Climate Change and Agriculture in South Asia: Studying Optimal Trade Policy Options

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Abstract:

This paper aims to study how alternative trade policies will help mitigate the effects of climate change in agriculture in South Asia. We use a modified version of MIRAGE CGE for long term projections and allowing modeling of climate change effects (impact on yield) at a subregional level (163 geographical units at the world level) to simulate the effects of 13 SRES scenarios in 8 different trade policy landscapes. Based on these results, we discuss the ranking of trade policy options based on expected values but also in terms of variance using the theory of decision in uncertainty. Choices between unilateral and regional strategies are discussed.

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1 Introduction

In an ideal case, modeling the long run economic impacts of climate change requires combining different models. On the one hand, climate models (Global Circulation Models) provide us with information about the effects of changes in water availability and temperature on yield given the probable evolution of rainfall and atmospheric conditions over the years. On the other hand, to assess the economy wide effects of such global changes, computable general equilibrium models (CGE) provide an unmatched framework. Indeed, climate change has an impact on agricultural productivity, on commodity and factor prices. Through the factor price channels, factors will be reallocated in the economy and thus sectoral specialization will change. In addition, income will be affected and the demand behavior will be modified. These changes however do not occur in a closed economy but at a global level with heterogeneous effects across countries and commodities. Comparative advantages evolve, trade patterns adapt and countries are affected by both the domestic effects of climate change but also by the modifications of relative prices on world markets (terms of trade effects). With time, considering income and current account constraints, productions will be reallocated across sectors and across regions to adapt to the exogenous changes in yields. Depending of the situation, general equilibrium effects will mitigate or magnify the initial impacts of climate changes. Similarly, in a second best world, the optimal ex ante trade policy is not straight forward to define.

Here we combine climate models and computable general equilibrium model to analyze the impacts of climate change in South Asia. First, we use the set of IFPRI tools gathered under the IMPACT framework to assess the effects of changes in water availability and temperature on yield assuming economic behavior as constant. Then, we feed these exogenous changes in a modified MIRAGE global computable general equilibrium model to assess the overall economic consequences of these evolutions. The model has been expanded to provide a more accurate description of land use and long term dynamic issues.

We focus our analysis on South Asia, a key player at the world level in terms of production and consumption for key cereals and staple food. It has managed to cope with increasing domestic demand for these commodities by improving yields but has not developed large export surplus. It also relies on many interventionist policies for grains that have forced domestic adjustments instead of trade solutions. In this context, it is obvious that strong yield growth is expected to protect this situation and that any perturbation coming from climate change can lead to a quick deterioration of the regional food balance.

While the general consequences of increasing atmospheric concentrations of GHGs are increasingly well known, great uncertainty remains about how climate change effects will play out in specific locations. We discuss the changes in yields related to the different climate change scenarios on yields for the selected crops (maize, wheat, rice, soybeans and groundnuts) estimated by the DSSAT crop model. All scenarios show an average decline in average global exogenous (before CGE effects) yields results ranging from -0.6 percent to -11 percent. We see that regions with the largest initial production are going to be relatively more affected by the climate change than initially low productive regions. This may involve significant changes in trade pattern when the high yield regions are the source of traditional exports. With respect to South Asia, the region is strongly affected, with wheat the most negatively impacted as yields are expected to decline by -11.5 percent.

Since policy makers have more control on trade policy options, and can implement them earlier, we consider different trade policy scenarios that will be implemented between 2010 and 2024 and will change the landscape in which climate change will occur. We consider eight trade policy landscapes, involving potential tariff reductions from their starting level in 2007 with varying degree of liberalization and regional integration. Therefore, we simulate 124 different combinations of trade policies and climate change cases using the MIRAGE model. Our results confirm that South Asia will be one of the most adversely affected regions in terms of the impacts of climate change on agricultural yield. Both the overall level of economic activity and trade flows will react to this change (-0.5 percent of real income for the region in average, up to -4 percent for Pakistan). Beyond national real income, we also look at the distributional effects of climate change. Unskilled worker real wages, proxy for poor people income, are largely and generally negatively impacted by climate change.

Finally, our analytical framework based on a large number of simulations has allowed us to have some information on the average but also the risk driven by climate change of different trade policy options. Adopting a risk analysis approach and assuming different levels of risk aversion for regional policy makers the choice of an optimal strategy is discussed (as in a portfolio approach). First using the simple average between SRES scenarios, it appears that except for India all the other smaller economies should favor the status quo or the deepening of regional, SAFTA focused, integration. India may choose more ambitious trade policies with a trade agreement agenda at a pan Asia level or even at a global scale. For some degree of risk aversion, these preferences may be reverted. Contrarily to the national representative agent, for the poorer, unilateral liberalization, including liberalization with sensitive products in some cases, may be the best strategy in terms of expected value. This is an important consideration for policy makers overweighting the welfare of poor people.

We conclude by showing that the degree of hysteresis and the sunk cost nature of some investments will be very important to know if some trade policy options have significant costs when they have to be chosen ex ante and need to be modified ex post.

2 Methodology

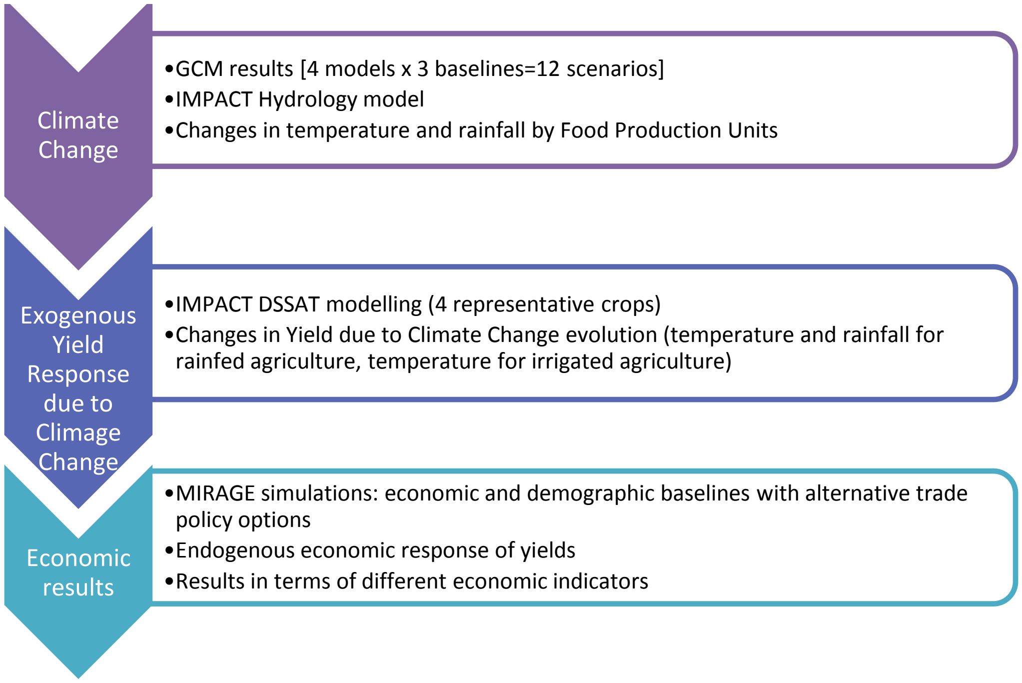
Modeling the economic impacts of climate change by 2050 requires combining different models. Our modeling framework is described in Figure 1. Taking results from different climate models (Global Circulation Models, GCM, listed in Table 1) about the probable evolution of temperature and rainfall, we use the set of IFPRI tools gathered under the IMPACT framework to assess the effects of changes in water availability and temperature on yield assuming economic behavior as constant. Then, we feed these exogenous changes in a modified MIRAGE global computable general equilibrium model (CGE) to assess the overall economic consequences of these evolutions. The CGE is also used to analyze these different climate change scenarios with different socio-economic baselines including alternative trade policies.

Table 1 List of GCM used in our analysis as inputs for climate change effects on temperature and precipitations

Label	Description
CNR(M)	Centre National de Recherches Météorologiques (Météo-France); abbreviation for the CNRM-CM3 general circulation model
CSIRO	Commonwealth Scientific and Industrial Research Organization; abbreviation for the CSIRO-Mk3.0 general circulation model
ECH(AM)	abbreviation for the ECHam5 general circulation model, developed by the Max Planck Institute for Meteorology, Germany
MIROC	abbreviation for the MIROC 3.2 medium resolution general circulation model (produced by the Center for Climate System Research, University of Tokyo; the National Institute for Environmental Studies; and the Frontier Research Center for Global Change, Japan)

This section details the methodology used.

Figure 1 Modeling Framework



2.1 Modeling the Climate Change effects on Yield: the IMPACT framework

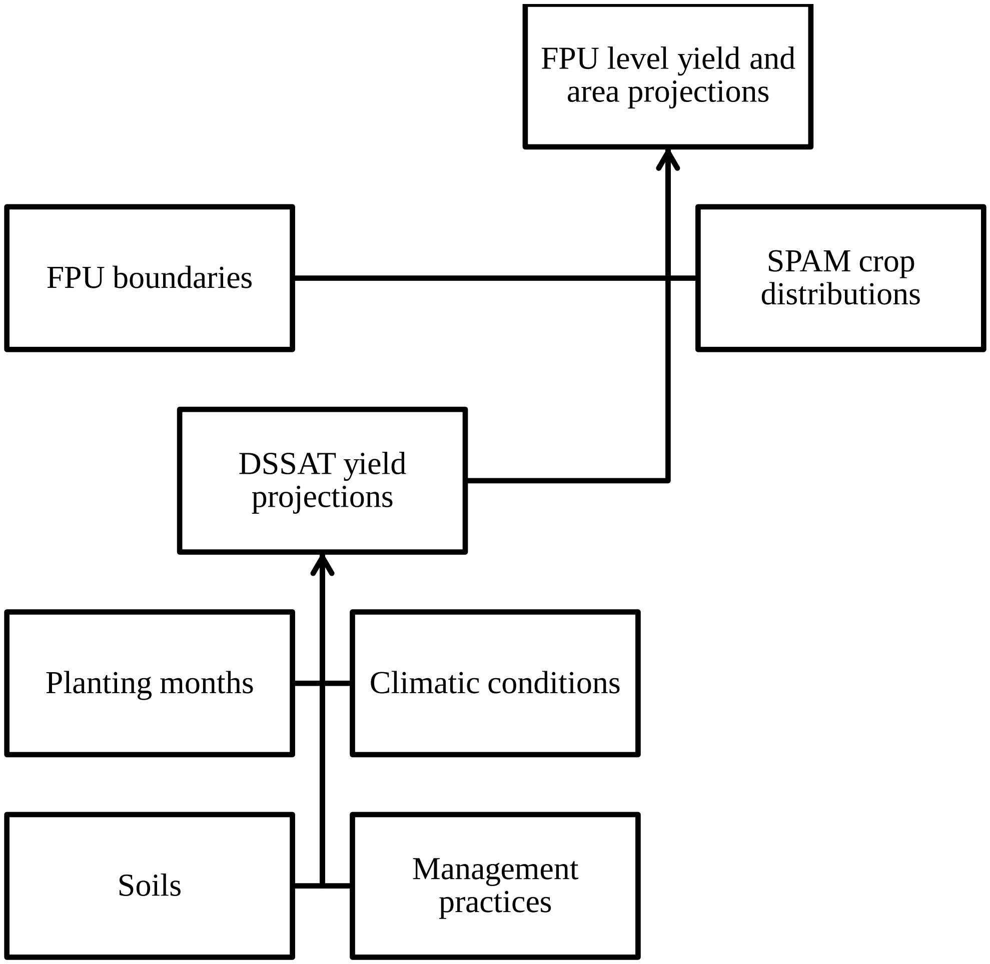
The guiding principle for linking the biophysical characteristics into the economic model is that climate change will affect the supply functions differently in different regions by altering the trajectory of the productivity growth rates. These effects are projected by calculating location-specific yields for each of the crops modeled with DSSAT (currently maize, soybeans, rice, wheat, and groundnuts) for both 2000 and future climates and calculating an annual growth rate. The growth rate is used to alter the intrinsic productivity growth rate of crop yield in economic models (IMPACT, MIRAGE).

2.1.1 The IMPACT framework

The adjustments that will affect intrinsic productivity growth rate are needed for each Food Production Unit (FPU) in IMPACT.

The overall linkages and dependencies leading to these typical yields are depicted in Figure 2. At the top of the diagram are the yields and areas that are used to compute the adjustments to the growth rates. These immediately depend on the pixel level yields projected by DSSAT which are aggregated up to the regional FPU level based on the geographic boundaries of the FPUs and are weighted by the crop distribution found in the SPAM datasets. The yield projections are based on four major inputs: the climatic conditions, the planting month, the soils, and the collection of management practices.

Figure 2 Links leading to the incorporation of climate change into IMPACT



To capture the different capacity of crops to react to climate change, based on their carbon fixation and photosynthesis capacity, a mix of C3 and C4 plants have been simulated with DSSAT. Currently, results for all SRES scenarios in the IMPACT framework are: Groundnut, Maize, Rice, Soybean and Wheat. These crops cover directly, or indirectly, most of the nutritional needs of the animal and human consumption based on active human production.

For other crops in the model, we use a simple average of the relevant C3 or C4 simulated crops based on the plant category. This method is imperfect but at least offer a consistent framework (same methodology). In addition, assuming no change in yield for non-simulated crops will be an even more challenging choice since it will assume that they perfectly adapt to climate change and will expand strongly. By choosing a simple average, we limit extreme behavior and ensure that these crops will follow the main trend.

The crop results used in this article are based on the work of Ricky Roberston and Jerry Nelson of IFPRI (see Nelson and al. 2010 and Laborde and al. 2010 for additional details).

2.2 The MIRAGE model for Climate Change Analysis

To assess the economy wide effects of such global changes, the CGE provides an unmatched framework. Indeed, climate change is going to modify agricultural productivity. It will have a direct impact on agriculture commodity prices and factor prices. Through the factor price channels, factors will be reallocated in the economy and as a result sectoral specialization will change. In addition, income will be affected and the demand behavior will be modified. Demand will also be affected by change in prices and food consumption, even if inelastic, will suffer from these changes. Since agricultural products (crops but also fibers and animal products such as leather) are important inputs for many sectors, the changes in their prices will affect other sectors. All these channels require the use of CGE that would monitor them. In addition, these changes do not occur in a closed economy but at a global level with heterogeneous effects across countries and commodities. Comparative advantages evolve, trade patterns adapt and countries are affected by both the domestic effects of climate change but also by the modifications of relative prices on world markets (terms of trade effects). With time, considering income and current account constraints, productions will be reallocated across sectors and across regions to adapt to the exogenous changes in yields. Depending of the situation, general equilibrium effects will mitigate or magnify the initial impacts. For instance, capital can leave agriculture due to the negative shock on return on these sectors, accelerating the fall in the yields and productions in one country, or can move to this sector attracted by high prices, and then, will compensate, at least partially, the exogenous reduction in yields. Therefore we need to use a multi country, multi sector, dynamic CGE. Our analysis uses an upgraded and adapted version of the MIRAGE model. This sub-section describes the core model as well as the modification done for these long term projections.

In terms of trade analysis, the choice of the Armington assumption, equivalent with goods differentiated by country of origin is important and a major difference when compared with most partial equilibrium analysis, including the IMPACT model. It involves imperfect price transmission between international and domestic markets, and specific trade patterns at the bilateral level. On the contrary, partial equilibrium assuming perfect substitutes consider one world market for agricultural commodity, and unilateral net trade flows (except for spatial trade models). Nevertheless, if the latter approach has advantage in terms of tracking quantity and simplifying the modeling framework, the empiric literature (see Villoria, 2009, for a recent analysis) strongly argue in favor of the features produced by the Armington assumption: price transmission is imperfect, there is no such thing as a "single world market" and geography, as well as history, matters for explaining trade patterns.

The sectoral (20 sectors) and regional (20 countries and regions) disaggregation used is detailed in Table 2 and Table 3. They cover the most important trade blocks and commodities for this study. Section III will provide justifications for these choices by discussing trade and production patterns.

Table 2 Sectoral decomposition of the MIRAGE model

Code Sector	Description	Code Sector	Description
cattle	Cattle	**ffl**	Fossil Fuels
coarse	Coarse Grains	**Forestry**	Forestry
cotton	Cotton	**omn**	Other Minerals
Maize	Maize	**crp**	Chemical rubbers and plastics
oagr	Other Ag. Products	**mmet**	Mineral and metals
oilseed	Oilseeds	**moto**	Motor vehicles
Pulses	Pulses	**ome**	Machinery and equipment
rice	Rice	**omf**	Other manufacture products
sugar	Sugar	**p_c**	Petroleum & coal products
veget	Vegetables	**text**	Textiles
wheat	Wheat	**wap**	Wearing apparel
DairyMeat	Dairy and Meat products	**wpp**	Wood and paper products
Ofood	Other Processed Food	**serv**	Services
VegOils	Vegetal Oils	**trade**	Trade
Fishing	Fishing	**trans**	Transportation

Table 3 Regional decomposition of the MIRAGE model

Code Region	Description	Code Region	Description
ANZCERTA	ANZCERTA	**NAFTA**	NAFTA
CHN	China	**ARG**	Argentina
RAS	Rest of Asia	**LAC**	Latin America
CEA	Central Asia	**BRA**	Brazil
ASEAN	ASEAN	**CAM**	Central America
BGD	Bangladesh*	**EU27**	EU27
IND	India*	**XER**	Russia & Ukraine
PAK	Pakistan*	**MED**	Mediterranean Region
SLK	Sri Lanka*	**WAF**	Sub Saharan Africa
XAS	Rest of South Asia*	**SAF**	South Africa

*Note: An asterisk * indicates countries/regions belonging to South Asia*

2.2.1 Generic features of the MIRAGE model

This section summarizes the features of the standard version relevant for this study. MIRAGE is a multi-sector, multi-region Computable General Equilibrium Model devoted to trade policy analysis. The model operates in a sequential dynamic recursive set-up: it is solved for one period, and then all variable values, determined at the end of a period, are used as the initial values of the next one. Macroeconomic data and social accounting matrixes, in particular, come from the GTAP 7 database (see Narayanan, 2008), which describes the world economy in 2004. From the supply side in each sector, the production function is a Leontief function of value-added and intermediate inputs: one output unit needs for its production *x* percent of an aggregate of productive factors (labor, unskilled and skilled; capital; land and natural resources) and (1 – *x*) percent of intermediate inputs. The intermediate inputs function is an aggregate CES function of all goods: it means that substitutability exists between two intermediate goods, depending on the relative prices of these goods. This substitutability is constant and at the same level for any pair of intermediate goods. Similarly, in the generic version of the model, value-added is a constant elasticity of substitution (CES) function of unskilled labor, land, natural resources, and of a CES bundle of skilled labor and capital. This nesting allows the modeler to introduce less substitutability between capital and skilled labor than between these two and other factors. In other words, when the relative price of unskilled labor is increased, this factor is replaced by a combination of capital and skilled labor, which are more complementary.[2]

Factor endowments are fully employed. The only factor whose supply is constant is natural resources with a few exceptions detailed later. Capital supply is modified each period because of depreciation and investment. Growth rates of labor supply are fixed exogenously. Land supply is endogenous; it depends on the real remuneration of land. In some countries land is a scarce factor (for example, Japan and the EU), such that elasticity of supply is low. In others (such as Argentina, Australia, and Brazil), land is abundant and elasticity is high.

Skilled labor is the only factor that is perfectly mobile. Installed capital and natural resources are sector specific. New capital is allocated among sectors according to an investment function. Unskilled labor is imperfectly mobile between agricultural and nonagricultural sectors according to a constant elasticity of transformation (CET) function: unskilled labor's remuneration in agricultural activities is

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[2] In the generic version, substitution elasticity between unskilled labor, land, natural resources, and the bundle of capital and skilled labor is 1.1 - for all sectors except for agriculture where it is equal to 0.1 - whereas it is only 0.6 between capital and skilled labor.

different to that in nonagricultural activities. This factor is distributed between these two series of sectors according to the ratio of remunerations. Land is also imperfectly mobile between agricultural sectors.

In the MIRAGE model there is full employment of labor; more precisely, there is a constant aggregate employment in all countries (wage flexibility). It is quite possible to suppose that total aggregate employment is variable and that there is unemployment; but this choice greatly increases the complexity of the model, so that simplifying assumptions have to be made in other areas (such as the number of countries or sectors). This assumption could amplify the benefits of trade liberalization for developing countries: in full-employment models, increased demand for labor (from increased activity and exports) leads to higher real wages, such that the origin of comparative advantage is progressively eroded; but in models with unemployment, real wages are constant and exports increase much more.

Capital in a given region, whatever its origin, domestic or foreign, is assumed to be obtained by assembling intermediate inputs according to a specific combination. The capital good is the same whatever the sector. In this version of the MIRAGE, we assume that all sectors operate under perfect competition, there is no fixed cost, and price equals marginal cost.

The demand side is modeled in each region through a representative agent whose propensity to save is constant. The rest of the national income is used to purchase final consumption. Preferences between sectors are represented by a linear expenditure system–constant elasticity of substitution (LES-CES) function. This implies that consumption has a non-unitary income elasticity; when the consumer's income is augmented by *x* percent, the consumption of each good is not systematically raised by *x* percent, other things being equal. The sector sub-utility function used in MIRAGE is a nesting of four CES-Armington functions that defines the origin of the goods. In this study, Armington elasticities are drawn from the GTAP 7 database and are assumed to be the same across regions.

Macroeconomic closure is obtained by assuming that the sum of the balance of goods and services and foreign direct investments (FDIs) is constant.

2.2.2 Specific changes to deal with Climate Change analysis

To tackle the issues related to climate change, the MIRAGE model has been modified at several levels. After that new crops have been introduced, then the land use modeling has been to integrate the change in yields from IMPACT and adapted to operate at the water basin level, matching the

IMPACT FPU and finally numerous modifications have been done to reconcile the dynamic aspect of long term projections.

Introduction of new crops

To consider the heterogeneous effects of climate change on different crops and the important role of pulses in South Asia diet, we have added two sectors to the GTAP7 database: Maize and Pulses. The former has been “extracted” from the “other coarse grains” sector while the pulses have been taken from the “vegetable and fruits” GTAP sector. Information on production are originated from FAOSTAT. Trade information and tariffs are based on ADEPTA (Laborde, 2010).

Land use and Yields impacts

The first important modification of the MIRAGE model is to have land allocation decisions breakdown by water basins. Each region / country of the model has a land market operating at an infra-regional level, mimicking the IMPACT FPU. Using the FPU and the underlying river basin decomposition appears to be more robust for climate change analysis than using the Agro Ecological Zones (AEZ) as done in previous studies on medium term land uses effects (see Al Riffai, Laborde and Dimaranan 2010 for an illustration). Indeed, the AEZ classification incorporates elements on precipitation, water and cropping period that are highly endogenous to the question we study here.

We have 161 land markets (region x basin) in which producers allocate land among crops, through a CET function (elasticity of transformation of 0.5 for all basins), mimicking the standard land supply representation in MIRAGE at a national level. Of course, the same river basin can be shared by different countries. In such a case, markets are segmented by both the river basin and political borders. Each segment will have its own land price and producers will take independent decisions. However, the yield evolution in these differentiated segments may be correlated due to climatic events. At a national level, all the sub-regional land supplies for one crop are aggregated through a CET function (with an elasticity of transformation equals to 6) and provide the aggregate land supply for the production function. This large but still imperfect substitution captures the fact that production can be redistributed among different regions of a country on the long run, still respecting biophysical yield, but such reallocation is still sluggish (infrastructure, road etc.).

This modeling approach is important the following reason by considering only one national land market, the yield shift coming from the crop model need to be aggregated at the national level using some weights. Using fixed weights, e.g. initial surface, will freeze the link between geographical distribution of production within a country and yield changes. It will not allow to capture the endogenous reallocation effects. Worst, it brings a confusion between geographical yield change and sectoral yield change. Let's take an example with a country having two regions A & B, and two crops X and Y. Yields are initially homogenous. Assuming that A & B have the same area and A is specialized at 90% in X and B at 90% in Y. We assume that the region A is strongly affected by climate change (e.g. one specific river basin) and yield decrease by 50%, B is unaffected. Operating with a single land market and importing aggregated yield will conclude that Y has an average yield going done by 5% when X will have a sharp yield decline by 45%. In most of the case, except extreme inelastic demand and close economy, substitution effects will dominate and production factor (as capital) will flow from sector X to Y. In addition, since the change in yield is sector specific and with a standard MIRAGE closure, productivity of land moved from X to Y will increase. However, this effect is erroneous since the new land taken from X comes from region A and has lower yield for both crops. With our basin approach, we are sure to respect the message from the crop model by river basin and for each specific crop.

A second important issue is our treatment of irrigation. We do not model irrigation expenditures or effects in the CGE. Even if agriculture can become more intensive (more unit of labor and/or capital by unit of land) and physical productivity of land will increase, we do not associate this with concrete investment projects in physical infrastructures (irrigation, roads, draining) or immaterial assets (R&D, new varieties). The IMPACT framework provides the change in yield for irrigated and rainfed crops separately. We assume that the ratio between rainfed and irrigated areas will remain the same for each crop, and each food production unit, for all years, for all scenarios. Therefore, we can compute an average yield by crop, and its changes, for each FPU using initial ratio between irrigated and rainfed production. Since we do not model irrigation activity, we do not model the water market neither in the CGE. A limitation of this approach is that during expansion of crops that are initially highly irrigated, we consider that these infrastructures are provided for free, underestimating these expansion costs. However, the problem is only significant when large areas initially occupied by a rainfed crop are replaced by a strongly irrigated crop. With the lack of representation of the water market and irrigation in the CGE, it also implies that the extension of irrigated crop will lead to an incremental demand of water that is not considered as a scarce resource here. Therefore, it will not lead to a competition with other sectors or crops and will not generate water stress somewhere else.

Last, it is important to model the yield shock properly. Indeed, the crop model provides us information on the changes in yield - based on temperature and water availability variation - for a define technology (fertilizers, other inputs) for each period. Therefore, we need to calibrate in our model, with our own technology (i.e. production function and elasticity), the shift in land productivity at the FPU level that will generate for each crop the same change in physical yield (unit produced by unit of land) estimated by the crop model. This procedure is straightforward since we can use the CES function that defines value added and rearrange it to compute a parameter γ for each FPU and each crop that multiply the amount of land use in this sector generating the targeted yield assuming other factors constant. Then, during the simulations, this parameter is fixed and the producer will modify his factor demands to take into account this factor specific productivity shifter. Indeed, we consider here a non-neutral productivity shock. Depending on the elasticities of the model, more factors can be used to compensate the productivity loss of land and support production or at the opposite due the decline of their marginal productivity (positively correlated with the exogenous productivity of other factors) will leave the sector. For capital, new investment will be avoided and the capital stock will erode.

Dynamic perspectives

Projecting the world economy to 2050, in particular when focusing on a fast growing, and large region as South Asia is a challenging task that requires adapting the dynamic structure of MIRAGE as well as make careful choice in terms of baseline assumptions: dynamic modeling choices affect significantly the comparative advantages in the baseline since they modify relative factor endowment in the different economies.

First, the model operates not on a yearly basis but by step of five years. This solution saves computational time and since no scenario information is provided with more accuracy - climate impacts are estimated for 2050 and then backwardly interpolated linearly - there is no gain to use a yearly frequency. In terms of factor supply, we have operated different modifications. Physical investment decisions follow the same behavior as in the standard version of MIRAGE. No foreign direct investment is allowed. Saving rate is not readjusted since this parameter is impacted by many different mechanisms some being known (demography) and other unknown (future social safety net, pension system reform) for the economies we study. The only change is performed for China that stands as an outliner in the GTAP database (saving rates above 40%) when all other important economies are between 15 and 25%. We bring down the saving rate of China linearly to 30% by 2050 to avoid the explosive investment path generated otherwise. A more important modification is done for the labor accumulation. The total number of workers is based on the population projections (United Nations) and an activity rate (ILO for available projected years). The split between skilled and unskilled evolve through a wage gap equation that is aimed to mimic incentives for education. The ratio between skilled and unskilled labour of the representative household is an isoelastic function of the ratio between the last ten year mobile average of skilled labour and unskilled labour. The elasticity has been calibrated (0.9) for all countries to have a meaningful dynamic path in terms of catching up by developing economy. Last, to avoid an explosion of natural resource prices, especially minerals, we consider an isoelastic supply of natural resources (production factor) in the mining sector, but not for fossil fuels. All these mechanisms are activated only during the baseline calibration. These factor supplies will remain constant between all alternative trade policy baselines and climate change scenarios.

In terms of demand, two modifications have been made. First, for final demand, a dynamic recalibration of the CES – LES is implemented. It aimed to capture the evolution of the standard of living. Indeed, without dynamic recalibration, the CES LES displays an increase of price elasticity for countries where the rise in income has brought current level of consumption, in particular for food products, far from their initial level. Our dynamic recalibration allows to redefine the minimal per capita consumption of the CES LES and the elasticity of substitution, between each period in order to remain as close as possible of our targeted income and price elasticity for each commodity and region. This recalibration is only performed in the baseline and temporal values of parameters are used in the simulations. This allows maintaining the same preferences structure between the baseline and the simulations and perform welfare analysis. Second, we introduce an energy efficiency parameter on the use of fossil fuels (oil and gaz). We calibrate this parameter, applied homogenously on all demand, to reproduce the IEA projection of energy prices.

Finally, to avoid explosion of cumulated current account imbalances, we force all current account to converge to zero by 2050. Consequently, the real exchange rates evolve endogenously to adjust the trade balance.

In addition to the other dynamic calibration steps described above, we have additional assumptions and mechanisms that allow us to build our dynamic baseline. Our main target is a GDP growth based on World Bank projections and used in the central scenario of IMPACT long term projections (see Nelson et al, 2010). With total labor force exogenous (population and activity rate assumptions), endogenous capital accumulation and endogenous skilled / unskilled split, our model has only one degree of freedom by region to reach this target in GDP, volume: the total factor productivity (TFP) for all sectors and factors. Therefore we calibrate endogenously (normal MIRAGE procedure). However, if this TFP is applied to all factors, agricultural yield will grow at a very impressive rate, in particular in the case of India. Therefore, we correct this TFP with an agriculture specific TFP that reduces the generic term. Practically, this additional term is country, sector specific and is freed during the calibration stage to target exogenous growth rate of physical yield in agriculture based on the IMPACT baseline that provides detailed assumption for different crops and regions.

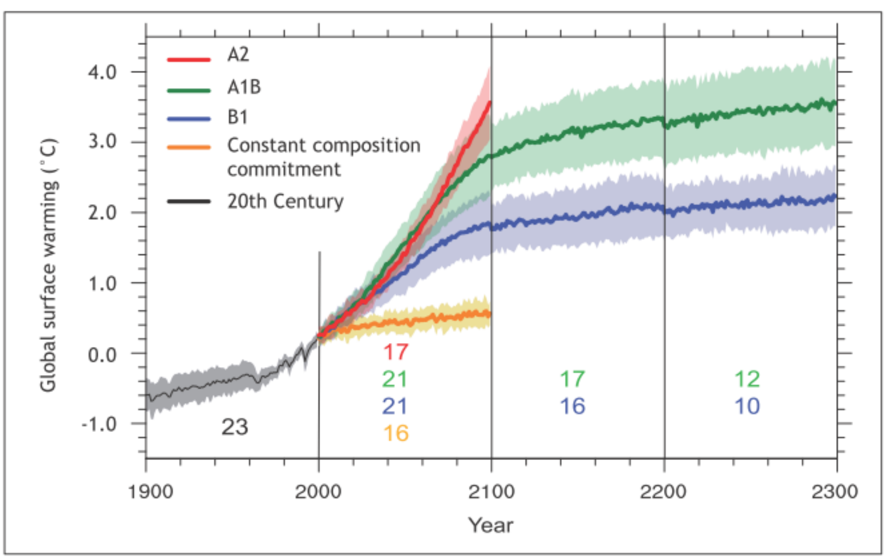
Using this procedure, we manage to build a dynamic baseline presenting different desired features: evolution of the economic size of the different regions (GDP), income per capita, relative prices between factors, relative productivity between sectors… Last, it is important to precise three elements: our baseline is independent of the SRES scenarios in terms of emissions. Indeed, the same GDP growth can be achieved through very different technological pathways in terms of GHG effects. Similarly, all the calibration process is performed with a status quo assumption in terms of trade policy. Our study includes different trade policy options to study the role of the trade environment on the consequences of climate change. However, these trade policy modifications are implemented in the last stage of the baseline, during the policy pre-experiment and not during the calibration stage. It implies that GDP of countries will change between alternative trade policy baselines, but not the TFP. Finally, we do not incorporate any demand of agricultural feedstock for biofuels. In this study we consider that 1st generation biofuels, and potentially the second generation, will be phased out by 2050 and that bioenergy program will not imply more pressure on agricultural lands.

3 Climate change scenarios

Introducing the effects of climate change scenarios into the overall food and agriculture scenarios presents a particular challenge, to take into account the range of plausible pathways for greenhouse gas (GHG) emissions. Moreover, the general circulation models (GCMs) translate those emission scenarios into varying temperature and precipitation outcomes. While the general consequences of increasing atmospheric concentrations of GHGs are increasingly well known, great uncertainty remains about how climate change effects will play out in specific locations. Therefore we will rely on 12 alternative climate change scenarios that will help us provide the space of potential outcomes from climate change for South Asia. These 12 SRES[3] scenarios are the result of the combination of GHG paths and alternative GCM models.

Figure 3 shows the range of average surface temperature outcomes for the GHG pathways in the SRES scenarios of the IPCC. By 2050, the global surface warming for the A1B, A2, and B1 scenarios is roughly the same, at about 1°C above the reference period of the late 20th century. The temperature increases diverge significantly after 2050, with the A2 scenario resulting in the highest increases by the end of the 20th century, of about 3.5 °C. Because the analysis in this report stops in 2050, it does not capture the effects of the large increases expected in later years.

Figure 3 Emissions scenarios: change in temperature



Source: Reprinted with permission from the Intergovernmental Panel on Climate Change (2007).

[3] Special Report on Emissions Scenarios of the Intergovernmental Panel on Climate Change

Table 4 displays the consequences of these different emission paths in terms of precipitation and temperature. First, as average temperatures rise, so does the annual precipitation that falls on land. A 1°C increase in average temperature typically results in less than a 1 percent increase in average annual precipitation. Temperature increases of over 2°C result in 2–5 percent increases in precipitation. Second, with identical GHG emissions, the GCM climate outputs differ substantially. The most extreme comparison is with the outcomes of the B1 scenario. The CSIRO GCM has almost no increase in average annual precipitation and the smallest temperature increase of any of the GCM/GHG scenario combinations. The MIROC GCM has the second largest increase in precipitation (with the B1 scenario) and one of the largest increases in average temperature. So, it appears that the CSIRO scenarios are dryer and cooler when the MIROC results describe a warmer and more humid future. The ECH and CNR models display intermediate pictures where the ECH GCM appears to be dryer than the former.[4]

Table 4 Alternative GCM models results in terms of temperature and precipitation

GCM	SRES scenario	Change between 2000 and 2050 in the annual averages			
		Precipitation (percent)	Precipitation (mm)	Minimum temperature (°C)	Maximum temperature (°C)
CSIRO	**B1**	**0.0**	**0.1**	**1.2**	**1.0**
CSIRO	**A1B**	**0.7**	**4.8**	**1.6**	**1.4**
CSIRO	A2	0.9	6.5	1.9	1.8
ECH	B1	1.6	11.6	2.1	1.9
CNR	B1	1.9	14.0	1.9	1.7
ECH	A2	2.1	15.0	2.4	2.2
CNR	A2	2.7	19.5	2.5	2.2
ECH	A1B	3.2	23.4	2.7	2.5
MIROC	A2	3.2	23.4	2.8	2.6
CNR	A1B	3.3	23.8	2.6	2.3
MIROC	**B1**	**3.6**	**25.7**	**2.4**	**2.3**
MIROC	**A1B**	**4.7**	**33.8**	**3.0**	**2.8**
Multi-model ensemble mean					
	A1B	1.51		1.75	
	A2	1.33		1.65	
	B1	1.65		1.29	

Source: From Nelson and al. 2010.
Note: Please consult appendix II of Nelson et al, 2010, for exhaustive discussion on the GCMs. Model acronyms are explained in Section 2.

[4] See www.ipcc.ch/publications_and_data/ar4/wg1/en/suppl/chapter10/Ch10_indiv-maps.html for detailed results and maps.

In the following sections, each scenario will be named by the three first letters of the GCM and the two first letter of the SRES scenario (e.g. *mir_a1* will stand for MIROC GCM, SRES A1B).

3.1 Analysis of Climate Change on Yields

This section will display and discuss the changes in yields related to the different climate change scenarios on yields for the selected crops (maize, wheat, rice, soybeans and groundnuts) estimated by the DSSAT model.

3.1.1 Impact on global yields

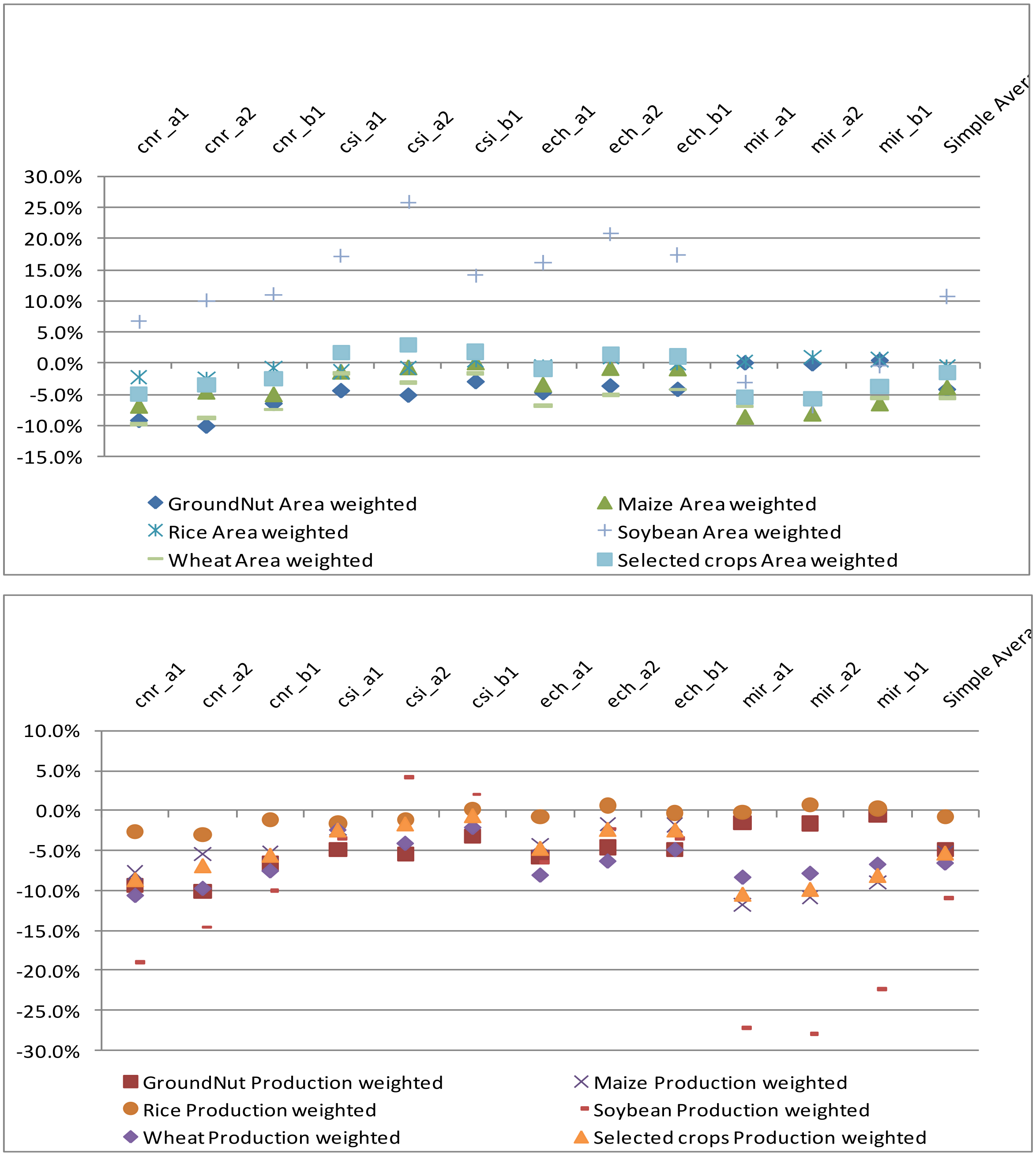
We summarize the DSSAT simulations with Figure 4 showing the change in yields driven by climate change for different scenarios at a global level. We also display the simple average across scenarios.

First, all scenarios show an average decline in average yields (weighted by initial production) from -0.6% (*csi_b1* scenario) to -11% (*mir_a1* scenario). These extreme values match the extreme temperature and precipitation scenarios discussed in Table 4. The wetter and warmer scenario (*mir_a1*) being the most adverse.

The most affected crops are wheat and maize overall (simple average across scenarios show a decline of yield of 5% or more). For these commodities, heterogeneity among scenarios is still important at the world level (with a coefficient of variation across scenarios of 45% and 75%, respectively). However, rice (rainfed) and soybeans are less affected in average but the variance across scenarios is higher (coefficient of variation above 100%, up to 160% for rice).The extremes (10% or more in yield declines) are reached for groundnut and wheat in scenarios *cnr_a1* and *cnr_a2* and maize and soybeans scenarios *mir_a1* and *mir_a2.*

Second, a broad hierarchy can be defined across scenarios from the most adverse to the less: *mir_a1, mir_a2, cnr_a1, mir_b1, cnr_a2, cnr_b1, ech_a1, csi_a1, ech_b1, ech_a2, csi_a2, csi_b1*. Of course, some crops display some reversal: for instance, the groundnut production is less affected by the *mir* scenarios, that are in average more adverse, than by others.

Figure 4 Changes in world yield (Rainfed) due to climate change for different scenarios and selected crops. Initial Area and Production weighted.

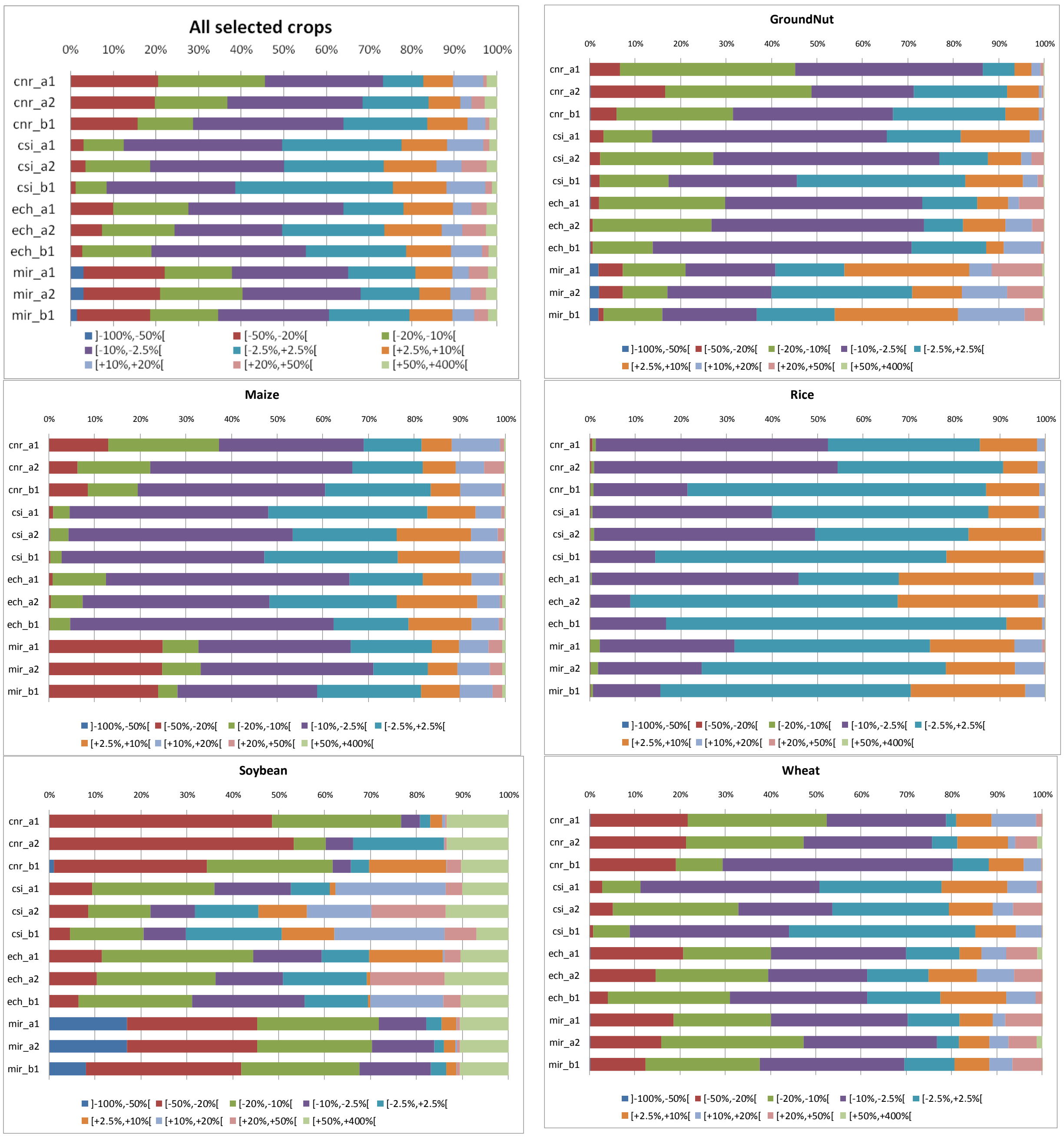


Source: DSSAT model simulations

By comparing the lower and upper panels of Figure 4, we can see that the average change in yields weighted by initial production are more pessimistic that the average changes weighted by area (e.g. scenario *cnr_a1* the increase of average yield by ha is improved by 6.7% when it declines by 18% when weighted by production). This pattern is checked for all crops and all scenarios. However, the effects are very large for soybeans (from +11% in average to -11% in average) and maize (-4% to -

5.2%). The explanation is simple: the regions with the highest yield are going to be relatively more affected by the climate change than initially low productive regions. This may involve significant changes in trade pattern when the high yield regions are the source of traditional exports.

Figure 5 Distribution of yield changes under alternative climate change scenarios. Weighted by area (Rainfed).



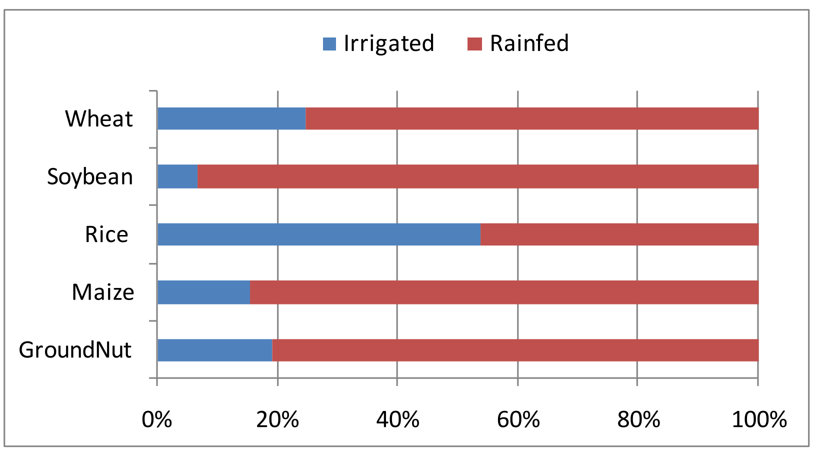
Source: DSSAT mode simulations

Figure 5 displays the yield change distribution of the rainfed cropland. As it is shown, except for soybean and rice, most of the areas affected will suffer from a moderate decrease of yield (-10% to -

2.5%). If we neglect rainfed rice all the distributions have flat tail on the right. Soybean has the most contrasted picture across regions and scenarios with at the same time both large areas with large yield decrease (more than 20%) and large potential gains (beyond 20%). For several scenarios (*cnr* and *mir* types), maize and wheat have large areas affected by fall in yield of more than 20%.

The previous discussion was focused on rainfed agriculture. As show by Figure 6, rainfed agriculture represents more than 80% of cultivated area for all the crops considered. In the DSSAT simulations, irrigated crops are just affected by the change in temperature. Water availability is considered to be sufficient to maintain optimal level. However, the change in yields are more important for irrigated than rainfed agriculture (-6% to -11% for the production weighted average for selected crops over all scenarios). The yield decrease is larger but less disperse across scenarios (standard deviation about 20% for the different crops). Indeed, only the temperature heterogeneity across scenarios plays a role here. Among irrigated crops, wheat yields are the most affected: for all scenarios they are between 10% and 16% at the world level (versus below 10% for the rainfed wheat). As already noticed, it implies that the different climate change scenarios will have larger effects on regions with initially high yields (both driven by better conditions under rainfed management or by irrigation)[5].

Figure 6 Share of rainfed agriculture at the world level for selected crops



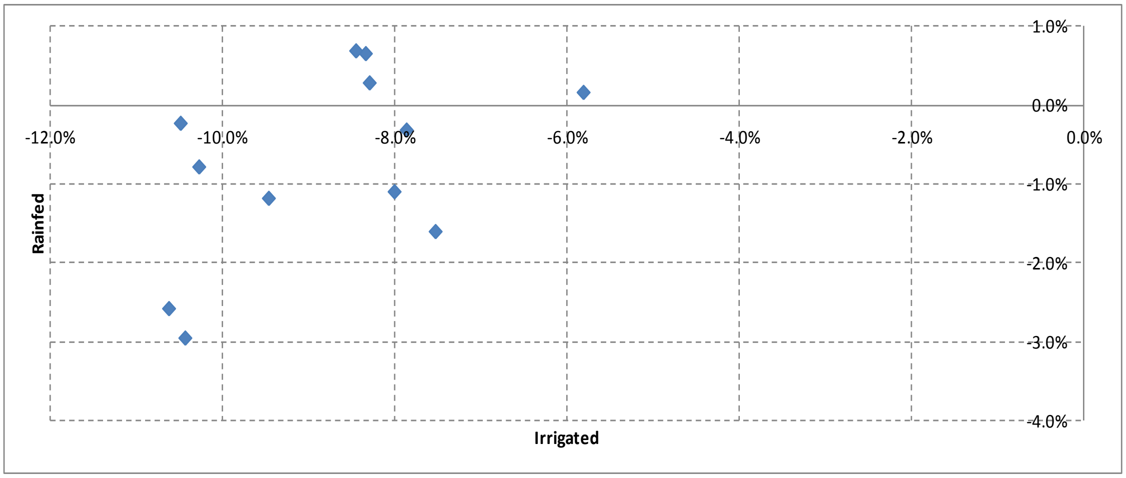
Source: IMPACT model database

Last, it is important to discuss specifically the case of rice. As shown in Figure 4 and Figure 5, rainfed rice is weakly affected by climate changes (changes between +1% and -3%). Figure 7 displays for rice the average change in yields between rainfed and irrigated. We clearly see that the effects on

[5] Incidentally, it also implies that in some regions, the adverse effects of higher temperature are compensated by additional water for rainfed crops.

irrigated rice will be much larger (two to three times) than for the rainfed case. Therefore, the optimistic picture we got for rainfed rice will be changed when we will look at overall rice production since most of it comes from irrigated land. More precisely, the rice yield will decrease by 6.6% in average over all scenario (production weighted).

Figure 7 Distribution of change in global yield of rice (production weighted) for rainfed and irrigated production.



Source: IMPACT model database and DSSAT simulations

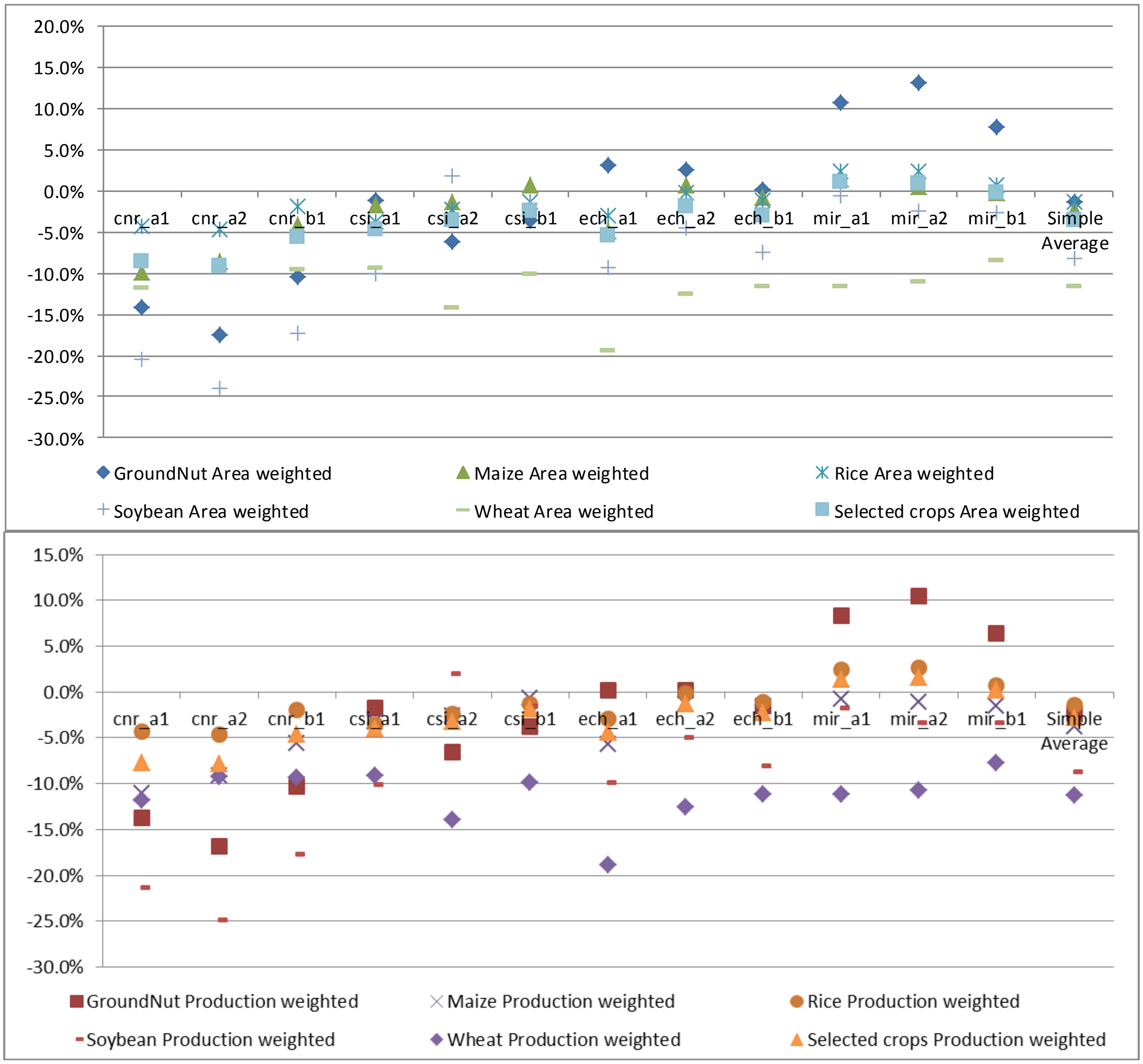
3.1.2 Impact on yields in South Asia

While the previous section discussed the impact of different climate change scenarios on yields on a global level, this section is aimed to provide further details for SAFTA countries (we only discuss the 4 SAFTA countries that are explicitly represented in the model).

Figure 8 below represents changes in yield in South Asia for selected crops (rainfed) as a result of different climate change scenarios. Let's start with a closer look at simple averages across crops and scenarios: thus we find that as opposed to what we find on the global level the results weighted by area are slightly more pessimistic (-3.5% decrease in yields) than those weighted by production (-2.8% decrease in yields). Across scenarios, scenarios *cnr_a1* and *cnr_a2* have prominent negative effects on average yields (-8.6% and -9.1% area weighted decline in yields, respectively) while scenarios *mir_a1* and *mir_a2* lead to a slight increase in average yields. Interestingly, we note that results weighted by area are close to that weighted by production reflecting a relative homogeneity in productivity across SAFTA counties (compared to the global level where the heterogeneity in productivity across countries lead to a more pronounced gap between the production and area weighted results).

Among crops, the average across different scenarios is negative for all crops using both production and area weights. Wheat and soybeans are the most negatively impacted as yields are expected to decline by -11.5% and -8.2% (area weight), respectively. On the other hand, across scenarios groundnuts and rice are the least impacted. Nevertheless, a closer look at average yield change for groundnuts for different scenarios shows very high coefficient of variation (779% using area weights and 352% using production weights). More specifically, we find that scenarios *cnr_a1, cnr_a2* and *cnr_b1* result in significant declines in groundnut yields, while *mir_a1, mir_a2* and *mir_b1* lead to significant increase in yields. With respect to wheat, all climate change scenarios considered here lead to a decline in yields in SAFTA countries, more pronounced in *ech_a1* and *csi_a2* (-19.4% and -14.2% using area weights, respectively).

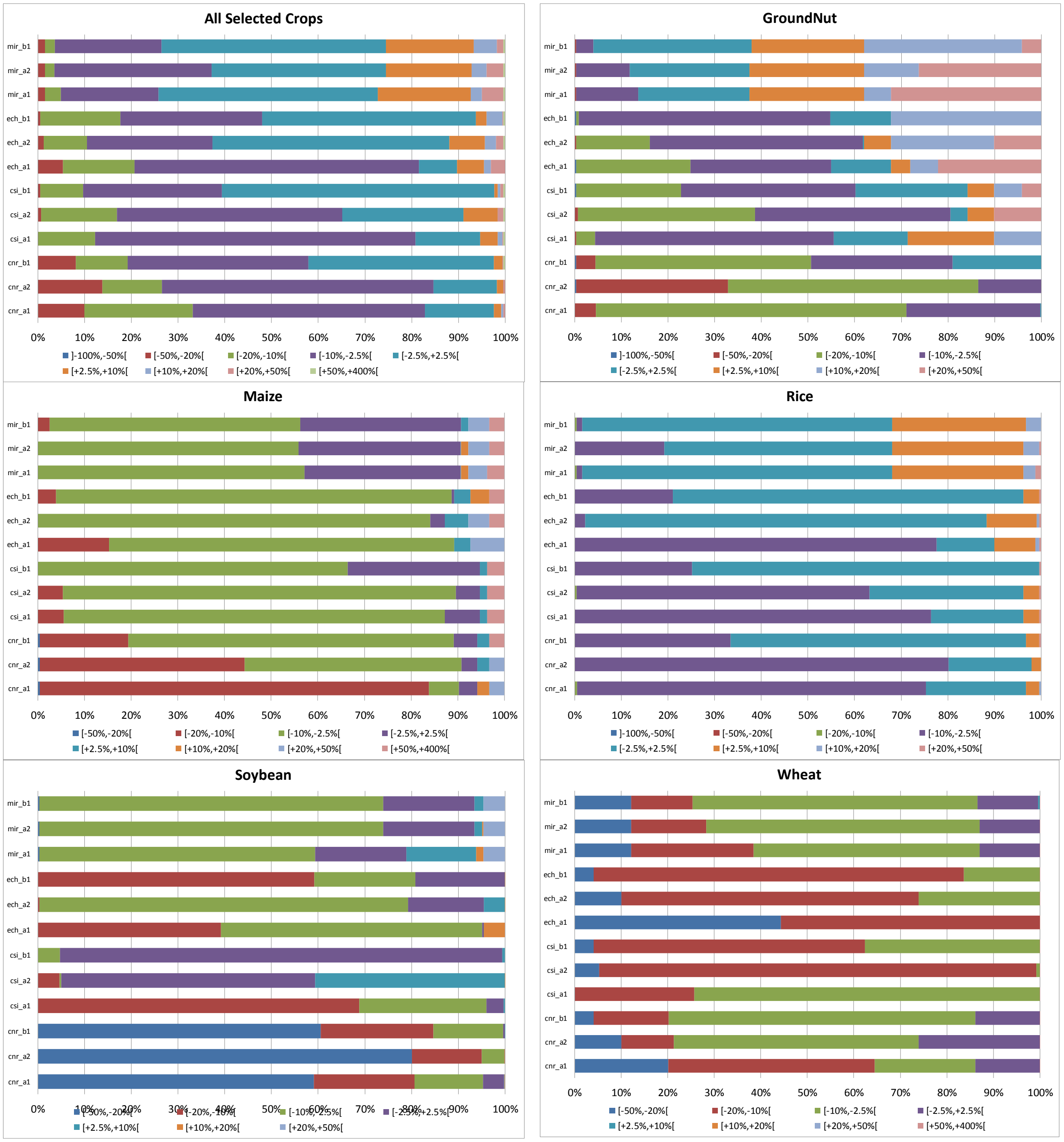
Figure 8 Changes in South Asia yield (Rainfed) due to climate change for different scenarios and selected crops. Initial Area and Production weighted.



Source: DSSAT model simulations

The overall yield change distribution of the rainfed cropland in SAFTA countries is presented Figure 9 and it is similar to what we observe on the global level. Thus, a moderate (-10% to -2.5%) decrease in yields affects large areas across all scenarios. Notable exceptions to this case are wheat and soybeans where we see a more pronounced negative change covering large (-20% to -10%). With respect to groundnuts we find large areas with large yield increase (20% to 50%), while in the case of wheat more than half of rainfed areas are impacted by significant yield declines (from -50% to -10%).

Figure 9 Distribution of yield changes under alternative climate change scenarios. Weighted by area (Rainfed).



Source: DSSAT model simulations

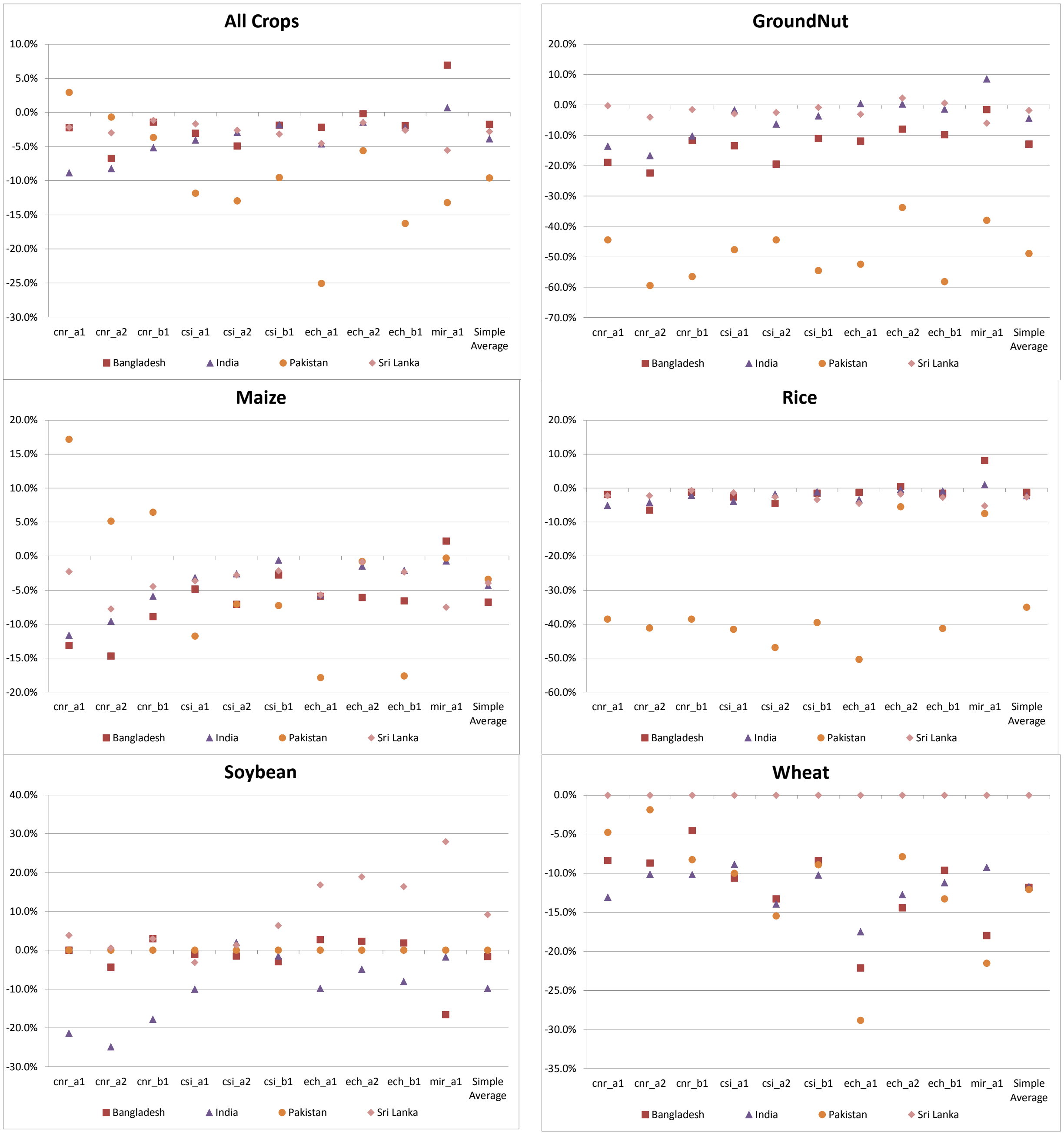
Figure 10 further decomposes changes in yields for selected crops by the four SAFTA countries considered here: Bangladesh, India, Pakistan and Sri Lanka. Considering average yields across all crops and scenarios we find that all four countries are negatively impacted by decreasing yields, with Pakistan and India being most hurt (-9.6% and -3.9% decrease of yields weighted by production).

Most notably, in the case of Pakistan we see large decreases in average yields for scenarios *ech_a1* and *ech_b1* of -25.1% and 16.3, respectively.

The -9.6% decrease in average crop yields in Pakistan is mainly driven by significant drops in rice yields of -35.1% and groundnut yields of -49% (a negative and significant yield pattern is found across all scenarios). Other crops such as maize (-3.4%) and wheat (-12.1%) are less negatively impacted in Pakistan (among all countries, maize yields increase only in Pakistan in scenarios *cnr_a1, cnr_a2* and *cnr_b1*).

Groundnuts yields decrease most significantly in Bangladesh (-12.8%) across all scenarios and found to be increasing in India in scenario *mir_a1* by 8.6%. Rice yields are only slightly negatively impacted in SAFTA (except the case of Pakistan discussed previously). Wheat yields decrease across all countries and scenarios most significantly in scenario *ech_a1.* Finally, soybean yields are found to be increasing in Sri Lanka across all scenarios with an average of 9.2%.

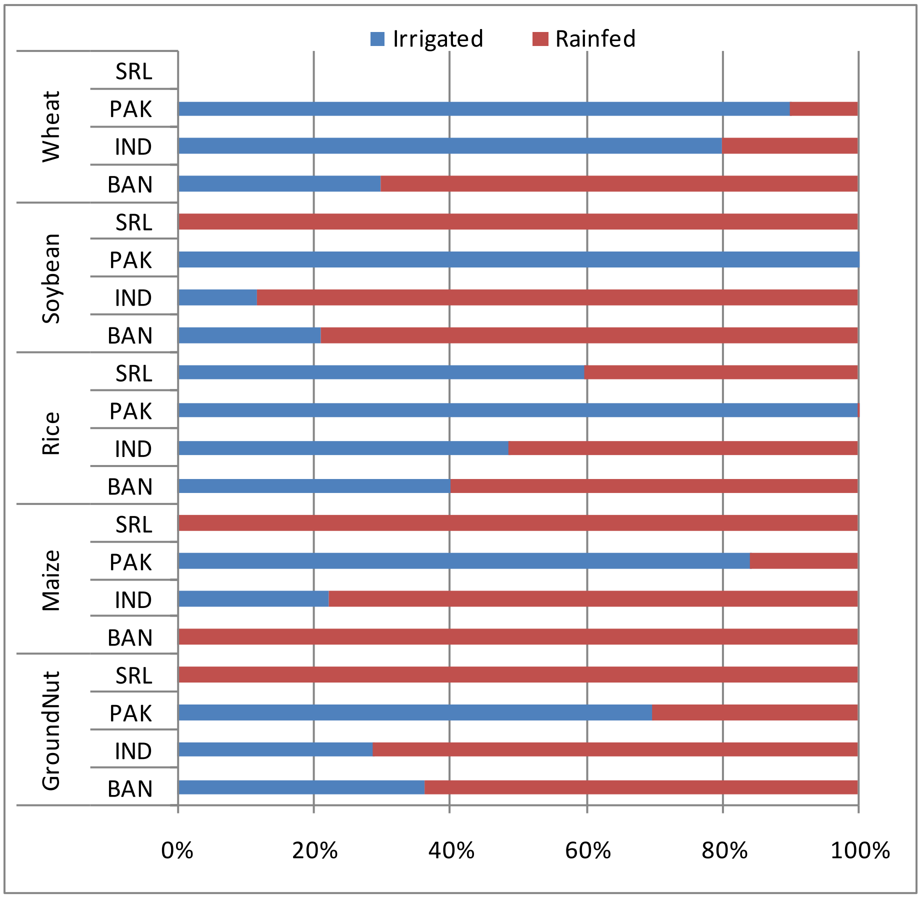
Figure 10 Distribution of yield changes across countries under alternative climate change scenarios. Weighted by Production (Rainfed).



Source: DSSAT model simulations

It is important to bear in mind that the results discussed previously concern exclusively changes with respect to rainfed crops. However, as shown in Figure 11, in SAFTA countries the share of irrigated crops is significant. For instance, Pakistan is one of the leading irrigation countries in the world where irrigated land accounts for about 80% of the total cropland (with about 90% of wheat, 100% of rice and soybean crops irrigated). Furthermore, India is an important irrigating country with 80% of wheat and 50% of rice crops being irrigated. On the other extreme, Sri Lanka does not irrigate maize or groundnuts at all.

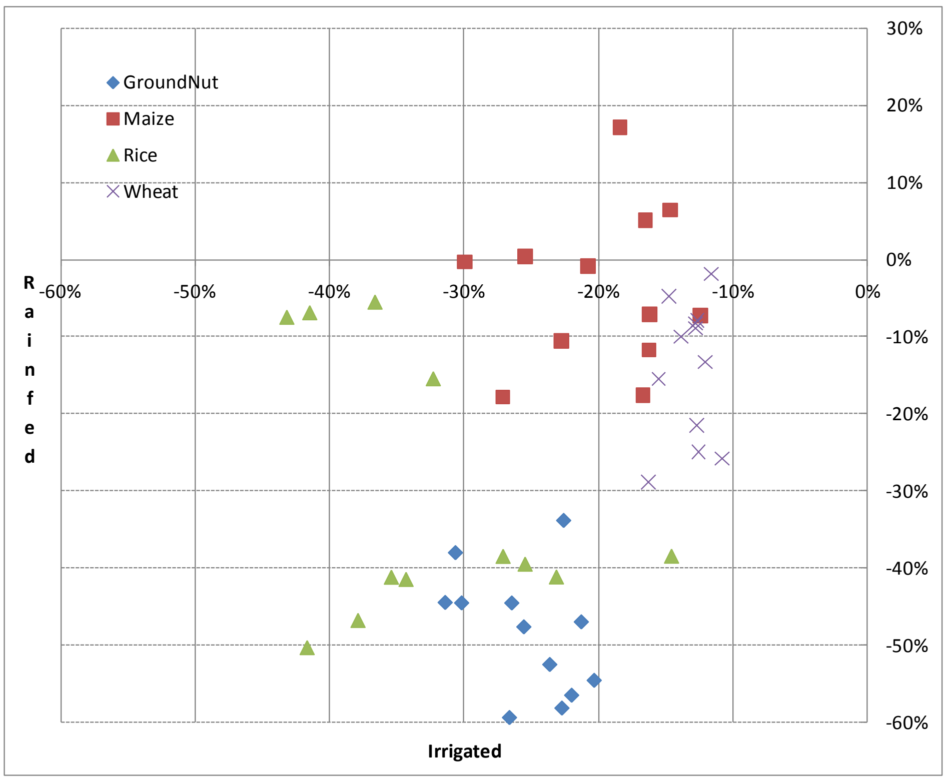
Figure 11 Share of rainfed agriculture at the world level for selected crops



Source: IMPACT model database

Given the importance of irrigation in Pakistan, we proceed with comparing the distribution of yields for selected crops for rainfed and irrigated production (see Figure 12). As pointed out previously, in the case of irrigated crops water availability does not change as a result of climate change (assumed to be sufficient and maintained at an optimal level) and consequently the driver of yield changes in this case is only changes in temperature as opposed to rainfed crops where both temperature and precipitation changes are considered. Note that in the case of groundnuts the results show similar patterns across all scenarios: yields with irrigation fall less than in the case of rainfed crops (on average across scenarios -25.3% for irrigated versus -48.4% rainfed groundnuts). This is a somehow expected result given that in case of irrigated crops the shock of climate change should be lessened. With respect to rice and wheat yield changes the results are more contrasted: in some scenarios rainfed yields are more affected than irrigated ones while in other scenarios vice versa. There is nevertheless an interesting pattern that emerges: with respect to rice we find that in more cool and dry scenarios rainfed yields decline more than irrigated rice, while with respect to wheat more humid and warm scenarios lead to bigger decline in irrigated rice yields. Finally, in the case of maize yield changes we find that irrigated crop yields decline more than rainfed ones. Interestingly, in scenarios *cnr_a1, cnr_a2* and *cnr_b1* climate change leads to an increase in yields of maize and a decrease of irrigated maize.

Figure 12 Distribution of yield of selected crops in Pakistan for rainfed and irrigated production (production weighted)



Source: DSSAT model simulations

4 Simulations and Results

This section presents the different trade policy scenarios considered and display the results of our simulations. Due to high number of scenarios (124)[6], we do not display all the detailed figures for all simulations.[7] Moreover, the goal of this study is not to determine what will be the detailed consequences of each potential climate scenario but to see how changes in trade policy could allow South Asia to mitigate the effects of an uncertain future. For this reason, we display the simple average and the variation range across climate scenarios for each trade policy baseline to identify a potential optimal policy. Indeed, we do not have an a priori bias with respect to the occurrence of one scenario or another. In addition, in our analysis we place a special emphasis on presenting results by individual South Asian countries given that a single SAFTA aggregate would over-represent the importance of India and consequently underestimate the smaller countries such as Sri Lanka.

This section first looks at the trade policy alternatives designed for different baselines and then we show and discuss simulation results. All results will be compared, and computed, versus the perfect mitigation case: the equivalent of a 13 SRES scenario that involve no yield effects related to climate change.

4.1 Trade policy options: different baselines for the climate change scenarios

As explained in the methodological section, the assumptions about trade policies[8] are critical at different levels. Since policy makers have more control on trade policy options, and can implement them earlier, we consider different trade policy scenarios that will be implemented between 2010 and 2024 and will change the landscape in which climate change will occur. Let's summarize the role of trade policy, here tariffs, on the effects of climate change for the countries:

- Ad Valorem duties, assuming that they are not endogenous to world prices, amplify in absolute terms the domestic price increase caused by climate change on world markets. Therefore, they magnify the cost increase for the consumers by applying the tax on the exogenous price change. This is a direct effect.

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[6] (12 SRESxCGM + 1 (perfect mitigation))x8

[7] All the results for each scenario are available on request.

[8] Other assumptions of the baseline are discussed in the methodology section: 2.2.2.

- Duties affect relative prices between sectors in an economy. Therefore, the relative size of agriculture, directly affected by climate change, compared to manufacturing and services depends on the trade policy options:
    a. Since agricultural protection is much higher than non agricultural protection in all SAFTA countries, unilateral trade liberalization will lead to a reallocation of production from agriculture to the other sectors, reducing the economic size of this activity. In this case, the direct shock of climate change, i.e. modification of agricultural productivity, is dampened for economies which GDP is poorly dependent on agriculture. The overall income will be more resilient and larger possibilities of income redistribution are available to support potential losers.
    b. In case of multilateral trade liberalization, the comparative advantages will play to the maximum. Some new market opportunities will be reinforced for some sectors (that can involve some agricultural sectors e.g. rice if Japan opens fully its economy). The effects of trade policy on the consequences of climate change on income and production will then depend on how agricultural commodities are affected in which South Asian countries have their comparative advantages.
    c. If some agricultural sectors are excluded from the trade liberalization movement, it will be important for the region to see if these commodities are more negatively affected regionally than elsewhere. In the former case, protectionist policies will maintain artificial specialization (contrarily to comparative advantages resulting from free trade) on the sectors that will face severe productivity losses and lead to impoverishing specialization.
- The previous item was discussing how the sectoral structure, and the dependency of the economy on agriculture, has consequences for the overall income through the production channel (productivity losses). However, trade liberalization also changes how countries depend on world markets, the degree of openness, and how they are exposed to different price shocks on world markets through the terms of trade effect. Indeed, depending on the exposure to world prices and the structure of trade the cost for the domestic economy of a relative price shock will vary. Two channels through relative prices are at stake: how relative prices between domestic and foreign producers within one sector are affected and how relative prices between exports and import, across sectors, are impacted. If trade liberalization leads to import more of one commodity that will suffer a high price increase when climate change will occur, the cost for the importing economy will be stronger.
- Last, discriminatory trade policies, i.e. preferential trade agreements, will play an important role by shifting regional trade patterns into one direction. Assuming that policy makers can predict which countries will be more negatively affected, it will be important that they get market access for their own exports to these markets and that they develop trade relations with other regions for their own supply. In other terms, it should be optimal to use trade policy to diversify trade partners in order to reinforce trade relations with regions for which climate shocks will be negatively correlated with the domestic economy, as in a portfolio

management strategy. This can lead to pursue non regional integration strategy if the region does not provide enough diversification opportunity.

Based on previous explanations it is straightforward that we need to analyze alternative trade policy scenarios combining different mix of sectoral and geographical liberalization.

4.1.1 Trade policy option descriptions

We study eight trade policy scenarios, involving potential tariff reductions from their starting level in 2007:

1. Baseline tariffs (*BASE*): the status quo. In this scenario, we freeze tariffs to their 2007 level and they are not changed;
2. SAFTA implementation (*SAFTA*). This scenario describes the full implementation of SAFTA as it has been negotiated, including sensitive products (see the SAFTA scenario description in Bouet et Corong, 2009);
3. A SAFTA-plus scenario (*SAFTAFULL*) that involves the full elimination of all tariffs between the South Asian countries;
4. SAFTA countries liberalize unilaterally all their sectors (agriculture and non-agriculture) except sensitive products in a fourth scenario (*UNISEN*). For each SAFTA economy the list of sensitive products for this unilateral liberalization is identical to the one used in the SAFTA agreement. It involves remaining tariffs in most key agricultural products.
5. A stronger scenario involves the unilateral elimination of all tariffs in agriculture (*UNIAGR*). It leads to a sharp decline in agricultural prices vs manufacturing prices and a reallocation of resources towards this sector;
6. A scenario involving the full liberalization of SAFTA economies towards all partners for all sectors. This is a complete unilateral liberalization of these economies (*UNIALL*). The liberalization of manufacturing dampen the shock on relative prices driven by previous scenario;
7. An ambitious FTA scenario among all countries in Asia and Oceania. It includes Central Asia, China, the developed East Asian economies, the ASEAN countries, Australia, New Zealand (ANZCERTA) and the South Asian countries. It is a strong regional integration scenario without any remaining tariff restrictions. It creates both new market opportunities (e.g. on the initially highly protected South Korea and Japanese markets) and accrued competition on domestic markets (from competitive countries in the ASEAN and ANZCERTA blocks) for South Asia;
8. The final scenario is complete trade liberalization, i.e. tariff elimination, at a global level. This very ambitious scenario is aimed to provide a benchmark.

Table 5 summarizes these descriptions.

Table 5 Trade policy scenarios summary

Label	Description	Sensitive Products in Agriculture for SAARC	Manufacturing Liberalization for SAARC	Unilateral/ Regional policy for SAARC	Market access gains in other regions
BASE	Status quo	n.a.	n.a.	n.a.	n.a.
SAFTA	Implementation of the post 2007 SAFTA commitments	yes	partial	yes	no
SAFTAFull	SAFTA + elimination of all remaining tariffs on sensitive products	no	yes	yes	no
UNISEN	SAFTAFull + unilateral liberalization with all partners for non sensitive products in SAFTA	yes	partial	yes	no
UNIAGR	SAFTAFull+ unilateral liberalization in agriculture	no	no	yes	no
UNIALL	Full unilateral liberalization of all SAFTA countries	no	yes	yes	no
FTA	Full FTA in Asia and Oceania	no	yes	no	in Asia
MULTI	Full multilateral liberalization	no	yes	no	World

4.1.2 Baseline results

Projecting the world up to 2050 has an important impact on the economic structure of different countries, especially in South Asia where both economic and demographic growth will change significantly the existing situation. Therefore, it is important to discuss the evolution of key indicators in the baseline. Detailed discussion about the assumptions with respect to the baseline used here is presented in Section 2 about the methodology. This subsection is aimed to provide details about the evolution of selected variables in the baseline. Even if we build one baseline for each trade policy landscape, we just focus in these paragraphs on the two extreme cases: status quo and full liberalization.

As presented in Table 6, by 2025 we project the world to have 9.05 billions of inhabitants, and for instance India is assumed to have 1.6 billion and Bangladesh 0.22 billion inhabitants. These figures are consistent with latest UN projections (central case). The annual growth rate in GDP per capita is the nearly the same in the base trade policy and the full multilateral liberalization scenarios. This result is not surprising. In model with full employment, trade policy effects are always below 1 percent of real income. GDP per capita growth is highest in India (6.2 percent), followed by Bangladesh (4.6 percent) and Pakistan (4.5 percent). Due to the shift in demand and activity, growth rate in industry dominates those in agriculture, except for specific cases. However, due to high level o trade barriers in this sector, the multilateral liberalization will boost agriculture exports and imports. India benefits from the largest increase in trade flows in percentage change terms for both the base trade policy scenario and multilateral full liberalization. A notable exception is exports of staples where (percent) growth in India is exceeded by Bangladesh, Pakistan and Sri Lanka. Finally, not surprisingly trade growth in the multilateral full liberalization scenario is systematically higher than that in the base trade policy scenario for all South Asian countries.

The next section presents the detailed analysis of the outcome of our simulations.

Table 6 Baseline: evolution of selected indicators

		Bangladesh	India	Pakistan	Sri Lanka	Rest of South Asia	World
Population in 2050 (Bil. habitants)		222	1,611	332	22	123	9,058
Annual growth rate (Base trade policy)	GDP per Capita	4.6%	6.2%	4.5%	4.1%	3.8%	3.9%
	Import (staple)	4.4%	9.8%	7.2%	4.5%	6.6%	5.4%
	Import (agrifood)	5.0%	7.0%	4.8%	3.0%	5.7%	4.5%
	Import (Industry)	5.9%	10.3%	8.4%	5.3%	7.0%	5.1%
	Export (staple)	7.9%	7.0%	7.4%	7.7%	7.0%	5.4%
	Export (agrifood)	5.3%	10.5%	9.9%	4.7%	3.7%	4.5%
	Export (Industry)	5.0%	11.1%	8.7%	6.1%	9.1%	5.1%
Annual growth rate (Multilateral full liberalization)	GDP per Capita	4.6%	6.2%	4.5%	4.1%	3.8%	3.9%
	Import (staple)	4.6%	11.6%	7.7%	5.5%	7.4%	5.9%
	Import (agrifood)	5.5%	8.4%	6.1%	3.9%	6.1%	5.4%
	Import (Industry)	6.6%	10.8%	8.9%	5.5%	7.5%	5.3%
	Export (staple)	9.4%	7.8%	8.1%	9.1%	9.0%	5.9%
	Export (agrifood)	6.0%	12.6%	10.4%	5.2%	4.2%	5.4%
	Export (Industry)	5.7%	11.5%	9.3%	6.5%	9.7%	5.3%

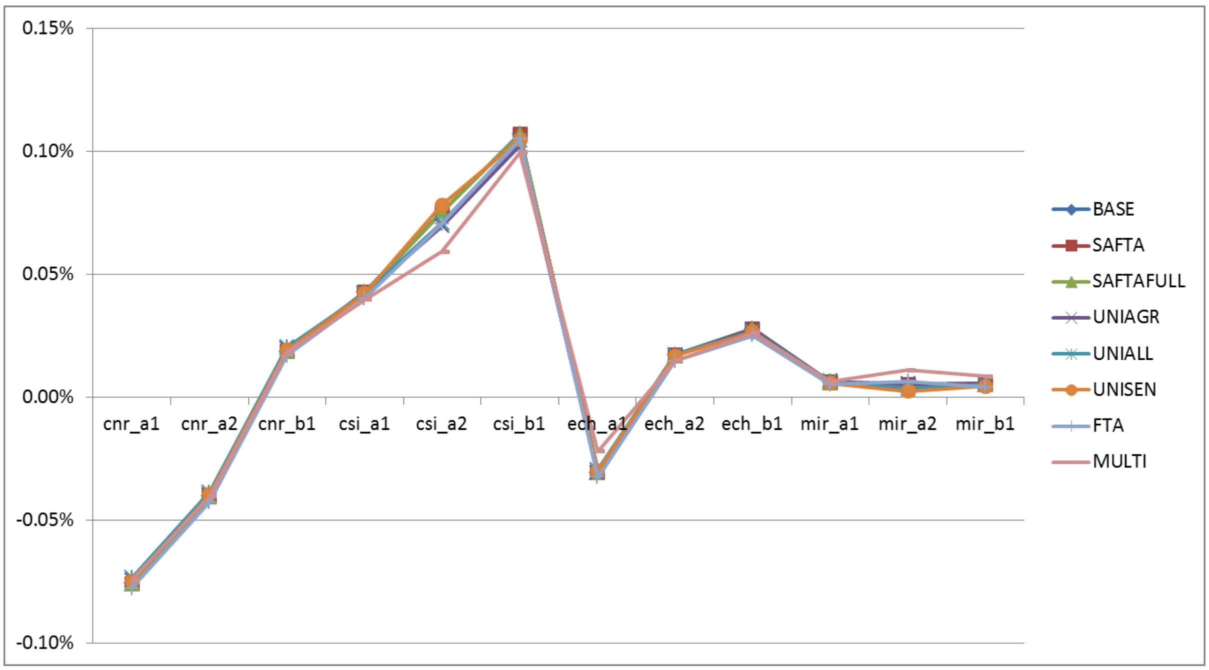
Source: MIRAGE simulations

4.2 Simulation Results

4.2.1 Impact on real income

Figure 13 displays the evolution of changes in real income in 2050 for the world across trade policy options and climate change scenarios. Results show that the impact on real income in relative terms is relatively small explained by the decline in the share of agriculture in world GDP, but still represent between -740 and +1,015 billion 2004 constant USD. Nevertheless, we see relatively large variations across climate change scenarios with most important increase for scenario *csi_b1* and most significant decline for *cnr_a.* Further, we note that trade policy options have limited effects on changes in real income. Free trade leads to an increase in real income compared to the status quo only in 5 out of the 12 scenarios showing the complexity of the mechanisms at play. Nevertheless, it appears that free trade plays a more important role in difference cases: for instance in the case of *csi* scenarios, free trade (MULTI) minimizes the potential real income gains but at the same time maximizes gains in *mir* scenarios while limits the losses significantly in *ech_a1.* The *csi* cases, as it will be discussed in the trade subsection, is the one that leads to more trade readjustments. The MULTI scenario by bringing in the baseline a large trade expansion leads to more limited readjustment and therefore, less important real income gains from trade.

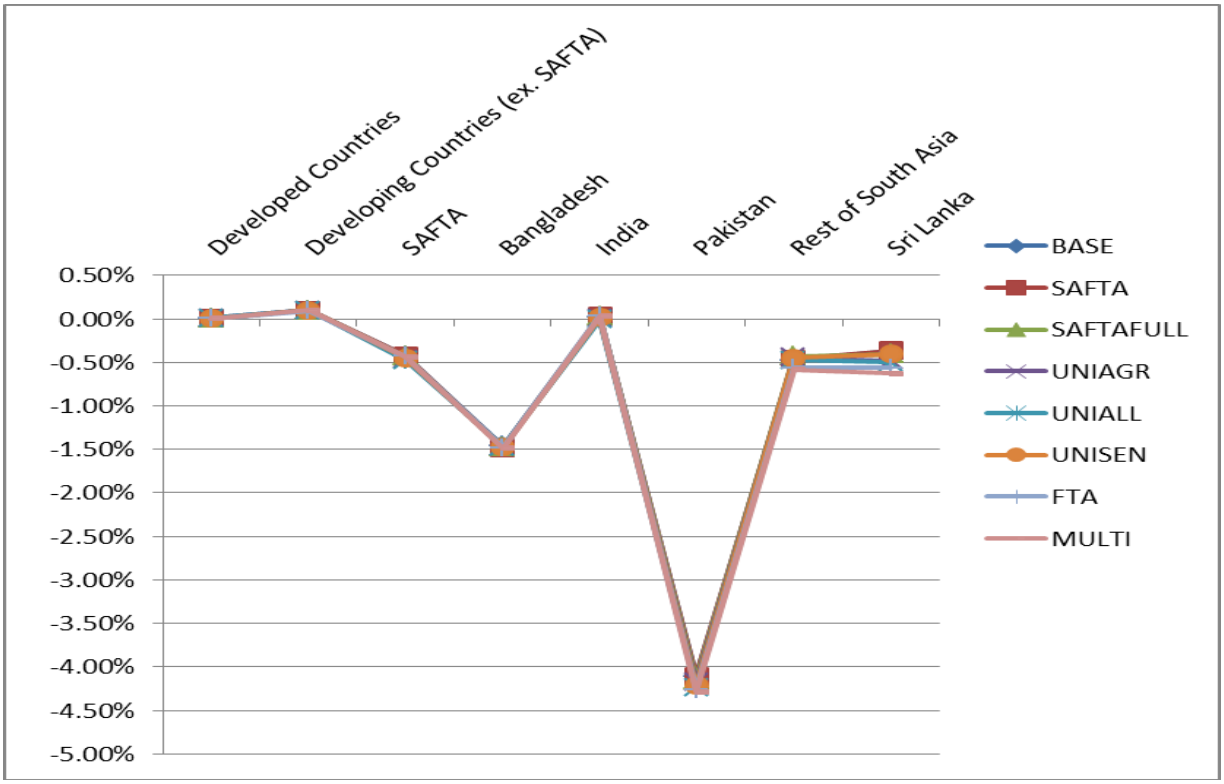
Figure 13 Changes in real income by 2050 (annual) for the world



Source: MIRAGE simulations

As shown in Figure 14, SAFTA is one of the most negatively affected regions. Among individual countries, Pakistan is most adversely impacted in terms of real income followed by Bangladesh and Sri Lanka. On the other hand, India benefits from a slight increase in real income and acts as a stabilizer in the region. A decomposition by liberalization and climate change scenarios (Figure 15) illustrates that there is relatively high dispersion with respect to the impact on real income across countries. Accordingly, we find a negative correlation between country size and the degree of dispersion, that is the impact of different trade liberalization scenarios varies more significantly in the case of Sri Lanka than in that of India. In addition, Sri Lanka and the Rest of South Asia experience bigger declines in real income as the degree of liberalization increases. Detailed results by each scenario are presented in Table 12 in the Appendix.

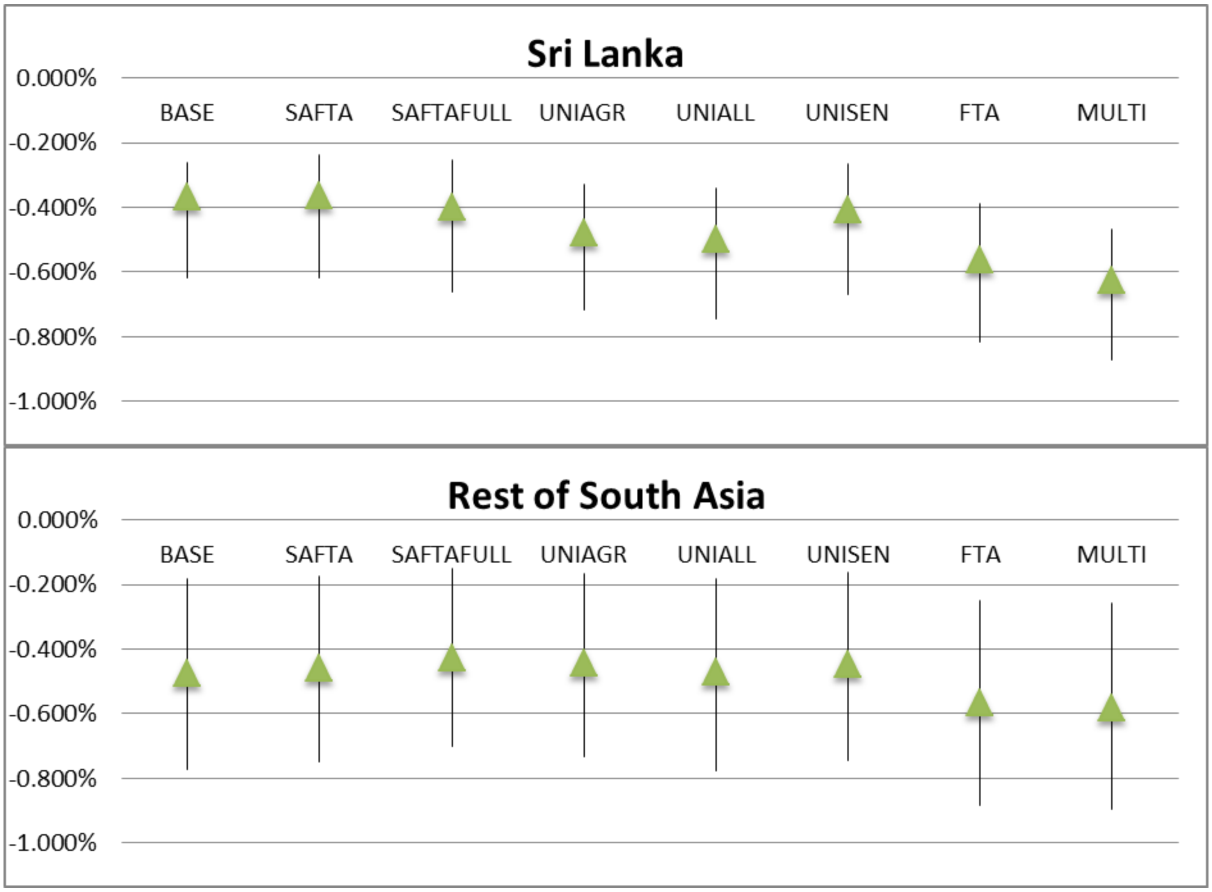
Figure 14 Changes in real income for SAFTA countries compared to the rest of the world (simple average across climate scenarios)



Source: MIRAGE simulations

Figure 15 Real Income effects (simple averages and extreme values) for SAFTA countries

(continue on next page)



Note: The length of the bars represent minimums and maximums across climate scenarios.
Source: MIRAGE simulations.

Table 7 is aimed to summarize the ranking (by real income criteria) of different trade policy options for SAFTA countries. *Optimistic* describes the highest real income increase across climate scenarios, *average* the average change and *pessimistic* the most adverse real income change. Interestingly, our results show that all countries except India would favor more conservative liberalization scenarios. For India, full liberalization maximizes the increase in real income, while a full FTA in Asia and Oceania leads to the average real income change. On the other hand, Pakistan and Sri Lanka would favor the SAFTA scenario while Bangladesh UNIAGR.

Table 7 Summary table of best options for trade policies. Real Income criteria

	Bangladesh	India	Sri Lanka	Pakistan	Rest of South Asia
BASE	*Pessimistic, Average*		*Average*	*Pessimistic*	
SAFTA		*Pessimistic*	*Pessimistic, Optimistic*	*Average, Optimistic*	
SAFTAFULL				*Pessimistic*	*All cases*
UNIAGR	*Optimistic*				
UNIALL					
UNISEN					
FTA		*Average*			
MULTI		*Optimistic*			

Given that agriculture will represent a small share of world GDP by 2050, as well as for a booming economy like India, our previous results on real income were not surprising. However, it is important to keep in mind that we model only a small part of the consequences of climate change, that is only the direct changes in crop yield due to water and temperature modifications. We do not consider the possibility of new pest and diseases related to variation in climatic conditions, the shift in cattle productivity due to temperature changes or more generally any negative productivity shocks associated to warmer climate. Last but not least, extreme events (flooding) or loss of agricultural area due to rise in the sea level are not taken into account although may represent a key issue for the region.

4.2.2 Impact on Agricultural Production

Beyond the large scale macroeconomic consequences of crop yield changes, it is important to focus on the first order sectoral effects, i.e. changes in agricultural and food production. Table 8 describes changes to the volume of both staple (primary crops) and agri-food (processed food) production across liberalization scenarios highlighting the extreme values and averages across climate scenarios. In order to better understand these changes, we refer back to the discussion on yield changes described in section 3.1. As expected, larger yield changes in Pakistan lead to larger changes in output on average ranging from -8.7 percent to -8.4 percent in the case of staple production and from -6.5 percent to -5.4 percent for ag-foods across different liberalization scenarios. Bangladesh is the second most adversely affected among SAFTA countries with staple production falling by roughly -5.1 percent and agri-food by -4.1 percent. Overall, the negative impact of yield decline on the output of agri -food sectors is dampened compared to primary crops that are more directly impacted. In

India (as well as in Sri Lanka) we notice an expansion of the food processing sector explained by a shift to larger value added goods (including exports).

India in particular is the most resilient among SAFTA countries and therefore it strengthens its comparative advantage in agribusiness (lower increase in input costs). In addition, India (despite being also negatively impacted by falling yields) manages to cope with the direct climate change effects more effectively thanks to strong advantages. First, due to its higher growth rate and large productivity gains, India will generate a large flow of savings and therefore investment capacity during the next forty years. Driven by high agricultural prices, investment will go to agriculture and will reinforce the productivity of this sector, mitigating the exogenous yield decline. It is important to keep in mind that since the model closure used does not allow for foreign direct investments and since no foreign aid is modeled, countries only depend on their own income and savings for investment. Second, due to its size and a larger number of river basins, India can reallocate production across crops and regions more efficiently. For instance, when wheat production declines, we see an increase of corn[9] and other coarse grains output. Therefore through domestic trade and production shifting allowed in our model due to the river basin land markets, the overall negative shock is partially mitigated. Finally, from the point of view of policy makers it is important to ensure flexible domestic markets and equitable social consequences of production relocation.

It's interesting to take the analysis further from averages, thus in Table 8 we report extremes (minimum and maximum) across climate change scenarios. Overall, we find a coefficient of variation of about 100%. In most cases, we do not find sign reversals from an extreme to another with the exception of staples in India and the Rest of Asia.

Last, note that trade policy does matter in key cases: for instance, in Pakistan a greater degree of liberalization reduces the decline in agro-food production. Full SAFTA integration also reduces the negative effects on staple food production by creating a larger (but still protected) market.

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[9] Indeed, the crop model predict the doubling of corn yield for some large areas where the corn production is initially very limited.

Table 8 Impact on agricultural and agro-food production (volume, % change relative to the baseline in 2050)

	BASE	SAFTA	SAFTAFULL	UNIAGR	UNIALL	UNISEN	FTA	MULTI
Bangladesh								
Agro-food								
Average	-3.8%	-3.9%	-4.0%	-4.0%	-4.1%	-4.1%	-4.3%	-4.0%
Maximum	-1.3%	-1.3%	-1.4%	-1.5%	-1.6%	-1.5%	-1.7%	-1.5%
Minimum	-6.3%	-6.4%	-6.4%	-6.5%	-6.6%	-6.5%	-7.1%	-6.7%
Staple								
Average	-5.1%	-5.1%	-5.0%	-5.1%	-5.0%	-5.0%	-5.1%	-5.1%
Maximum	-0.8%	-0.8%	-0.7%	-0.7%	-0.7%	-0.7%	-0.8%	-0.8%
Minimum	-8.9%	-8.9%	-8.8%	-8.8%	-8.8%	-8.8%	-9.0%	-8.9%
India								
Agro-food								
Average	4.6%	4.6%	4.6%	4.6%	4.3%	4.3%	4.6%	3.7%
Maximum	5.8%	5.7%	5.7%	5.3%	5.1%	5.5%	5.4%	4.2%
Minimum	4.0%	3.9%	4.0%	4.1%	3.8%	3.7%	4.2%	3.3%
Staple								
Average	-1.2%	-1.2%	-1.2%	-1.3%	-1.3%	-1.2%	-1.2%	-1.3%
Maximum	0.3%	0.3%	0.3%	0.2%	0.2%	0.3%	0.2%	0.1%
Minimum	-3.0%	-3.0%	-3.0%	-3.0%	-3.0%	-3.0%	-3.0%	-3.0%
Pakistan								
Agro-food								
Average	-6.5%	-6.1%	-6.0%	-6.2%	-6.1%	-6.1%	-5.4%	-5.4%
Maximum	-4.6%	-4.3%	-4.4%	-4.4%	-4.3%	-4.5%	-4.0%	-3.9%
Minimum	-9.4%	-8.9%	-8.7%	-9.0%	-8.9%	-8.8%	-7.6%	-8.0%
Staple								
Average	-8.5%	-8.4%	-8.6%	-8.5%	-8.6%	-8.6%	-8.7%	-8.7%
Maximum	-5.3%	-5.2%	-5.3%	-5.3%	-5.3%	-5.3%	-5.4%	-5.4%
Minimum	-10.6%	-10.6%	-10.7%	-10.6%	-10.7%	-10.7%	-10.9%	-10.9%
Sri Lanka								
Agro-food								
Average	1.4%	1.4%	2.7%	1.6%	1.7%	2.9%	2.7%	1.0%
Maximum	2.7%	2.6%	4.5%	2.7%	2.8%	4.8%	3.8%	2.2%
Minimum	-0.2%	-0.2%	0.8%	0.5%	0.5%	0.8%	1.5%	-0.3%
Staple								
Average	-3.9%	-3.8%	-3.9%	-4.2%	-4.2%	-3.9%	-4.6%	-4.4%
Maximum	-2.6%	-2.6%	-2.6%	-2.8%	-2.8%	-2.6%	-3.1%	-3.1%
Minimum	-5.1%	-5.1%	-5.1%	-5.4%	-5.4%	-5.1%	-5.9%	-5.6%
Rest of South Asia								
Agro-food								
Average	-2.5%	-2.5%	-2.6%	-2.7%	-2.7%	-2.5%	-2.6%	-2.4%
Maximum	-1.9%	-2.0%	-1.7%	-2.2%	-2.2%	-1.6%	-2.1%	-1.8%
Minimum	-3.2%	-3.3%	-3.6%	-3.4%	-3.4%	-3.6%	-3.3%	-3.1%
Staple								
Average	-1.7%	-1.7%	-1.6%	-1.7%	-1.7%	-1.6%	-2.1%	-2.1%
Maximum	0.5%	0.6%	0.7%	0.6%	0.5%	0.6%	0.5%	0.6%
Minimum	-3.3%	-3.2%	-3.1%	-3.2%	-3.3%	-3.2%	-3.8%	-3.9%

Source: MIRAGE results

Table 9 displays the five agricultural and agri-food products whose supply is most negatively affected across South Asian countries considered here.

Results show that maize is the most adversely affected in Bangladesh (ranging from -17.6 percent to -18.8 percent across liberalization scenarios), Sri Lanka (from -8.8 percent to -23.6 percent) and Rest of South Asia (from -11.4 percent to -13.3 percent). This effect on maize is the result of both the direct effect of yield decrease in these regions but also the boom of India corn production that, driven by yield increase, bring down the price of this commodity in all the sub region, phasing out other producers. In India, the output of wheat and vegetable oils decline the most, while in Pakistan oilseeds and rice are among the most negatively affected.

Reported changes in output are the result of the combined impact of the yield shocks, the trade relocation effect, the demand inelasticity and the land competition among crops (despite the yield decline land use can still increase to support increased production).

To consider a specific example, wheat is negatively affected by the yield shock; India will phase out but at the same time production Pakistan will resist (not in the top 5 decline) and will need to attract resources, first of all land taken from other agricultural sectors (rice, cotton, pulses). Meanwhile, India increases production of maize (+89 percent on average, not in the table that focuses on losses) and that of other coarse grains concentrating on regional production in this sector (notice the decline in maize output in other regions).

Further, intersectoral linkages come into play as well: the decline in oilseed yield (groundnut) in India leads to a (more than proportional) decline in vegetal oil production. Goods with higher demand elasticity such as cotton that can be easily substituted with other fibers including artificials, will free land to food production.

Table 9 Most negatively affected agricultural and agri-food products (volume, % change relative to the baseline in 2050)

	BASE	SAFTA	SAFTAFULL	UNIAGR	UNIALL	UNISEN	FTA	MULTI
Bangladesh								
Maize	-18.8%	-18.5%	-18.3%	-18.2%	-17.9%	-18.2%	-17.6%	-17.3%
Other Coarse Grains	-17.6%	-18.0%	-17.9%	-17.5%	-17.3%	-17.4%	-18.0%	-17.0%
Cotton	-13.7%	-13.6%	-13.5%	-13.4%	-13.5%	-13.5%	-13.4%	-13.5%
Oilseeds	-13.1%	-13.0%	-12.9%	-13.0%	-12.8%	-12.9%	-12.9%	-12.9%
Wheat	-12.5%	-12.5%	-12.3%	-12.3%	-12.3%	-12.3%	-12.4%	-12.5%
India								
Wheat	-7.2%	-7.2%	-7.2%	-7.3%	-7.3%	-7.2%	-7.4%	-7.5%
Vegetal Oils	-4.6%	-4.7%	-5.0%	-6.3%	-6.6%	-5.2%	-7.2%	-4.8%
Rice	-4.8%	-4.8%	-4.8%	-4.8%	-4.9%	-4.8%	-4.9%	-5.3%
Cotton	-3.5%	-3.5%	-3.5%	-3.6%	-3.6%	-3.5%	-3.6%	-3.6%
Oilseeds	-2.0%	-2.0%	-2.0%	-2.1%	-2.1%	-2.1%	-2.0%	-2.1%
Pakistan								
Oilseeds	-35.1%	-35.1%	-35.0%	-34.8%	-34.8%	-35.1%	-34.7%	-34.6%
Rice	-32.7%	-32.6%	-32.6%	-32.6%	-32.6%	-32.6%	-33.2%	-33.5%
Cotton	-27.6%	-27.6%	-27.6%	-27.6%	-27.7%	-27.7%	-27.6%	-27.6%
Pulses	-27.2%	-27.1%	-27.4%	-27.4%	-27.3%	-27.3%	-27.4%	-27.3%
Vegetables and Fruits	-22.2%	-22.2%	-22.2%	-22.3%	-22.3%	-22.2%	-22.6%	-22.6%
Sri Lanka								
Maize	-23.6%	-23.3%	-23.6%	-23.4%	-22.9%	-23.3%	-8.8%	-12.3%
Other Coarse Grains	-14.6%	-14.5%	-16.4%	-15.0%	-14.9%	-16.2%	-16.5%	-15.4%
Sugar	-11.4%	-11.4%	-16.7%	-11.5%	-11.4%	-16.5%	-14.4%	-8.1%
Rice	-8.4%	-8.5%	-10.5%	-11.4%	-11.6%	-10.8%	-13.5%	-12.4%
Cotton	-11.2%	-10.6%	-10.4%	-10.3%	-10.3%	-10.4%	-10.5%	-10.6%
Rest of South Asia								
Maize	-12.9%	-13.1%	-13.3%	-13.1%	-12.8%	-13.1%	-12.0%	-11.4%
Sugar	-11.4%	-11.7%	-12.3%	-11.8%	-11.4%	-11.9%	-10.8%	-9.5%
Other Coarse Grains	-10.1%	-10.2%	-10.3%	-9.9%	-9.7%	-10.0%	-9.2%	-9.3%
Wheat	-6.3%	-6.3%	-5.6%	-5.7%	-5.6%	-5.6%	-5.3%	-5.2%
Vegetables and Fruits	-4.1%	-4.1%	-4.0%	-4.3%	-4.2%	-4.0%	-3.8%	-4.0%

Source: MIRAGE results

4.2.3 Impact on the income of the Poor

This subsection focuses on the real rate of return of unskilled labor. To convert nominal rates of return into real ones we use country specific price indexes, meaning that we do not consider the significant role of food products for the lower income category. Due to the long term horizon and the possibility of urban-rural migration, we focus on the average unskilled labor wage in the economy.

The evolution of the wage of unskilled labor reflect the combined impact of the productivity shock in agriculture (large user of unskilled workforce), the overall price index in the economy (less affected by food prices the consumption basket specific to this labor category) and the mobility of unskilled labor across sectors.

Thus, our results show that average real unskilled wage declines in all SAFTA countries except in India. This decline is most significant in Pakistan (from -5.2 percent to -5.9 percent across liberalization scenarios) followed by Sri Lanka and Bangladesh (each between -1.9 percent and -2.3 percent). On the other hand, real unskilled labor wages in India increase on average between 0.4 percent and 1.6 percent across liberalization scenarios.

The comparison between changes in real income (discussed in section 4.2.1) and changes in the real wage of unskilled labor could yield to interesting insights about the inequalities that result from the impacts of climate change and/or trade liberalization. Thus, we find that the negative impact on the wages of unskilled labor are systematically higher than that on real income across all trade liberalization scenarios and all countries. The only exception is India: in this case unskilled labor benefits relatively more as unskilled labor wages increase more than real income. Note however that in the case of India although average unskilled labor wages increase, minimum wages show a significant decline (between -4.7 percent and -9.1 percent) and consequently implies a higher coefficient of variation across climate change scenarios that any other SAFTA country.

Last we find that trade liberalization matters for the evolution of wages of unskilled labor, even if the variation is much smaller that with respect to climate change scenarios. Except India, unilateral liberalization appear to be attractive for unskilled workers. Even more interestingly, more liberal trade policies (unilateral liberalization) is even for India unskilled workers the best insurance for the worst case scenario.

Table 10 Changes in real Unskilled Wage (% change relative to the baseline)

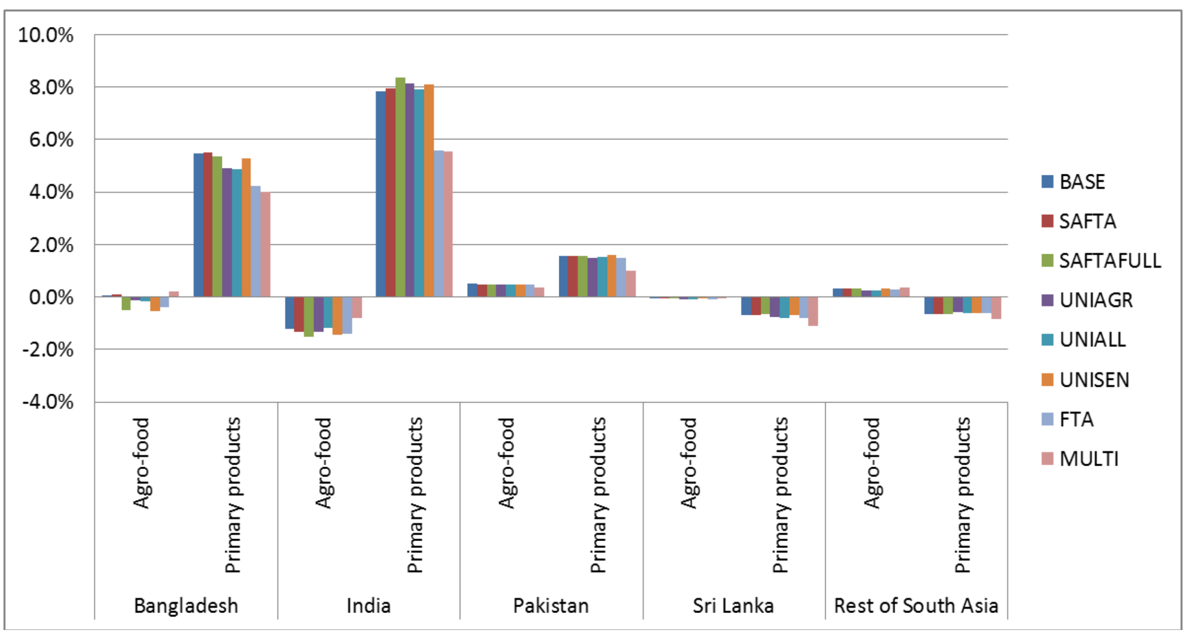
	BASE	SAFTA	SAFTAFULL	UNIAGR	UNIALL	UNISEN	FTA	MULTI
Bangladesh								
Average	-2.1%	-2.1%	-2.0%	-2.0%	-1.9%	-2.0%	-1.9%	-1.9%
Maximum	-0.4%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%
Minimum	-3.6%	-3.5%	-3.4%	-3.3%	-3.3%	-3.3%	-3.3%	-3.3%
India								
Average	1.6%	1.5%	1.4%	0.8%	0.4%	0.8%	1.0%	0.8%
Maximum	8.2%	8.1%	8.0%	6.1%	3.9%	4.9%	5.4%	4.3%
Minimum	-9.1%	-9.1%	-9.1%	-7.8%	-5.4%	-6.0%	-6.0%	-4.7%
Pakistan								
Average	-5.9%	-5.8%	-5.7%	-5.7%	-5.3%	-5.3%	-5.4%	-5.2%
Maximum	-3.3%	-3.2%	-3.1%	-3.3%	-2.8%	-2.8%	-2.8%	-2.7%
Minimum	-8.2%	-8.1%	-8.0%	-7.9%	-7.4%	-7.5%	-7.5%	-7.3%
Sri Lanka								
Average	-1.9%	-1.9%	-1.9%	-2.0%	-2.1%	-1.9%	-2.3%	-2.3%
Maximum	-1.2%	-1.2%	-1.2%	-1.3%	-1.4%	-1.2%	-1.6%	-1.6%
Minimum	-2.4%	-2.4%	-2.4%	-2.5%	-2.6%	-2.4%	-2.9%	-2.8%
Rest of South Asia								
Average	-0.9%	-0.9%	-0.8%	-0.9%	-0.9%	-0.8%	-0.7%	-0.7%
Maximum	-0.1%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	0.1%	0.0%
Minimum	-1.5%	-1.4%	-1.4%	-1.4%	-1.5%	-1.5%	-1.2%	-1.2%

Source: MIRAGE results

4.2.4 Food Consumption and Food Prices

As next step, we turn to the analysis of the impacts on final consumers with emphasis on variables such as average food prices and food consumption per capita.

Figure 16 Average changes in food prices (% changes relative to the baseline)

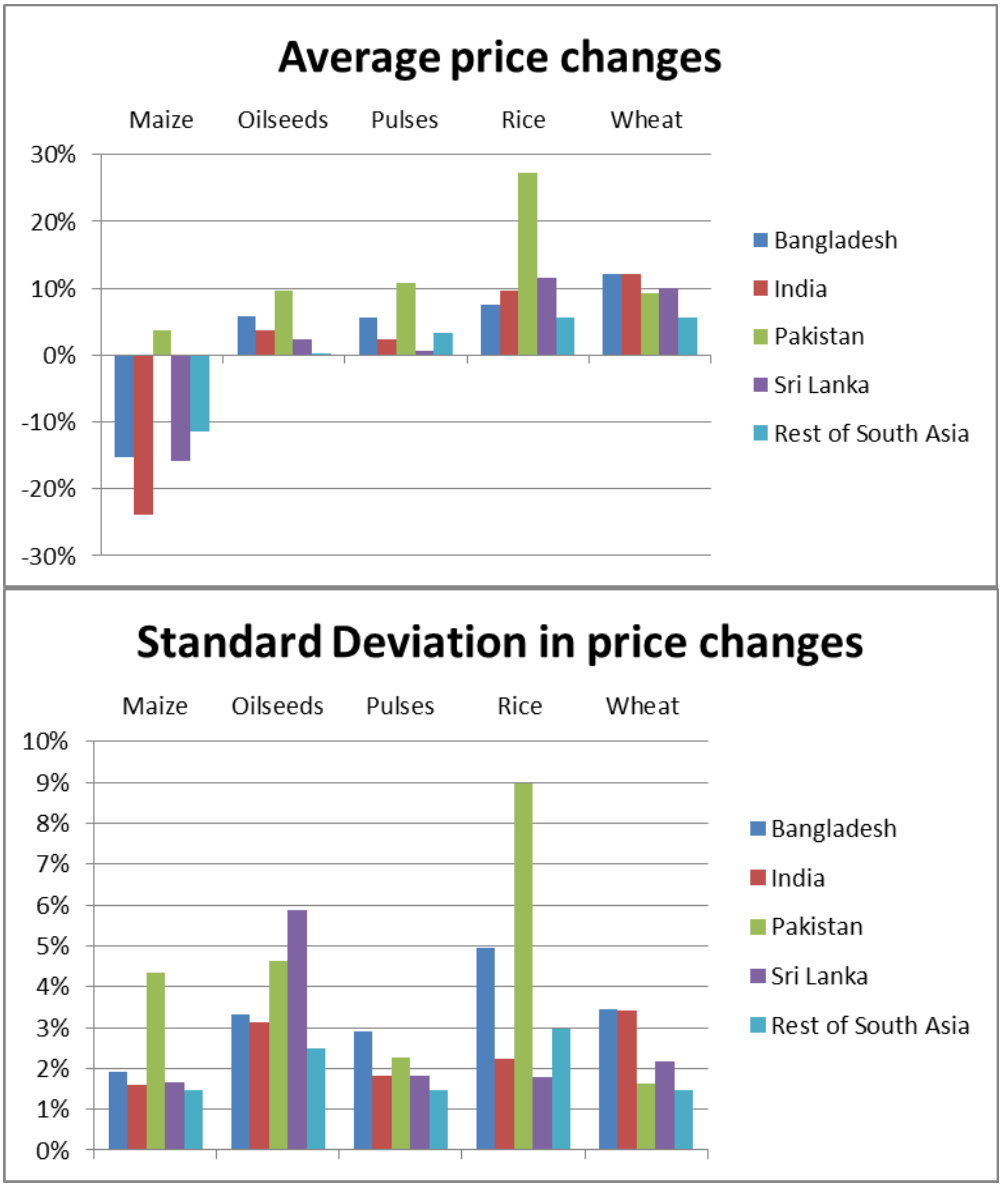


Source: MIRAGE simulations

There are few patterns that emerge with respect to the evolution of average food prices represented in Figure 16. First, the effect on primary products in Bangladesh, India and Pakistan are more preeminent than on agri-food products. Second, the hike in average food prices is found to be the most significant in India. Note however the importance of the role of the overall macro effects: in India income is less reduced or even increased such that it supports increased demand. Third, trade policy has an important role in mitigating the price increase. Nonetheless, it appears that the regional (FTA) or multilateral solutions are the only true options to get significant success: markets need to operate freely on a large scale to absorb the shock. Unilateral liberalization of SAFTA countries will not play the same role. It is important to keep in mind that these results compare the effects of climate change given the different trade policy baselines and *not* the combined effects of tariff removal and climate change relative to a full status quo baseline. More specifically, the price reduction effects of full liberalization is the consequence of less distorted markets and not the consequence of tariff elimination. The latter is an effect that is included in the baseline. In addition, we can state that progressive liberalization combined with the price increase due to increased tensions on productivity could help the mitigation strategy for consumers.

Next, the question arises, why does the average food price decline (or increase moderately)? The answer is related with the way this price is computed. Note that these prices represent a Fisher price index (the "true" price index on food products would pose computational difficulties in our CES LES demand framework). Therefore, in the computation of the price index weights change and consequently product shares evolve. In our analysis there are two basic crops (maize and other grains) that know price declines, while area and yield increases. Similarly, sugar will benefit from large price declines (locally and imported). The role of these products based on C4 crops (maize and sugar cane) plays a key role as their price reduction, driven by large yield increase in some areas, will lead to a doubling of the effects on the price index computed here: direct price decrease and substitution effects with other crops. In our results, we get a nearly perfect mitigation (Bangladesh's case through the sugar channel) or even overall price reduction (but they remain limited). In order to get a more accurate picture, we also represent price changes domestic market price of key crops (domestic supply).

Figure 17 Changes in domestic price for local varieties of key commodities – Status quo trade policy baseline (% change relative to the baseline in 2050)

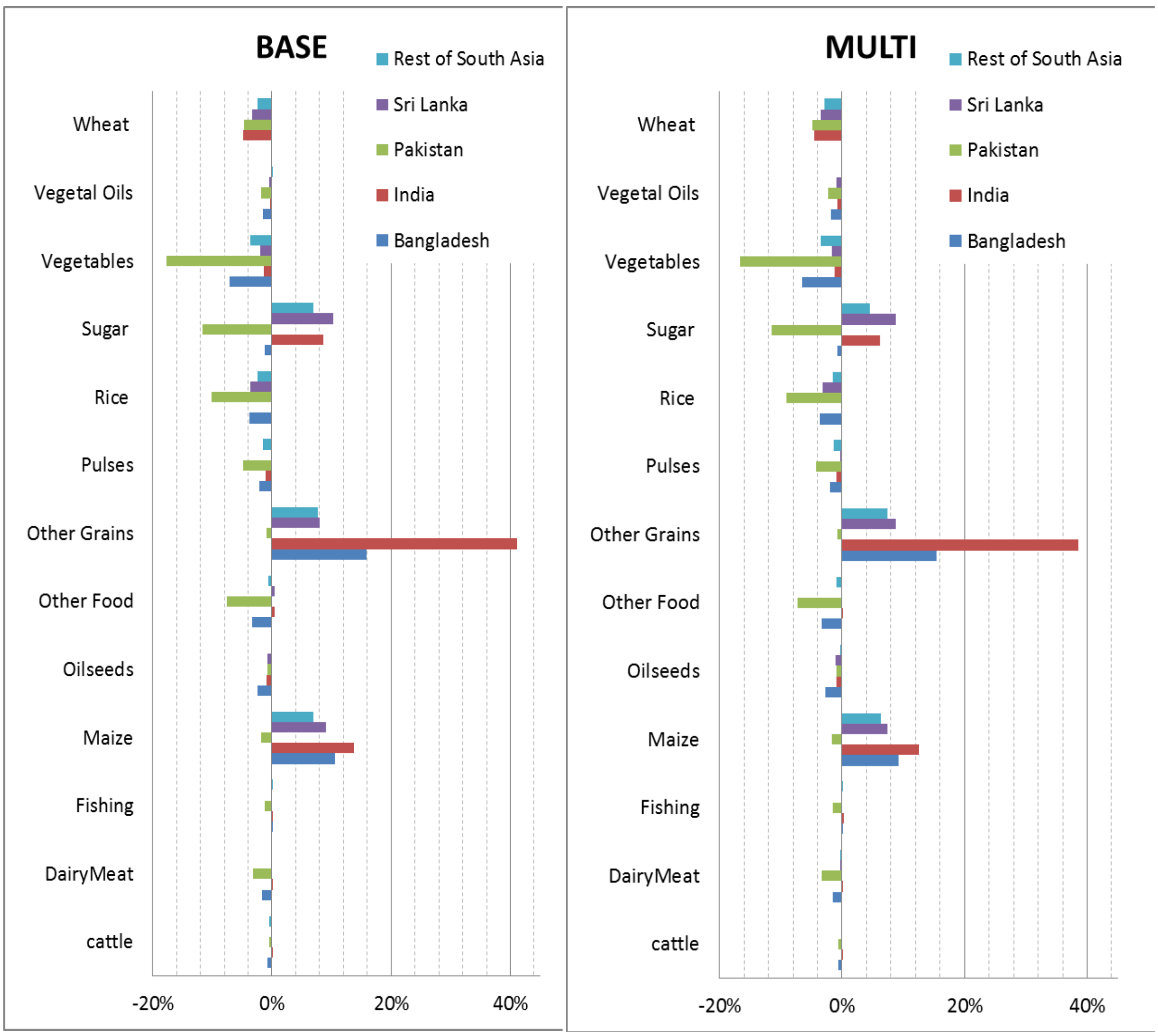


Source: MIRAGE Simulations

Figure 17 provides details of the changes and variability of the domestic price for local varieties of selected commodities. Note that there is an increase in the average price of all commodities, except for maize. Among all commodities, the average price of rice increases the most in particular in Pakistan (+27 percent). In addition, we find large price increase for wheat, too (+10 percent). Pakistan is found to be the most affected with respect to all crops. In addition, we note a strong decline in corn prices across all regions (except in Pakistan). Indeed, in India a very strong yield gain (yield increase associated with large amounts of land available when converted from other crops that do not perform as well) leads to the explosion in corn production that in turn drives corn prices down.

From the point of view of variability of price changes across scenarios, Sri Lanka and Pakistan shows large uncertainties. It noteworthy to mention that very poor consumer (consuming mainly wheat and rice) will be most adversely affected by these price changes.

Figure 18 Changes in average consumption per capita (% change relative to the baseline in 2050, simple average across climate change scenarios) for selected trade policy scenarios



Source: Mirage simulations

We now investigate the impact on food consumption per capita. This variable is an average that is determined by the combined effects of changes in real income at the country level and food price changes. We do not consider household heterogeneity.

As pointed out previously, different trade policy options lead to changes in income that are very similar across scenarios, thus in Figure 18 we resort to present only the impact of the two extreme cases of trade liberalization (status quo and full liberalization). Changes due to price differences (discussed above) are therefore the driver that differentiates per capital consumption across sectors.

Considering the full liberalization scenario, results show that average consumption per capita of most food products declines across all countries. Notable exceptions are other grains and maize for which household demand increases in all countries except Pakistan (most significantly in India by 39 percent as a result of the price effect on these commodities, as well as initially low level of consumption). As expected, negative effects are strong in Pakistan considering also the fact that the food basket is less diversified. Comparing the two scenarios, we notice interesting new consumption patterns such as the increase in maize consumption in Bangladesh and other coarse grains in India.

Table 11 Standard deviation in the % change of per capita food consumption across climate change scenarios in 2050

	Bangladesh	India	Pakistan	Sri Lanka	Rest of South Asia
Cattle	0.5%	0.2%	0.2%	0.2%	0.3%
Dairy & Meat	0.7%	0.2%	0.7%	0.1%	0.2%
Fishing	0.1%	0.2%	0.4%	0.1%	0.1%
Maize	1.1%	1.3%	1.5%	0.8%	0.8%
Oilseeds	1.3%	0.8%	1.3%	1.9%	0.9%
Other Food	0.7%	1.0%	1.2%	0.2%	0.4%
Other Grains	1.2%	1.0%	1.4%	0.6%	0.8%
Pulses	1.1%	0.9%	0.9%	0.6%	0.6%
Rice	2.1%	0.1%	2.5%	0.5%	1.1%
Sugar	2.8%	0.2%	3.7%	0.4%	0.8%
Vegetables	2.5%	1.7%	2.7%	0.6%	0.8%
Vegetal Oils	1.3%	0.9%	0.8%	1.0%	0.7%
Wheat		1.2%	0.7%	0.6%	0.5%

Source: MIRAGE simulations

Instead of using minimum and maximums across climate change scenarios, Table 11 represents the variation of results expressed as standard deviation in the percentage change of per capita food consumption. Countries with the highest variation are shown to be Pakistan (particularly in the case of sugar and vegetables).

Once again, we need to emphasize the fact that the adverse impact of the shocks on poor households will be relatively larger given that the change in their wages (discussed before) combined with the significant share of food in total expenditure (20-50 percent)and associated with food price changes (as a first order approximation) impact this strata of the population more significantly. To take a concrete example, we find that in Pakistan real income falls on average by -4.25 percent while food prices increase by nearly 2 percent and real wages of unskilled labor falls on average by -5.6 percent

Although it would be interesting to carry out a more detailed analysis at the household level, we would face difficulties to estimate the structure of households and their consumption patterns with precision by 2050. By aggregation, we avoid to be *precisely wrong*. Nevertheless, additional work is needed, including considering what will be the systemic safety nets in these economies by 2050 and about the role of automatic stabilizer. Our analysis stops here to avoid too many uncertainties.

Last, our results show that the coverage ratio (domestic production over total domestic consumption) remains relatively stable mainly due the reduction in consumption following the shock on production. For instance with respect to staple products (most negatively affected) it deteriorates by a maximum of 0.5 percentage points in the case of Pakistan. Beyond the range of changes directly resulting from climate change, trade policy options may play an important role for the evolution of domestic coverage: for Sri Lanka, the Asia-wide FTA[10] will increase the negative effects of the climate scenarios (-0.3 percentage points on the coverage) compared to the status quo (-0.1). This stability of this indicator is associated to a quite strong overall reduction of production and consumption occurring simultaneously (through the price and income effects). At the product level, the ratio for rice and pulses falls by more than 5 percentage points in Pakistan. It is quite possible that the demand system used in the model may overestimate the price and income elasticities of food by 2050, despite the recalibration procedure. In such a case, the coverage ratio will react strongly as well as the trade flows that will be discussed in the next section.

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[10] For the most pessimistic scenario, the decline in coverage ration can reach 1.1 percentage point for staple and 2.6 for agro food.

5 Concluding Remarks

Our concluding remarks focus on two aspects. First, which policy recommendations appear to be robust based on our results. Second, what are the limits of our current work and how they should be addressed in the future.

This report has confirmed that South Asia will be one of the most adversely affected regions in terms of the impacts of climate change on agricultural yield. Both the overall level of economic activity and trade flows will react to this change (-0.5 percent of real income for the region in average, up to -4 percent for Pakistan). India appears to be in the most favorable position with respect to real income variation comprised between -0.6 percent and +0.5 percent depending on the climate change occurrence. Indeed, uncertainty about the exact intensity of climate change and its exact geographical location, embodied in the 12 SRES scenarios considered by our analysis, has significant impacts in terms of variability of results. In this context, it is difficult to pinpoint what is the optimal trade policy for different countries. This is also a strong argument in favor of the type of quantitative assessment done in this study coupled with a large number of scenarios: climate change and trade interact through rich and complex mechanisms and it is difficult to provide ex ante standard recommendations. Looking at the simple average between SRES scenarios, i.e. assuming equal probability to each case and without consideration on volatility (no risk aversion of policy makers), it appears that except for India all the other smaller economies should favor the status quo or the deepening of regional, SAFTA focused, integration. India may choose more ambitious trade policies with a trade agreement agenda at a pan Asia level or even at a global scale. Nonetheless, India needs to have gains in foreign market access to choose this path and unilateral trade liberalization is not optimal for ex ante climate change management (i.e. when the exact nature, location and effects of the climate change remain highly uncertain). The specific case of India is quite interesting since it has implications for the region as a whole. On the one hand, India is a large country, and by 2050 will develop a real market power. If its markets are to open – unilateral efforts – it may be exposed to negative price shocks and large terms of trade losses. By maintaining restrictions, it uses its market power and the traditional “optimal tariff argument” to mitigate the increase of world prices and the deterioration of its terms of trade. At the same time, it will also benefit from initially strongly open foreign markets. The strengths of India go beyond its size on the international trade scene. Domestically, the size of the Indian market allows the country to reallocate production across crops and allows regions to redefine an optimal production pattern compatible with new climatic conditions. In particular, it can rely on a large amount of land used for cotton to produce additional food crops. For smaller countries, with a more limited choice of crops and limited area distribution, no internal diversification strategy is possible. Therefore, it will be important for the region as a whole to have flexible goods but also factors of production (land, capital, labor) markets to ensure good capacity of adaptation and reallocate resources efficiently.

Beyond national real income, it is important to look at some distributional effects of climate change. Unskilled worker real wages, proxy for poor people income, are largely and generally negatively impacted by climate change. This is logical since unskilled labor force is directly impacted by the change in agriculture productivity and yield of land, since this factor is largely used by this sector. For Pakistan, the losses are above 5.5 percent in real terms (using the country wide price deflator). For India, if the average is positive (about 1.6 percent) with status quo policy, the range of uncertainty is large: between +8.2 percent and -9.1 percent depending on the climate change scenario. In this context, for the poorer, unilateral liberalization, including liberalization with sensitive products in some cases, may be the best strategy in terms of expected value. For India this is not the case as on average, status quo is preferred. As for other countries, we also see that unilateral liberalization is the best strategy in the worst of the case.

Nevertheless, more open markets, especially at the world level, lead the reduction in price increase on key food products (for instance the average price of rice increases the most in particular in Pakistan by +27% while we find large price increase for wheat of +10%) and more stability. Here also, uncertainties about climate change lead to contrasted forecasts: global trade in agriculture may increase or decrease depending how traditional exporters (e.g. Cairns group countries) will be affected and how traditional importers will need to find new partners or to develop home based solutions. Indeed, beyond global developing markets, free trade in agriculture will also lead to important market opportunities for South Asia in other developed and developing markets. When climate change will occur, the expansion of the production done for these foreign markets can be reallocated to the sub regional markets, mitigating, by half in some cases, the price increase driven by the yield reduction.

Beyond the uncertainty inherent to climate change analysis, this study has also its own limits that should lead us to interpret our conclusions with precaution.

Our dynamic setting has only two types of irreversibility: decisions in terms of human capital and physical capital. Since only the latter is a sunk cost and sector specific, it is the only source of irreversibility and leads to potential path dependent effects. Do trade policies lead to long term costs if they have been erroneous and driven specialization in sectors domestically negatively affected? On the overall, our model display weak memory by 2050. This explains the relatively limited variance of results among trade policy baselines. Reality may be more adverse and we should look at three potential channels: fixed sunk costs in trade (based on the growing literature on international trade on this issue), R&D decisions and investment in agricultural research (which crops?) and other related infrastructure, and finally political economy locking mechanisms (when support or protection is given to a sector, it may be impossible to eliminate it and the sector will try to resist even if comparative disadvantages increase).

Finally, our analytical framework based on a large number of simulations has allowed us to have some information on the average but also the risk driven by climate change of different trade policy options. Adopting a risk analysis approach and assuming different levels of risk aversion for regional policy makers the choice of an optimal strategy may be performed (as in a portfolio approach). As discussed above, the degree of hysteresis and the sunk cost nature of some investments will be very important to know if some trade policy options have significant costs when they have to be chosen ex ante and need to be modified ex post.

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7 Appendix

Table 12 Detailed Real Income effects by country and scenarios. Bios of constant USD (2004)

	BASE	SAFTA	SAFTAFULL	UNIAGR	UNIALL	UNISEN	FTA	MULTI
Bangladesh								
cnr_a1	-48.6	-48.6	-47.5	-46.8	-46.1	-46.9	-48.2	-47.7
cnr_a2	-51.5	-51.7	-50.6	-49.9	-49.1	-49.9	-51.3	-50.8
cnr_b1	-30.6	-30.9	-30.3	-29.8	-29.4	-29.8	-30.8	-30.6
csi_a1	-38.8	-39.2	-38.3	-37.6	-37	-37.7	-38.6	-38.4
csi_a2	-53.4	-54	-52.8	-52.2	-51.2	-51.7	-53.3	-53.4
csi_b1	-30.3	-30.9	-30.2	-29.4	-29.1	-29.7	-30.4	-30.4
ech_a1	-46	-46.2	-45.1	-44.5	-43.8	-44.5	-45.6	-45.2
ech_a2	-28.3	-28.6	-27.9	-27.4	-27	-27.5	-28.2	-28.2
ech_b1	-28.8	-29	-28.3	-27.8	-27.4	-27.9	-28.6	-28.5
mir_a1	-16.6	-16.8	-16.3	-16	-15.8	-16	-16.6	-16.4
mir_a2	-11.4	-11.7	-11.3	-11	-10.9	-11	-11.5	-11.3
mir_b1	-23.1	-23.4	-22.9	-22.4	-22	-22.4	-23.1	-22.8
India								
cnr_a1	-316.1	-315.9	-315.4	-330	-339.4	-328.6	-321.5	-325.6
cnr_a2	-290.2	-289.9	-289.3	-303.9	-312.9	-301.3	-295.5	-304.9
cnr_b1	-165.9	-165.4	-164.8	-180.2	-186.8	-173.2	-165	-171.1
csi_a1	67.5	68.3	70.4	55.2	50.1	65.6	73.8	73.2
csi_a2	63.8	65	67.5	44	41.1	66.8	67.4	57.5
csi_b1	147.3	148.4	150.4	132.6	132.4	146.5	156.5	149
ech_a1	-314.5	-314.1	-312.6	-324.9	-333	-324.3	-321	-322.9
ech_a2	34.6	35.3	37.1	21.5	16.6	32	41.6	36.3
ech_b1	173.8	174.7	176.9	162.3	157.6	173.6	185.4	182.9
mir_a1	225.2	225.9	227.5	215	211.4	224.1	246.8	246.9
mir_a2	280.2	281.1	282.7	271.3	267	279.1	304.5	308.8
mir_b1	250.8	251.7	252.9	241.8	238.5	250.7	271.4	272.5
Pakistan								
cnr_a1	-235	-235.9	-239.1	-238.8	-232.1	-236.2	-244.2	-245.3
cnr_a2	-201.1	-201.9	-204.9	-205	-199.1	-202.6	-208.6	-210.8
cnr_b1	-154.3	-155	-157.5	-158.4	-153.6	-156	-161.2	-162.1
csi_a1	-238.8	-239.9	-244.2	-243.3	-235.5	-240.4	-248.6	-248.9
csi_a2	-249.7	-250.8	-255.6	-255.6	-247	-251.6	-260.8	-261.3
csi_b1	-177.3	-178.2	-181.9	-184	-175.7	-179.3	-185.8	-185.4
ech_a1	-304.3	-305.6	-310.1	-309.1	-300	-305.7	-316.4	-316.4
ech_a2	-233.2	-234.3	-238.1	-237.1	-229.6	-234.3	-242.5	-243
ech_b1	-238.5	-239.7	-243.9	-242.2	-234.5	-239.8	-247.7	-248.1
mir_a1	-305.4	-307	-311.6	-310.1	-300	-305.9	-317.8	-316.9
mir_a2	-291.3	-292.8	-297.4	-295.9	-286.3	-292.1	-303.4	-302.1

mir_b1	-228.3	-229.7	-233.4	-232.2	-224.6	-229	-238.1	-236.9
Sri Lanka								
cnr_a1	-1.3	-1.2	-1.3	-1.8	-1.8	-1.3	-2.4	-2.5
cnr_a2	-1.7	-1.7	-1.8	-2.2	-2.2	-1.8	-2.7	-3
cnr_b1	-1.7	-1.7	-1.8	-2.2	-2.2	-1.8	-2.7	-2.9
csi_a1	-1.9	-1.9	-2.1	-2.3	-2.2	-2	-2.8	-3
csi_a2	-3.1	-3.1	-3.4	-3.5	-3.5	-3.3	-4.2	-4.3
csi_b1	-2.2	-2.3	-2.4	-2.5	-2.6	-2.4	-3.2	-3.4
ech_a1	-2.2	-2.1	-2.2	-2.5	-2.6	-2.2	-3	-3.4
ech_a2	-1.6	-1.5	-1.7	-1.9	-1.9	-1.6	-2.4	-2.7
ech_b1	-1.3	-1.3	-1.5	-1.6	-1.6	-1.4	-2	-2.3
mir_a1	-2	-2	-2.5	-2.8	-2.8	-2.4	-3.3	-3.5
mir_a2	-1.8	-1.8	-2.2	-2.7	-2.6	-2.1	-3.4	-3.4
mir_b1	-1.4	-1.4	-1.8	-2.1	-2.1	-1.7	-2.7	-2.8
Rest of South Asia								
cnr_a1	-3.7	-3.7	-3.7	-3.7	-3.7	-3.6	-4.8	-4.8
cnr_a2	-3	-2.9	-2.9	-2.9	-3	-2.9	-3.9	-3.9
cnr_b1	-1.3	-1.3	-1.2	-1.3	-1.3	-1.2	-2	-2
csi_a1	-5.2	-5.3	-5.4	-5.3	-5.2	-5.2	-6.7	-6.5
csi_a2	-4.4	-4.5	-4.5	-4.6	-4.5	-4.4	-5.7	-5.6
csi_b1	-1.4	-1.4	-1.3	-1.5	-1.5	-1.3	-2.3	-2.3
ech_a1	-5.5	-5.6	-5.6	-5.7	-5.6	-5.5	-6.8	-6.6
ech_a2	-4.6	-4.7	-4.7	-4.7	-4.6	-4.6	-5.8	-5.8
ech_b1	-4.2	-4.3	-4.4	-4.3	-4.2	-4.2	-5.4	-5.2
mir_a1	-2	-2.1	-1.9	-2	-1.9	-1.8	-2.2	-2.3
mir_a2	-1.6	-1.7	-1.5	-1.6	-1.5	-1.4	-1.9	-1.9
mir_b1	-3.7	-3.8	-3.8	-3.8	-3.7	-3.6	-4.6	-4.5