears as an undifferentiated (non sector specific) expenditure without any additional effect respect to damage reduction. Both aspects will be addressed in future research.

ACKNOWLEDGMENTS

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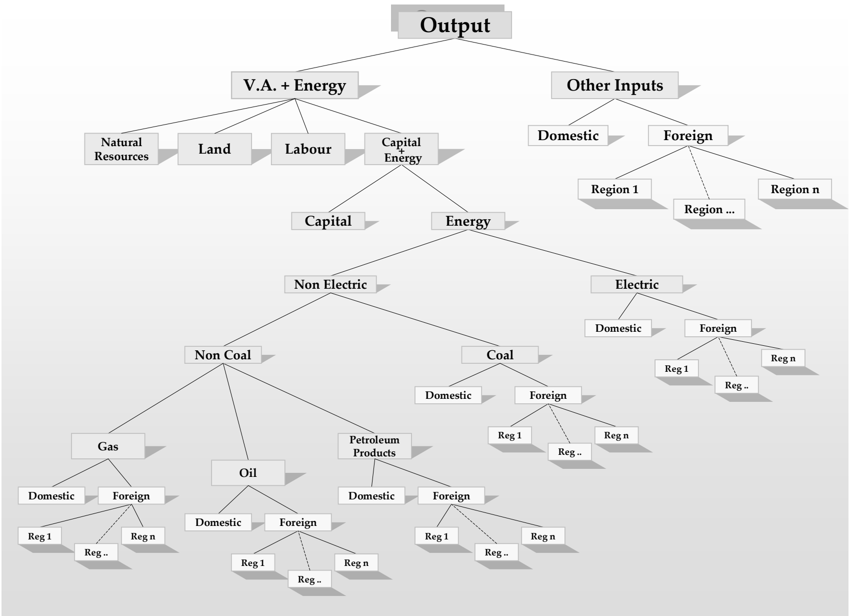
ANNEX: THE ICES MODEL

In its basic structure, ICES makes use of the Walrasian perfect competition paradigm to simulate market adjustment processes, although the inclusion of some elements of imperfect competition is also possible. Industries are modelled through a representative firm, minimizing costs while taking prices as given. In turn, output prices are given by average production costs. The production functions are specified via a series of nested CES functions. Domestic and foreign inputs are not perfect substitutes, according to the so-called "Armington" assumption (Figure A1).

Figure A1. Nested tree structure for industrial production processes of the ICES model

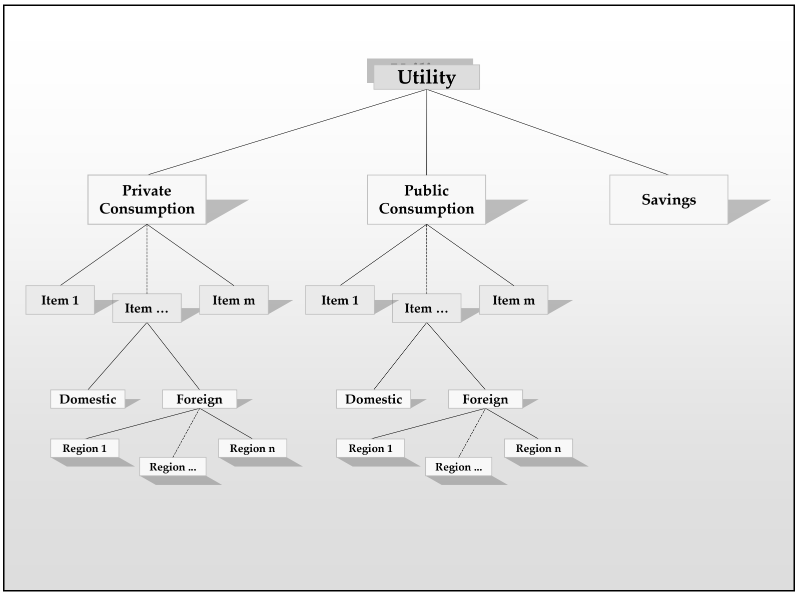


A representative consumer in each region receives income, defined as the service value of national primary factors (natural resources, land, labour, capital). Capital and labour are perfectly mobile domestically but immobile internationally. Land and natural resources, on the other hand, are industry-specific. This income is used to finance three classes of expenditure: aggregate household consumption, public consumption and savings. The expenditure shares are generally fixed, which amounts to saying that the top-level utility function has a Cobb-Douglas specification.

Public consumption is split in a series of alternative consumption items, again according to a Cobb-Douglas specification. However, almost all expenditure is actually concentrated in one specific industry: non-market services.

Private consumption is analogously split in a series of alternative composite Armington aggregates. However, the functional specification used at this level is the Constant Difference in Elasticities form: a non-homothetic function, which is used to account for possible differences in income elasticities for the various consumption goods (Figure A2).

Figure A2. Nested tree structure for final demand of the ICES model



Investment is internationally mobile: savings from all regions are pooled and then investment is allocated so as to achieve equality of expected rates of return to capital.

In this way, savings and investments are equalized at the world, but not at the regional level. Because of accounting identities, any financial imbalance mirrors a trade deficit or surplus in each region.

The recursive-dynamic engine for the model can replicate dynamic economic growths based on endogenous investment decisions. As standard in the CGE literature the dynamic is recursive. It consists of a sequence of static equilibria (one for each simulation period which in the present exercise is the year) linked by the process of capital accumulation. As investment decisions which build regional capital stocks are taken one year to the other, i.e. not taking into account the whole simulation period, the planning procedure is "myopic". Two factors drive endogenously investment and its international allocation: the equalization of expected rate of return to capital and the international GDP differentials. In other words, a country can attract more investment and increase the rate of growth of its capital stock when its GDP and its rate of return to capital are relatively higher than those of its competitors.

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