Climate Change, Water, and Agriculture in Morocco's Future: Scenarios for Managing Scarcity

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Abstract

Water scarcity presents a fundamental challenge to Moroccan agriculture. It is estimated that, over the coming decades, scarcity will increase significantly because of climate change, both on a seasonal and annual basis. Rainfall has been declining on a net annual basis for the last two decades, and this process is expected to continue, while seasonal variability rises sharply. Combined with significant expected population growth, particularly in urban areas, this will lead to considerable stress on the Morocco's physical and institutional capacity for water storage and allocation. The potential costs of these climate impacts remain very uncertain, but will depend to a significant extent on how Morocco adapts to a future of water scarcity. Even if the earth's climate is stabilized, major adjustments will need to be made in Morocco's water sector to adapt to scarcity imposed by population and unavoidable climate damage. This report evaluates the prospects for Morocco's agricultural sector as climate trends develop and policies evolve in response to this.

1 Introduction

Essential to all economic activities, water is very unequally distributed in Morocco, across both space and time. National water supplies originate in northern weather patterns and precipitate into the mountains as warm maritime air masses pass over the Atlas, yet most water is consumed at lower elevations and in urban areas far from the mountains. Overcoming these gaps in timing and geography of supply and demand requires an extensive system of water storage and conveyance, and this water re-allocation has been necessary to support more extensive agriculture and intensive urbanization across the country.

The environment (e.g., maintaining ecosystems) has historically been the largest water user in Morocco (57 percent, Figure 1.1), with agriculture second (38 percent) and

[†] World Bank and UC Berkeley. The authors would like to thank Saad Belghazi, Rachid Doukali and […] for many helpful discussions and suggestions, as well as participants at […]. The views and conclusions reported in this paper are those of the authors and should not be attributed to their affiliated institutions.

urban users a distant third (5 percent) (AIC, 2006).[1] Growth in urban water use, in particular, will require adjustments to these shares, and trend increases in use requirements (Figure 1.2) will increase pressures on Morocco's water supply as annual rainfall declines.

Figure 1: Moroccan Water Use by Destination, 2001

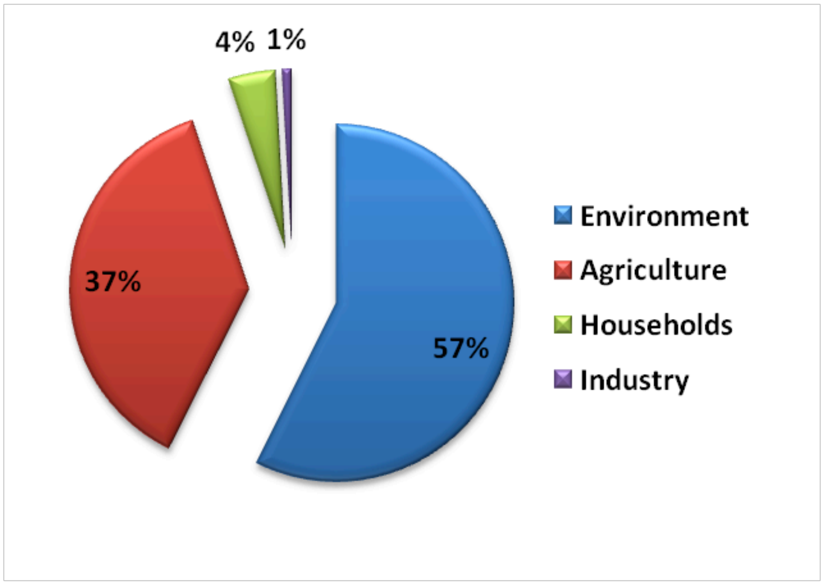
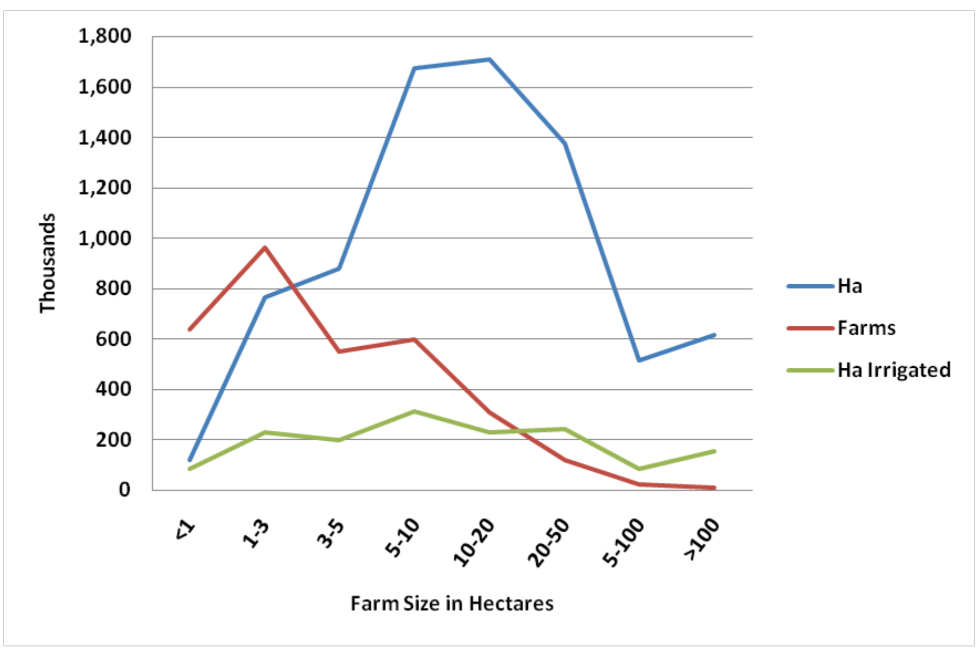


Figure 2: Size Distribution of Farms, Land Area, and Irrigation Water Use



[1] Agriculture thus accounts for 88% of exploited water resources. Even though over half of the country's water remains unexploited, water is economically scarce in Morocco because exploitation costs remain high in relation to domestic income.

Agriculture's dependence on water has special economic significance because this sector accounts for 18 of GDP and 40 percent of national employment. Within agriculture, both irrigation water and land are unevenly distributed. As Figure 1.2 suggests, most farmland in cultivated by household enterprises holding less than 20 hectares, and most farms are less than 3 hectares in size. As Figure 1.3 suggests, the overall distribution of land is relatively unequal, with a land/farm Gini of .60 compared to Morocco's official UN income Gini of .39. Irrigation water is more equally allocated on a per farm basis, but only about 14 percent of total farmland has access to irrigation water.

Figure 3: Distribution of Land and Irrigation Water by Farm

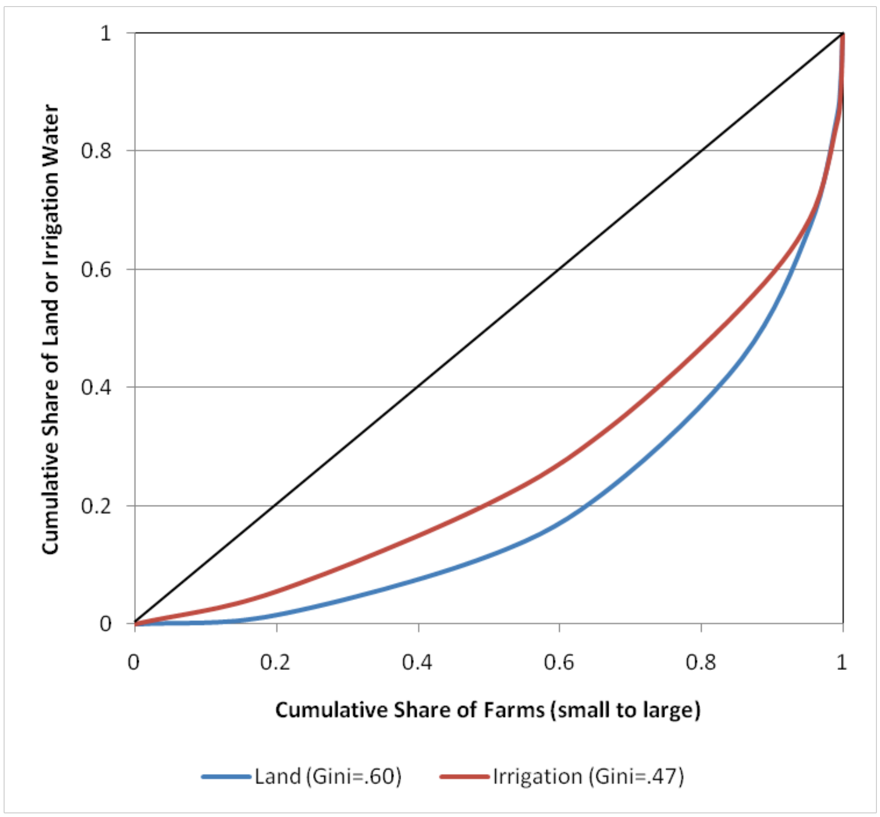
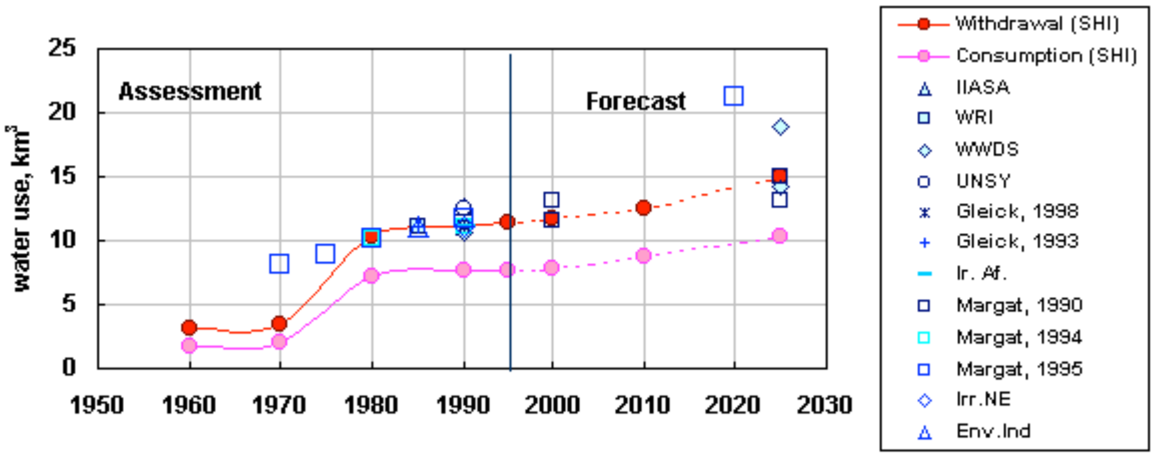


Figure 4: Consensus Estimates of Water Use Trends



Sources: IIASA (1993), WRI *(1991-1992, 1992-1993, 1994, 1996, 1997-1998)*, WWDS (1990- 2025), UNSY (1992, 1993), Gleick (1993, 1998, 1999), Margat (1990, 1992, 1994, 1995), IrrNE /FAO (1997), IrAf/FAO (1995).

1.1 Drivers of Water Scarcity in Morocco

Climate change presents a variety of water related challenges to Morocco, most of which will make this essential resource increasingly scarce, both in physical and economic (scarcity cost) terms. The primary drivers of water scarcity fall into three main categories:

1. Precipitation
   a. Trend declining
   b. Volatility increasing (deeper and longer droughts)
2. Storage – the two largest storage facilities are threatened
   a. Aquifers: overdraft risk
   b. Snowpack: shrinking
3. Demographics
   a. Population – rising
   b. Urbanization – rising national per capita use

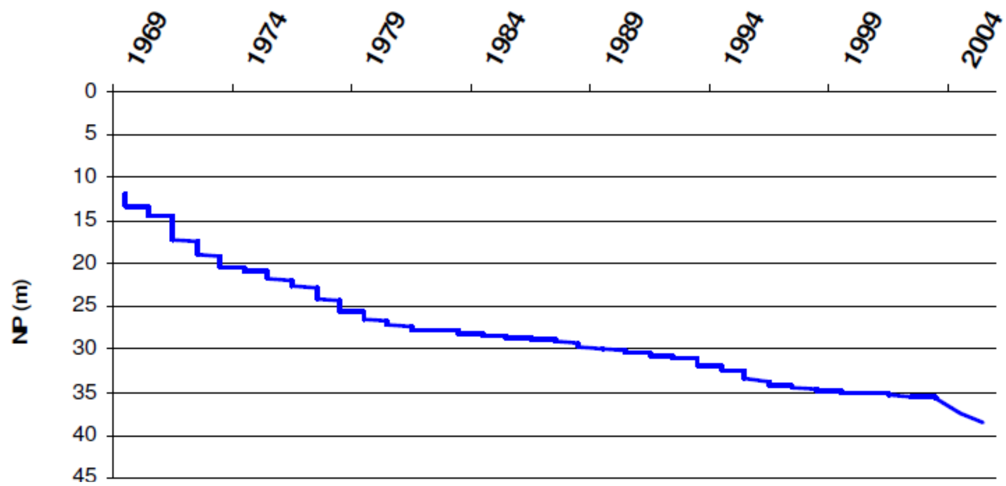
Precipitation

Most climate models agree that global warming will increase Morocco's winter precipitation and reduce it at other times. Spring rainfall has declined by over 40%, and the maximum dry-spell length has increased by 15 days since the 1960s, and this trend is expected to continue. This trend will lead to a steady decline in total water availability, moderate increases in annual variability, and sharp increases in seasonal variability.

Storage

Declining and increasingly variable rainfall will further challenge the sustainable exploitation of Morocco's main water storage facility, underground aquifers. Water captured in storage infrastructure has decreased some 35% in the period 1970-2000 in comparison to the period 1945-1970; this has resulted in a 52% drop in provision of water to irrigation districts over the last ten years.[2] As Figure 1.5 suggests, many of Morocco's important aquifers are already in overdraft.

Figure 5: Average Depth of the Souss Water Table



Source: Debat Nationale sur l'Eau, Souss-Massa:2006.

At the same time, climate change will be dramatically reducing the second largest storage facility, the Atlas snowpack, further intensifying seasonal disparities in natural water availability. For montane regions of the Atlas' elevation and latitude, most climate models predict snow pack losses of 30-80 percent over this century.[3] Combined with significant expected population growth, particularly in urban areas, this will lead to considerable stress on Morocco's existing water storage and allocation systems. Higher water flow variability will also lead to increased risks of drought-induced agricultural loss and habitat destruction, as well as winter flooding and related water damage. Water conservation offers the most cost-effective means of reducing scarcity and its attendant costs, but it will be difficult to offset a substantial part of long-term growth in aggregate demand.

[2] MATEE: plateforme du Débat National sur l'Eau
[3] IPCC:2006, NCAR:2008.

Demographics

The primary functional division in water is between agriculture and residential users, with industry a relatively small user. Most rural water goes to crops and livestock, while most urban water goes to residential consumers, the latter being about 3 times as water intensive per capita as their rural counterparts. Over the coming decades, aggregate Moroccan population growth is expected to be quite low by African standards and moderate for the North African region, at about 1.2 percent annually.[4] Because of sustained demographic transition from rural to urban residency, however, urban populations will rise faster, and water use even more so.

1.2 Policy Challenges

At the national level, climate induced water scarcity poses four basic challenges to Morocco

1. Food security
    a. Morocco has a significant degree of food self-sufficiency, yet it imports significant amounts of staple foods even in normal harvest years. While national average food security has generally been maintained, significant distributional disparities are apparent
    b. This means both the analysis and policy remedies must take account of regional/income heterogeneity
2. Living standards
    a. Like most developing countries, Morocco is experiencing long term demographic transition from rural to urban residency
    b. Urban lifestyles are much more water intensive, increasing the burden on national water resources even without population increases
    c. As water scarcity increases, urbanites will experience direct and indirect costs, including higher water and food prices
3. Export earnings
    a. A substantial proportion of Morocco's export revenue comes from irrigated agriculture, much of it with high water value added and vulnerable to adverse competitive impacts
4. Fiscal Sustainability
    a. Administrative and fiscal intervention in Morocco's agro-food economy remains extensive, and significant resource cost and relative price adjustments in this sector will have lasting budgetary implications

[4] This compares, for example, to 1.8 for Egypt and 1.5 for Algeria, 3.5 for Niger, and 3.3 for Uganda.

The Moroccan government is well aware of these challenges. In June of this year, King Mohammed VI called for setting up a multilateral fund to tackle climate change and to ensure food security, in a speech to a high-level Conference on World Food Security in Rome, he stated that: "Ensuring food security for all and tackling climate change are daunting challenges to which the international community cannot rise without enhanced international solidarity, greater North-South co-operation, and more efficient South-South co-operation." His statement also affirmed Moroccan calls for setting up of a multilateral fund to improve state capabilities, promote the transfer of technology to developing countries under preferential terms, and finance practical measures to tackle the effects of climate change. The current project seeks to complement these commitments by improving visibility regarding the economic consequences of long term, climate induced changes in the Moroccan water economy, including assessment of alternative policy responses.

1.3 Policy Responses

Responding to these challenges effectively will require a combination of policies, targeted at both sides of the water economy. On the supply side, investments in storage and efficient conveyance will be needed to overcome both scarcity and (temporal and spatial) variability. On the demand side, management policies with efficiency incentives must be combined with social protection to offset intermittent adversity.

1. Supply side commitments
    a. Storage investment
    b. Intermediate conveyance investments
    c. Rights management to promote marketing/conservation
2. Demand side management
    a. Agricultural extension services
    b. Incentives for efficient water use technology development, diffusion, and adoption (rural and urban)
    c. Standards
    d. Water pricing
    e. R&D investments/grants/subsidies
3. Social protection/stabilizers
    a. Temporary interventions to offset adverse supply shocks, risk management and coping (e.g. credit constraints, etc.)
4. Trade Policy

Supply Side Commitments

Climate adaptation in the Moroccan water sector will require extensive investments in both hard and soft infrastructure. Some of these will require new fiscal commitments, but others represent longer term adaptations that can be incorporated within renewal and replacement budgets. For the longer term, significant investments in storage, conveyance, and water management institutions are needed. Financing the former can be sustained by public-private partnership, particularly if rights are assigned in ways that promote resource conservation and marketability. In this area, intermediate conveyance infrastructure will be especially important as a commitment device that lowers transactions costs for small and medium scale water marketing. This can be wholly financed by the government, like large hydro schemes, or financed with mixed schemes partial subsidies, revenue sharing, etc.

In the soft infrastructure category, water management institutional reform will need to break new ground with respect to the public interest in water resources. Given strong legacy components in established water resource entitlement and allocation, a significant rise in its scarcity value could trigger intense rural-urban competition and instigate a re-appraisal of rules governing the water entitlements and private use.

Demand side management

a. Agricultural extension services
b. Urban adoption subsidies
c. Standards
d. Water pricing
e. Insurance schemes
f. R&D investments/grants/subsidies

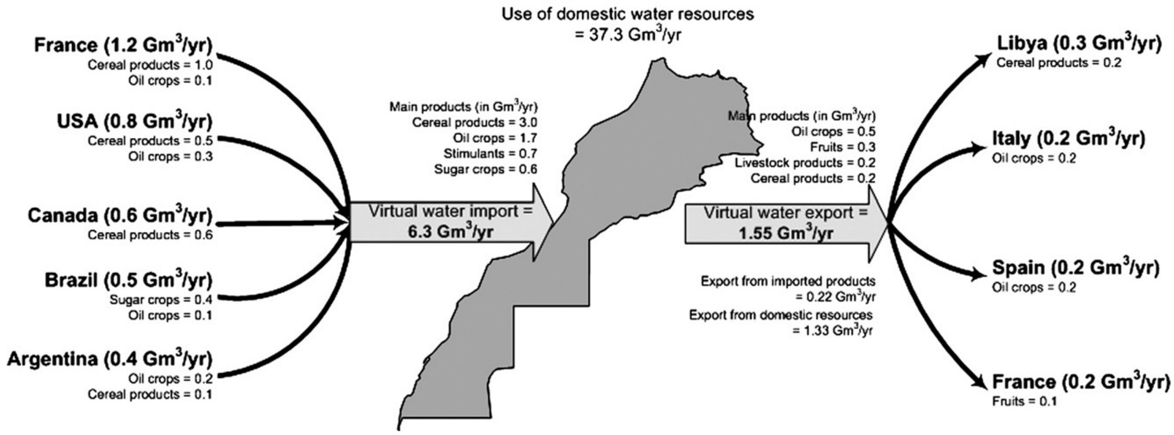
Social protection/stabilizers

g. Temporary interventions to offset adverse supply shocks, risk management and coping (e.g. credit constraints, etc.)

Trade Policy

About 70 percent of arable land cultivation in Morocco is dedicated to cereal crops, meaning that increased cereal imports could significantly offset agricultural water use. Independent research suggests that Moroccan trade already has a significant deficit in embodied or virtual water services, with water content of imports exceeding that of exports by about 4 to 1 (Figure 1.4). Food staple imports are already high, however, and there is some evidence that further liberalizing food trade could adversely affect the rural poor (Ravallion and Lokshin :2004 and Douidich et al: 2008). If increasing imports significantly reduced water constraints for the nation as a whole, however, it might be advisable to combine this with adjustment assistance or other compensatory measures.

Figure 6: Embodied Water Trade Balance, Morocco
Table 1:



Source: Hoekstra and Chapagain, 2007

1.4 Implications for Agriculture

Increased water scarcity will have profound implications for Moroccan agriculture. Farming in most of the country is already water constrained, with very uneven national water availability and high transpiration rates that increase water intensity of most traditional crops. Rising temperatures will increase water requirements for existing crops and evaporative losses from existing conveyance infrastructure, further increasing water scarcity costs to farmers. Four issues in particular are relevant for agricultural adaptation to water scarcity:

Crop substitution

This includes substitution of new genetic material, like drought tolerant varieties, but also planting different crops, including both drought tolerant and irrigation oriented crops. Farmers' capacity to make these changes will vary with access to new genetic material, complementary technology, knowledge, and capital.

Increased risk

Higher annual and seasonal water variability, particularly against trends of rising temperatures, will increase vulnerability of crops and livestock to drought. Like poverty, losses arising from these cycles can be sudden and difficult to reverse if they lead to stock losses, credit defaults, and even displacement. As the amplitude of such cycles increases, the risk of irreversible adversity also rises.

Higher capital costs

More efficient water use, as well as crop switching, technical substitution, and other adaptations require capital investments that may be outside the normal financial envelope of smallholders. As only 14 percent of Moroccan farm area is currently irrigated, this represents a substantial hurdle for national technology adoption.

Intensification

As rainfall declines and reliance on irrigation and groundwater increase, there will be a natural tendency to reduce acreage under cultivation and the returns to pasturage for livestock will decline. More intensive methods will reinforce and shape trends of crop substitution and technological change, but also present new capital constraints to smallholders.

2 General Equilibrium Assessment of Climate Impacts on Agriculture and the Moroccan Economy

Although many of the water challenges facing Morocco are already acknowledged, empirical evidence to support effective adaptation policies remains relatively weak. Because of the importance of agriculture generally and the long lead times required for structural adjustment in this sector generally and water resource management in particular, policy makers need better foresight about emerging risks in this sector. To provide this kind of empirical policy support, we use a dynamic forecasting model calibrated to detailed information on Moroccan economic structure, including regional crop and water use information.

Models like to one used here are intended to capture the extended linkages and indirect effects that follow from specific external shocks policies. The complexities of today's global economy make it very unlikely that policy makers relying on intuition or rules-of-thumb will achieve optimality. Market interactions are so pervasive in determining economic outcomes that more sophisticated empirical research tools are needed to improve visibility for both public and private sector decision makers. The preferred tool for detailed empirical analysis of economic policy is now the Calibrated General Equilibrium (CGE) model. It is well suited to trade analysis because it can detail structural adjustments within national economies and elucidate their interactions in international markets. Technical details of the Morocco CGE are presented in an annex to this report, and a large research and policy literature documents this general approach, but a few general comments will facilitate discussion and interpretation of the scenario results that follow.

Technically, a CGE model is a system of simultaneous equations that simulate price directed interactions between firms and households in commodity and factor markets. The role of government, capital markets, and other trading partners are also specified, with varying degrees of detail and passivity, to close the model and account for economywide resource allocation, production, and income determination.

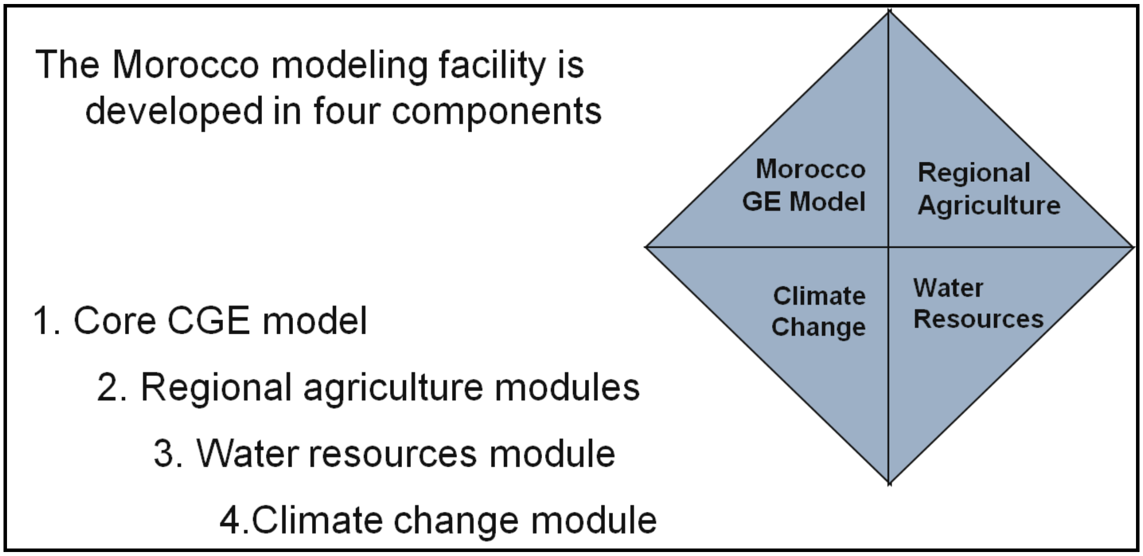
The role of markets is to mediate exchange, usually with a flexible system of prices, the most important endogenous variables in a typical CGE model. As in a real market economy, commodity and factor price changes induce changes in the level and composition of supply and demand, production and income, and the remaining endogenous variables in the system. In CGE models, an equation system is solved for prices that correspond to equilibrium in markets and satisfy the accounting identities governing economic behavior. If such a system is precisely specified, equilibrium always exists and such a consistent model can be calibrated to a base period data set. The resulting calibrated general equilibrium model is then used to simulate the economywide (and regional) effects of alternative policies or external events.

The distinguishing feature of a general equilibrium model, applied or theoretical, is its closed form specification of all activities in the economic system under study. This can be contrasted with more traditional partial equilibrium analysis, where linkages to other domestic markets and agents are deliberately excluded from consideration. A large and growing body of evidence suggests that indirect effects (e.g., upstream and downstream production linkages) arising from policy changes are not only substantial, but may in some cases even outweigh direct effects. Only a model that consistently specifies economywide interactions can fully assess the implications of economic policies or business strategies. In a multi country model like the one used in this study, indirect effects include the trade linkages between countries and regions which themselves can have policy implications.

The general equilibrium aspect is particularly useful in assessment of resource issues like those related to climate change. In this context, many activities compete explicitly or implicitly for resources (e.g. water), and direct effects on one (e.g. agriculture) induce many effects on others. While the present analysis will not include assessment of direct climate impacts on non-agricultural activities (e.g. mortality/morbidity, fire risk, coastal inundation and storm damage), the CGE model faithfully captures indirect effects across all actors as these arise from agro-food and water scarcity impacts.

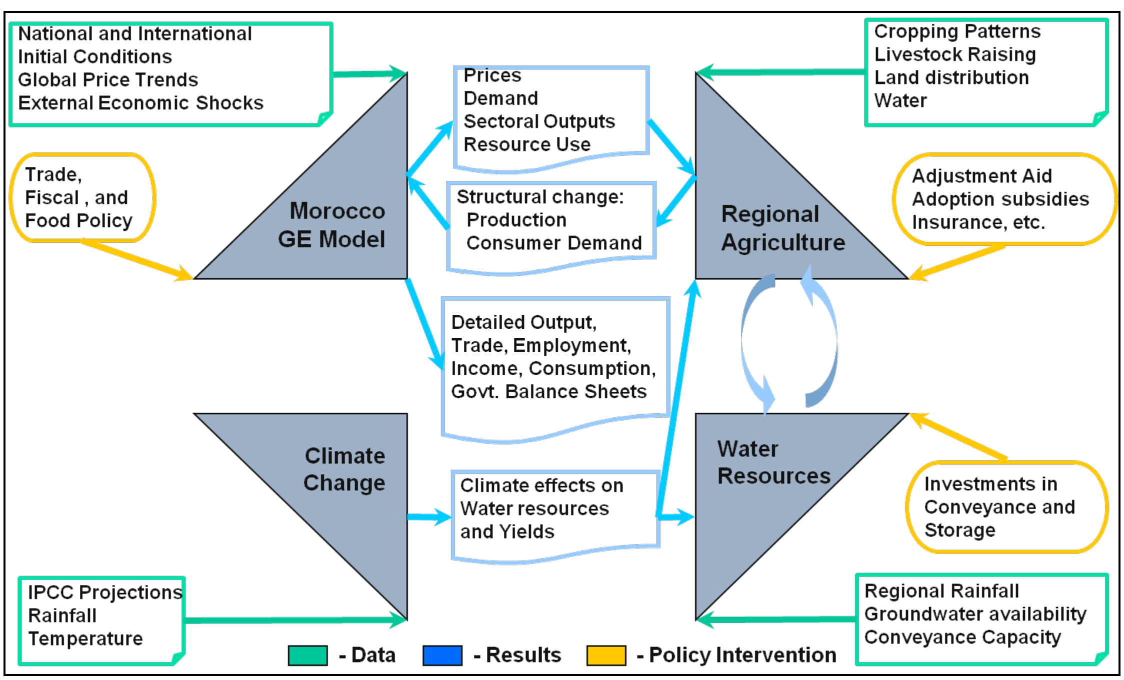
The model we use for this work has been constructed according to generally accepted specification standards, implemented in the GAMS programming language, and calibrated to a detailed base year (2001) Social Accounting Matrix (SAM) for Morocco. As Figure 2.1 indicates, the modeling facility has four generic components, each capturing a different aspect of the problem at hand, the overall economy, the agricultural sector, water resources, and climate change. We do not model climate change, but assume the exogenous climate trends are specified in this component according to internationally established independent estimates (see section 3 for details).

Figure 7: Model Components



Schematically, each component relies on different data resources and is relevant to different policies, yet all are connected through systemic linkages of economic activity, agronomic relationships, resource allocation, and environmental interaction. These linkages are illustrated schematically in Figure 2.2, although the functional relationships and structural detail are greatly simplified.

Figure 8: Schematic Decomposition of the Morocco Model



2.1 SAM Data Framework

The genesis of the SAM, the basic economic data resource, goes back to the Nobel Laureate Richard Stone's pioneering work on social accounting, and during the past 25 years a variety of formalizations have appeared in the academic literature. In essence, the SAM is an economywide accounting device that captures the many interdependencies among sectors and institutions in the economy. As such, the SAM becomes the basis for detailed multiplier analyses that go well beyond more traditional input-output multiplier analysis, and also forms the informational basis for the building and calibration of a variety of applied general equilibrium models. Such models are important analytical tools for policy support. They take explicit account of the importance of price-mediated resource allocation, the hallmark of a market economy, and are therefore well suited to analyze issues such as the impact of liberalization with respect to domestic and international markets.

Thus the SAM provides a closed form, economywide accounting of linkages between activities (and/or commodities), factors, households, domestic institutions (e.g., investment, government), and foreign institutions. The SAM used in the present study includes 51 activities and commodities, of which 40 are agro-food, and 29 are agricultural (Figure 2.3). Also detailed are four factors of production (labor, capital, land, and water), and quintile households in both rural and urban areas.

Figure 9: SAM/Model Activities and Commodities

Because of the importance of regional differences in Moroccan agriculture and water resources, we further disaggregate agricultural production across six agro-ecological zones (AEZ), defined as follows:

1. Most favorable agricultural (fvrbl)
2. Intermediate agricultural (intrm)
3. Poor Southern agricultural (sthpr)
4. Poor Eastern agricultural (estpr)
5. Mountainous agricultural (atlas)
6. Saharan agricultural (sahrn)

At the same time, we distinguish four functional categories of water resource use:

1. Large scale irrigation—hydro (hydir)
2. Other irrigation (othir)
3. Rain-fed (rnfed)
4. Not applicable (ntapp)

By including these characteristics for each agricultural activity and region, the complete regional model thus captures both structural and spatial heterogeneity in the Moroccan economy at an unprecedented level of detail.

From the base year calibration, we carry forward the model and data forward under a variety of scenario assumptions to 2030, discussed in the next section. Apart from its traditional neoclassical roots, an important feature of this model is product differentiation, where we specify that imports is differentiated by country of origin and exports are differentiated by country of destination (e.g., de Melo and Tarr, 1992). This feature allows the model to capture the pervasive phenomenon of intra industry trade, where a country is both an importer and exporter of similar commodities, and avoids tendencies toward extreme specialization.

2.2 Model Characteristics Relevant to Agriculture

While the overall structure of the model is schematically laid out in Figure 8 and specified analytically in the annex below, it is useful in the present context to summarize how the CGE captures linkages between water and agriculture. In particular, we discuss four important relationships in nontechnical terms to clarify the drivers of subsequent assessment results.

Water availability

Estimates of aggregate water stocks, the sum of underground, impounded, and snowpack water, will obtained from other project activities and independent sources on a n annual basis in the initial year (2003). This figure is disaggregated regionally, and then carried forward a constant in the base case and exogenously variable in climate change scenarios. For the latter, we rely on IPCC/FAO estimates of changing rainfall and snow retention. As indicated in Figure 1 above, we assume that current urban and rural water use constitutes about half of the national base year supply. For a given source of water, availability is assumed to be uniform across all agricultural activities in the same region. For the present we assume there is no inter-regional water transfer.

Water requirement / unit output

As summarized in equations S-1 and S-2 of the technical annex, water is assumed to be a factor of production for each commodity, differentiated by source: large-scale hydro, ground water, rain-fed and other. In this framework, water requirements and costs are calibrated directly from the regional and sectoral production structure of the base year SAM. These accounts detail water value added for each commodity, by source of the water, and thus reflect both unit input/output shares and costs.

As output changes in response to other economic forces over the baseline and in scenarios, water prices can respond to combinations of demand induced by corresponding water requirements and changing water supply conditions. The latter, as indicated above, will be specified exogenously for total water availability, but where water prices are endogenous markets will ration it across alternative uses. Thus output drives water requirements, but water prices will also drive output. For example, while only 14% Moroccan farmland is irrigated, 80% percent of export crops are irrigated. For this reason, the latter sector will be more output responsive to scarcity of transferable water, while the former may be more vulnerable to rainfall changes.

All the baseline water/output relationships depend on existing technologies, and improved conveyance and use efficiency can reduce the vulnerability of yields to water scarcity. For this reason, it would be desirable to assess the potential benefits of investments in agricultural water efficiency, including drip irrigation and low evaporation storage and conveyance.

Rainfed yield effects

Agricultural yields with respect to water inputs, both rainfed and irrigated, are calibrated in the base year with SAM shares of water value added for each crop. From this point, yields are assumed constant in the baseline scenario and then modified using FAO yield estimates in the climate change scenarios. In particular, FAO estimates that two components, a positive CO_2 fertilization and a negative heat/desiccation effect, will interact to reduce average crop yields (for constant inputs) as climate change progresses. These yield effects are captured in the CGE with a total factor productivity parameter that will fitted to FAO trend estimates. As a consequence, maintaining output will require higher total expenditure on agricultural inputs and, given variable scarcity of these, input substitution. For water in particular, it is reasonable to expect increased absolute and relative scarcity to drive agriculture toward less water-intensive technologies and/or crops. For irrigated agriculture, yields may also be affected, but we need examine the FAO estimates in more detail to ascertain the importance of this.

Livestock

In the CGE model, livestock is a commodity produced with inputs including pasturage, feed, and water. Water is a factor whose availability and use have already been described, but both pasturage and feed are commodity inputs. For pasturage, yield effects of climate change can be expected to be negative (see the last paragraph), so this input will be more scarce relative to the baseline scenario. Likewise, feed is crop dependent and can likewise be expected to be more scarce or expensive in the climate change scenarios. Because external supplies of feed may be more elastic than domestic ones, we can expect to see import substitution that will moderate but not completely offset higher costs of livestock production. Demand for domestic feed and grains will be lower, but the net income effect on Moroccan farmers will depend on prices and costs as well as quantities. In its current configuration, the CGE model allows for substitution between pasturage and other land use, @@but not between pasturage and feed. This may be a desirable extension.

3 Scenario Analysis

To better understand the implications of climate-induced water scarcity for Moroccan agriculture, and to assess policy options for effective adaptation, we use the dynamic CGE model to evaluate a baseline case and alternative policy scenarios. While we select only a subset of the policy instruments that will eventually be brought to bear on this problem, these results are indicative of the kinds of options open to the government for promoting food security and sustained agricultural export competitiveness.

3.1 Baseline with No Climate Change or Policy Response

This fictional scenario is used as a dynamic reference trend to evaluate both the costs of doing nothing and the potential benefits of action when climate change does occur. In this case, we simply project the Moroccan economy forward on consensus macro growth trends assuming that patterns of water availability and yields remain at levels of recent years, going forward into the foreseeable future. While climate science indicates this is too optimistic, this scenario is needed for comparative purposes. In addition to the initial data on Moroccan economic structure, as reflected in the SAM and supporting accounts, but baseline relies on a series of assumptions regarding the business as usual time path of the economy over the period 2003-2030. We detail the most important of these in this section.

Population and labor force

The population and labor force assumptions line up with the UN forecast. We have a complete forecast through 2050 at the 5-year cohort level for both male and female. For the moment we are aggregating the two sexes and forming three cohorts: 0-14, 15-64 and 65+. The growth of the middle group, equated to the working age population, constitutes the growth rate of the labor force. In essence we are holding the labor force participation rate constant for this cohort and assume it is zero for the other two cohorts. These assumptions can readily be relaxed if need be. Table 1 provides a breakdown of the population assumptions. Under these assumptions we have continuous decline in the total growth rate from an initial level of 1.6% per annum declining to 0,9% per annum. There is an early acceleration in the growth rate of the labor force, far exceeding the population growth rate, but declining towards the end of the period as the impacts of fertility declines show up in the later period. There is an absolute decline in the under-15 age cohort, alleviating pressures on education and other child-rearing expenditures, but a rapid rise in the over-65 cohort with implications for income support and health expenditures.

Table 2: Population Assumptions

	Population level ('000)				Cohort share (%)			Annualized growth (%)			
	0-14	15-65	65+	Total	0-14	15-65	65+	0-14	15-65	65+	Total
2003	9,913	18,888	1,332	30,134	32.9	62.7	4.4				
2004	9,897	19,333	1,372	30,602	32.3	63.2	4.5	-0.2	2.4	3.0	1.6
2005	9,876	19,783	1,405	31,064	31.8	63.7	4.5	-0.2	2.3	2.4	1.5
2006	9,850	20,238	1,430	31,519	31.3	64.2	4.5	-0.3	2.3	1.8	1.5
2007	9,817	20,698	1,451	31,966	30.7	64.7	4.5	-0.3	2.3	1.4	1.4
2008	9,776	21,161	1,470	32,408	30.2	65.3	4.5	-0.4	2.2	1.3	1.4
2009	9,725	21,627	1,492	32,844	29.6	65.8	4.5	-0.5	2.2	1.5	1.3
2010	9,663	22,094	1,520	33,277	29.0	66.4	4.6	-0.6	2.2	1.9	1.3
2015	9,317	24,319	1,786	35,422	26.3	68.7	5.0	-0.7	1.9	3.3	1.3
2020	9,336	26,020	2,246	37,602	24.8	69.2	6.0	0.0	1.4	4.7	1.2
2025	9,514	27,290	2,910	39,714	24.0	68.7	7.3	0.4	1.0	5.3	1.1
2030	9,672	28,367	3,595	41,634	23.2	68.1	8.6	0.3	0.8	4.3	0.9

GDP, savings and investment

GDP is exogenous in the baseline scenario and an economy-wide productivity factor is backed out by the model solution that is consistent with the imposed GDP growth rate. Even though this is how the baseline works mechanically, the model is actually used in an iterative fashion to find a plausible set of assumptions for the baseline that are internally consistent. Hence, if the calibrated productivity factor is inconsistent with recent trends, or implausible for other reasons, the assumptions underlying the baseline, including potentially GDP growth itself, are modified until a satisfactory baseline is developed. Table 2 presents the current growth assumptions for both aggregate GDP as well as GDP per capita. Through 2007 the baseline is calibrated to the historical series. The values for 2008-2010 represent the current World Bank forecast that underlies the recently published Global Economic Prospects 2009 report. For years beyond 2010 the baseline scenario is predicated on an estimation of the growth potential of the Moroccan economy.[5] This is largely a technical exercise as opposed to representing a particular view of the long-term prospects for the economy. While preserving this as a baseline, it is certainly possible to look at alternatives, notably higher growth, that would be based on some notion of convergence, perhaps driven by closer economic relations with the European Union and/or the United States. In other words, the baseline is intended to be plausible, but it is not intended to be normative nor probabilistic.

Table 3: GDP Assumptions

	Levels		**Annualized growth**	
	Total GDP	**GDP per capita**	**Total GDP**	**GDP p.c.**
	Dirham (billion)	Dirham	%	%
2003	512	16,989		
2004	539	17,599	5.2	3.6
2005	551	17,753	2.4	0.9
2006	595	18,862	7.8	6.2
2007	611	19,100	2.7	1.3
2008	648	20,008	6.2	4.8
2009	672	20,472	3.7	2.3
2010	711	21,378	5.8	4.4
2015	883	24,934	4.4	3.1
2020	1,066	28,347	3.8	2.6
2025	1,261	31,751	3.4	2.3
2030	1,478	35,509	3.2	2.3

[5] Technically, potential GDP is derived from a Hodrick-Prescott filter of long-term per worker output, with more weight on recent history than the distant past.

In per capita terms, GDP growth is expected to moderate somewhat towards the end of the period to around 2.3% per annum. This is a higher growth rate than assumed for the high-income countries, around 1% per annum, so with some convergence, but lower than the rapid growth countries in Asia.

Investment in the model is savings driven. Household savings as a share of income is fixed.[6] Government savings is fixed in real terms, in part to avoid sustainability issues, as are foreign capital inflows. Table 3 shows the main macro indicators for savings and investment as well as the growth rate of the capital stock in the baseline.[7] Under these assumptions combined with an assumed depreciation rate of 4% per annum, capital growth varies from 3.2 to 3.6 percent per annum, more or less the growth of output in the long-run. Note that in the baseline scenario, raising the depreciation rate would lower net capital accumulation, ceteris paribus, and also raise the calibrated productivity parameter as the lower capital contribution to growth is compensated by higher productivity contribution.

Table 4: Savings/Investment Assumptions

	Savings as percent of GDP			Investment as percent of GDP	Capital stock growth
	Household	*Public*	*Foreign*		
2003	21.9	1.7	2.6	24.2	
2004	21.9	1.6	2.5	24.1	3.5
2005	21.8	1.5	2.4	24.0	3.6
2006	21.9	1.4	2.2	24.0	3.4
2007	21.8	1.4	2.2	23.8	3.7
2008	21.9	1.3	2.1	23.8	3.6
2009	21.8	1.3	2.0	23.7	3.7
2010	21.9	1.2	1.9	23.6	3.7
2015	21.7	1.0	1.5	23.2	3.8
2020	21.5	0.8	1.3	22.8	3.7
2025	21.2	0.7	1.1	22.3	3.5
2030	20.8	0.6	0.9	21.8	3.2

Source: Model simulations.

Water

Because of the critical role played by water in both agro-food supply and in the climate change context, this analysis takes great care in modeling both economywide water allocation and water use practices by farm enterprises. For convenience, we assume water is a regional resource, limited in supply within each AEZ annually but with limited

[6] In the World Bank's global dynamic model, household savings behavior is influenced by demographic variables among other things and could be added.

[7] The discrepancy between the sum of the savings share and the investment share is linked to stock-building activities that are fixed in base year levels and thus fade as a share of GDP.

intertemporal transferability between AEZs. Within each region and year, we assume that urban water requirements represent the first stage of regional water allocation. After these needs are met, water in each region's public storage and conveyance is allocated to meet derived irrigation demands of priority crops, including:

@@[We need to specify this, but AEZ]

Finally, water that remains available is assumed to be marketable in each region and allocated to meet derived irrigation demand for other agricultural production. All stages of public water allocation take place at administered prices, and individual farmers use this water until it is exhausted or unless the cost of groundwater (G) extraction is lower. If irrigation water supplies do not meet the needs of farmers, they exploit groundwater as long as its marginal cost exceeds the marginal revenue product of this factor of production.

Land

Land is assumed to be fixed in aggregate supply, within regions and between both rural and urban areas. Land use can shift within these areas between economic uses, including formal sectors and agricultural products. We assume for the present, however, that land tenure patters (i.e. the size distribution of farms) remains constant from the point of view of water use technologies within each crop category. Changes in land quality are also not modeled in the present version.

Productivity

In broad terms all sectoral activities are divided into three groups--agriculture, manufacturing and services.[8] The following assumptions are made:

Productivity growth in agriculture is exogenous and is uniform across all inputs.[9] In the current baseline, the rate of productivity growth is 2.5 percent per annum.[10]

In the other sectors, productivity is labor-augmenting only. In the absence of sector-specific productivity growth estimates, the baseline is used to calibrate an economy-wide productivity factor that achieves a target level of GDP growth (for each period).[11] In

[8] Note that in our global model of climate change we have additional sources of productivity growth--energy efficiency improves at an exogenous rate and the cost of international transportation services also decline at some given rate.

[9] In terms of the model specification, both λ^n and λ^v grow at the same exogenous rate.

[10] This is probably on the high side as agricultural productivity growth has dropped over the last decade. In the last GEP, we lowered it to 2.1 percent.

[11] This is the variable g^l in the model specification.

these sectors, we assume there is a sector-specific wedge that allows for labor productivity to grow more rapidly in some sectors than in others. In essence, the non-agricultural sectors are partitioned into two sets--manufacturing and services, with the assumption that labor productivity in the manufacturing sectors grows 1 percent more rapidly per annum than in services. Table 4 shows the partitioning of the non-agricultural sectors.

Under the assumptions described herein, the resulting services labor productivity growth, as calibrated by the model is provided in Table 5. There are a few things to note in this table. First, there is a fair amount of volatility in the initial years. This is because the model is tracking aggregate GDP growth to the observed growth, but not necessarily taking into account other macro events such as changes in employment levels, government expenditures or trade. The model is not designed to mimic more standard macro models. Its strength lies in the long-term structural trends. Second, over the long-term, services labor productivity growth is slated to slow to 0.9 percent per annum consistent with the assumption of long-term GDP growth of 2.3 percent per capita. Third, it should be re-stated that labor productivity is some 1 percent greater in manufacturing than in services, so the economy-wide average will be somewhere between 0.9-1.9 percent in the long-term.

Table 5: Partition of non-agricultural sectors

Manufacturing (higher productivity)		**Services**	
forst-a	Forestry	wtrel-a	Water and electricity utilities
fshry-a	Fishery	srvpr-a	Private services
dairy-a	Dairy	srvpb-a	Public services
sgrrw-a	Raw sugar		
sgrrf-a	Refined sugar		
milhw-a	Hard wheat mill		
milsw-a	Soft wheat mill		
oilrw-a	Raw oil		
oilrf-a	Refined oil		
olvwh-a	Whole olives		
olvol-a	Olive oil		
xfdpr-a	Other food processing		
chmcl-a	Chemical industries		
refol-a	Refined petroleum		
xinds-a	Other industries		

Table 6: Labor productivity in services*

(average compounded percent growth per annum)

2004	4.7
2005	-3.2
2006	12.7
2007	-2.6
2008	7.7
2009	0.2
2010	6.5
2015	2.4
2020	1.4
2025	0.9
2030	0.9

Note: * Labor productivity growth in manufacturing sectors is 1 percentage point higher than in services.

Source: Model simulations.

Trade and International Commodity Prices

Morocco is highly dependent on imported energy and increasingly dependent on foreign food. It would be desirable to lay out some reference trends for prices of in these two categories, as well as to establish baseline a trade regime that realistically captures Morocco's external commitments, particularly with respect to the EU and US. Some salient considerations in this context include the following:

- Although relying heavily on imports for grain and feeds, Morocco is a net exporter of seafood, fruit (citrus) and vegetables (tomatoes and potatoes) largely to the European Union (EU).
- On March 1, 2001, Morocco implemented a Free Trade Agreement with the EU that does present certain advantages to EU exporters in the Moroccan market.
- High tariffs for many products were a significant barrier to U.S. exports until implementation of the U.S.-Morocco Free Trade Agreement (FTA) began on Jan. 1, 2006. Under the agreement, most agricultural tariffs between Morocco and the United States are eliminated immediately or over 2 years, 6 years, or 9 years. This is expected to precipitate larger trade flows as result of tariff reductions and offers opportunities for new product trade (trade creation) as well as increased market share for each country in the partner market (trade diversion). In the latter case, penetration by subsidized US cereals could be very significant, particularly in response to Moroccan water scarcity and declining yields.

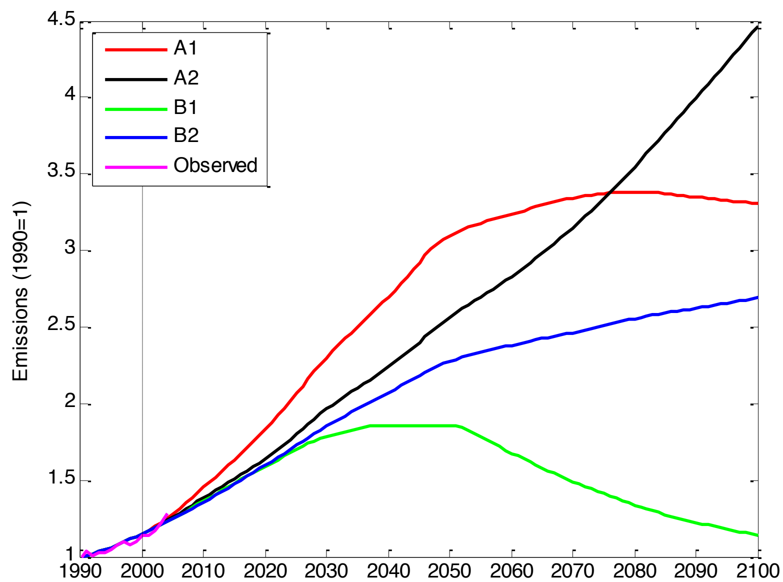
Concluding remarks

This brief note is intended to clarify the growth dynamics of the CGE model and its decomposition by channel--between growth in factors and growth in productivity. There is significant flexibility designed into the baseline that allows for a wide variety of scenarios. One of the strengths of these classes of models is the ability to use the model to test the plausibility and impacts of varying some of the key assumptions. One could also test the sensitivity of the alternate scenarios, for example the impact of climate change, with respect to the baseline assumptions. For example, what are the macro impacts of climate change under a high agricultural productivity scenario in the baseline, versus one with lower agricultural productivity.

3.2 Baseline with Climate Change and No Policy Response

In this case, we take the previous policy neutral baseline and project a future of changing water availability and agricultural yields, as these would result from independent projections of climate trends and yield effects. The climate base cases we consider correspond to the IPCC/NCAR climate stabilization climate A2 and B2 in Figure 3.1. There is still considerable uncertainty regarding the more detailed implications of scenario B2, however, and for this reason our baseline and policy projections will be assessed in quintile sub-scenarios ranging from less more extreme conditions. In particular, the baseline will be divided into five cases representing packages of temperature, rainfall, and external trade conditions, all of which are considered to be exogenous from the viewpoint of Moroccan policy makers.

Figure 10: IPCC/NCAR Global GHG Emission Trends



Notes: IPCC refers to the Intergovernmental Panel on Climate Change, a UN institution awarded the 2006 Nobel Peace Prize for its climate research. NCAR is the National Center for Atmospheric Research, a leading U.S. climate research institution.

3.3 Scenarios for Adaptation

The Baseline assumes Business as Usual, or no specific government intervention in response to climate change. To assess options open to the Government of Morocco, we compare this to a series of counterfactual cases that include responses along the lines already suggested. In particular, we examine four families of policy options:

1. Supply side interventions, including investment in storage, conveyance and related water technology
2. Demand side interventions, including
    1. Urban adoption subsidies – exogenous urban efficiency trends
    2. Standards – minimum irrigation technology adoption for access to metered water
    3. Water pricing/taxes
    4. Quotas
    5. R&D investments/grants/subsidies – need independent information on MC and yield effects of varietal substitution
3. Trade Policies
    1. Import policies to offset food scarcity
    2. Import policies to substitute for domestic water requirements
    3. Export policies to increase water use efficiency, nationally, regionally, and crop by crop
    4. Incentives for inbound technology transfer including domestic adoption and FDI

Table 7: Proposed Scenarios

BAU 1	No climate change, no new policies
BAU 2	Climate change with no policy response
A1	Water quotas
A2	Investments in storage/conveyance
A3	Farm efficiency measures
A4	Import promotion

Table 8: Variables of Interest

1	GDP
2	Agricultural GDP
3	Agricultural Terms of Trade
4	Real Consumption
5	Exports
6	Imports
7	Terms of Trade
8	Agro-food Share of Imports
9	Agro-food Share of Exports
10	Decile Real HH Incomes
11	Cereal Share of Imports
12	Livestock and Meat Share of Imports
13	Gini
14	Water value added
15	
16	
17	
18	
19	
20	

4 References

Allan, J.A., 2003. Virtual water — the water, food, and trade nexus: Useful concept or misleading metaphor? Water International, 28 (1), 106–113.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration — Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper, vol. 56. FAO, Rome.

Douidich, Mohammed; Ezzrari, Abdeljouad; Lanjouw, Peter, 2008. Simulating the impact of geographic targeting on poverty alleviation in Morocco : what are the gains from disaggregation? Research Working Paper 4724, World Bank, Washington.

Env.Ind. – Environmental Indicators, 1992. In depth analyses of individual indicators: intensity of use of water resources. Paris, OECD.

FAO Regional Office for the Near East. 2008. A Review of Drought Occurrence and Monitoring and Planning Activities in the Near East Region.

FAO Regional Office for the Near East. 2008. The Near East Drought Planning Manual: Guidelines for Drought Mitigation and Preparedness Planning. FAO.

FAO, 2008. Climate Change: Implications for Food Safety, Rome.

FAO, 2008. Morocco: Impact of Climate Change on Agriculture, Rome.

FAO. 2005. Rising Atmospheric CO2 and Global Climate Change: Responses and Management Implication for Grazing Lands. In Grasslands: Developments Opportunities Perspectives, Rome, FAO and Science Publishers.

FAO. 2008. Climate change adaptation and mitigation: challenges and opportunities in the food sector. High Level Conference on World Food Security - Information Paper HLC/08/INF/2. report.

FAO. 2008. Improved Adaptive Capacity to Climate Change for sustainable livelihood in the agricultural sector. Summary report project phase I. Community Based adaptation in Action. Rome, FAO.

Gleick, 1993 - Water in Crisis. A Guide to the World's Fresh Water Resources, 1993. Edited by P. Gleick. N.Y. Oxford Univ.Press.

Gleick, 1998 - The World’s Water. The Beneficial Report on Freshwater Resources 1998-1999, 1998, Peter Gleick, Washington, D.C. Covello, California.

Hoekstra, Arjen Y., Ashok K. Chapagain, 2007. The water footprints of Morocco and the Netherlands: Global water use as a result of domestic consumption of agricultural commodities, Ecological Economics, 6 4, 1 4 3 – 1 5 1.

IIASA – Kulshreshtha S.N., 1993. World Water Resources & Regional Vulnerability: impact of future changes. Luxenburg: IIASA.

IrAf – Irrigation in Africa in figures, 1995. Extract from report 7. Rome: FAO.

IrrNE – Irrigation in the Near East Region in Figures. 1997. Water Report 9. Rome: FAO.

Kurukulasuriya, Pradeep; Mendelsohn, Robert, 2007. Endogenous irrigation : the impact of climate change on farmers in Africa, Policy Research Working Paper 4278, World Bank, Washington.

Lotsch, Alexander, 2007. Sensitivity of Cropping Patterns in Africa to Transient Climate Change, Policy Research Working Paper 4289, World Bank, Washington.

Margat, 1990 – Prospects for Water Resourcesand Needs in the Mediterranean Countries, 1990. Contributions of the "Plan Blue". J. Margat. Paris: EC.

Margat, 1994 - Water use in the World Present and Future., 1994. J.Margat. Paris: UNESCO.

Margat. 1995 - Prospective des Penuries d'Eau au Maghreb. J. Margat., Colloque intern. Rabat.

Ravallion, Martin; Lokshin, Michael, 2004. Gainers and losers from trade reform in Morocco, Policy Research Working Paper 3368, World Bank, Washington.

Seo, Sungno Niggol; Mendelsohn, Robert, 2007. A Ricardian analysis of the impact of climate change on Latin American farms, Policy Research Working Paper 4163, World Bank, Washington.

Seo, Sungno Niggol; Mendelsohn, Robert, 2007. An analysis of crop choice : adapting to climate change in Latin American farms, Policy Research Working Paper 4162, World Bank, Washington.

Seo, Sungno Niggol; Mendelsohn, Robert, 2007. An analysis of livestock choice : adapting to climate change in Latin American farms, Policy Research Working Paper 4164, World Bank, Washington.

Seo, Sungno Niggol; Mendelsohn, Robert, 2007. Changing farm types and irrigation as an adaptation to climate change in Latin American agriculture, Policy Research Working Paper 4161, World Bank, Washington.

Seo, Sungno Niggol; Mendelsohn, Robert, 2007. The impact of climate change on livestock management in Africa : a structural Ricardian analysis, Policy Research Working Paper 4279, World Bank, Washington.

Skees, Jerry; Gober, Stephanie; Varangis, Panos; Lester, Rodney; Kalavakonda, Vijay, 2001. Developing rainfall-based index insurance in Morocco, Policy Research Working Paper 2577, World Bank, Washington.

Strzepek, Kenneth, and Alyssa McCluskey, 2007. The Impacts of Climate Change on Regional Water Resources and Agriculture in Africa, Policy Research Working Paper 4290, World Bank, Washington.

SWAC/OECD, FAO. 2008. Strategic note on "Climate, climate change and agropastoral practices in the Sahel region". FAO.

UNSY – United National Statistical Yearbook 1992, 39, 1993– N.Y..:UN.

WRI – World Resources *(1991-1992, 1992-1993, 1994, 1996, 1997-1998*) – N.Y.: Oxford Univ. Press.

WWDS – World Water Resources. Demand & Supply: 1990 to 2025., 1998. Scenarious & Issues. Colombo:IWMI.

5 Annex – Technical Description of the Morocco CGE Model

This annex provides a full technical specification of a regional and dynamic computable general equilibrium model developed for the Moroccan economy. The main purpose of the model is to analyze the interactions between potential climate change damages, water availability and regional, sectoral and national economic activity—clearly with a significant focus on agricultural impacts. For the purposes of this study the Moroccan economy has been divided into six agro-ecological zones. Within each zone four types of agricultural technologies are identified. Three of the technologies relate to crop production with access to three water sources—large scale hydro, other irrigation (pumping ground water) and rain-fed. The fourth relates exclusively to the livestock sector. Non-agricultural sectors exist only at the national level. The model has a 2003 base year and a baseline scenario, also known as a business-as-usual scenario, is elaborated through the year 2030. Alternative scenarios that focus on water availability and water policies are subsequently developed and compared to the baseline.

5.1 Model Dimensions

The national SAM is indexed by the set *is*. It is composed of activities (subset *a*), commodities (subset *c*), other domestic demand (subset *af*), production factors (subset *fp*), and additional accounts as described below. The following tables describe the different subsets of the SAM. Table 1 is the full list of activities. The agricultural activities are produced in each of the six agro-ecological zone and are further sub-divided by water access—described further below.

Table 1: List of activities (*a*)

hdwht-a	Hard wheat	xfrut-a	Other fruit
sfwht-a	Soft wheat	xcrop-a	Other crops nes
barly-a	Barley	bovin-a	Cattle etc
xgrns-a	Other grains	ovine-a	Sheep
gnleg-a	Other dry beans	avine-a	Poultry
sgrbt-a	Sugar beets	xmeat-a	Other animal products
sgrcn-a	Sugar cane	forst-a	Forestry*
xcshc-a	Other industrial crops	fshry-a	Fishery*
tomat-a	Tomatoes	dairy-a	Dairy*
potat-a	Potatoes	sgrrw-a	Raw sugar*
onion-a	Onions	sgrrf-a	Refined sugar*
melon-a	Melons	milhw-a	Hard wheat mill*
wtmln-a	Watermelons	milsw-a	Soft wheat mill*
xvegt-a	Other vegetables	oilrw-a	Raw oil*
xvgin-a	Other industrial vegetables	oilrf-a	Refined oil*
alfaf-a	Alfalfa	olvwh-a	Whole olives*
forag-a	Other fodder	olvol-a	Olive oil*

olive-a	Olives	xfdpr-a	Other food processing*
agrms-a	Mandarins and small citrus	chmcl-a	Chemical industries*
xagrm-a	Other citrus	refol-a	Refined petroleum*
grape-a	Grapes	wtrel-a	Water and electricity utilities*
almnd-a	Almonds	xinds-a	Other industries*
apple-a	Apples	srvpr-a	Private services*
dates-a	Dates	srvpb-a	Public services*

Note: * Activities at the national level.

Table 2 defines the list of commodities. There is in general a one-to-one mapping between activities and commodities—but not in all cases. The SAM (and each regional IO matrix) contains a make matrix that maps activities into commodities. The make matrix allows for activities to produce one or more commodities and it allows for commodities to be composed of output from multiple activities. To whit, there are 48 activities identified and 51 commodities.

Table 2: List of commodities (*c*)

hdwht-c	Hard wheat	byprd-c	Agricultural byproducts
sfwht-c	Soft wheat	byfdp-c	Processed food byproducts
barly-c	Barley	meatr-c	Red meat products
xgrns-c	Other grains	meatw-c	White meat products
gnleg-c	Other dry beans	mlkrw-c	Raw milk
sgrbt-c	Sugar beets	eggrw-c	Raw eggs
sgrcn-c	Sugar cane	xmeat-c	Other animal products
xcshc-c	Other industrial crops	forst-c	Forestry
tomat-c	Tomatoes	fshry-c	Fishery
potat-c	Potatoes	dairy-c	Dairy
onion-c	Onions	sgrrw-c	Raw sugar
melon-c	Melons	sgrrf-c	Refined sugar
wtmln-c	Watermelons	milhw-c	Hard wheat mill
xvegt-c	Other vegetables	milsw-c	Soft wheat mill
xvgin-c	Other industrial vegetables	oilrw-c	Raw oil
alfaf-c	Alfalfa	oilrf-c	Refined oil
forag-c	Other fodder	olvwh-c	Whole olives
olive-c	Olives	olvol-c	Olive oil
agrms-c	Mandarins and small citrus	xfdpr-c	Other food processing
xagrm-c	Other citrus	chmcl-c	Chemical industries
grape-c	Grapes	refol-c	Refined petroleum
almnd-c	Almonds	wtrel-c	Water and electricity utilities
apple-c	Apples	xinds-c	Other industries
dates-c	Dates	srvpr-c	Private services
xfrut-c	Other fruit	srvpb-c	Public services
xcrop-c	Other crops nes		

The model identifies six factors of production indexed by *fp*, table 3. There is a single labor type and a single capital type. Land is split into three—crop land, fallow land and pasture land. There is only one water type—however the source of water is associated with different activities. In other words each (agricultural) activity is associated with a different source of water, indexed by *w*, and potentially a different technology. The water sources are described further below. There are a number of factor subsets as detailed in table 3.

Table 3: Production factors and subsets (*fp*)

		National (*nfp*)	Labor (*l*)	Capital (*k*)	Land (*lnd*)	Water (*wat*)
labor	Labor	x	x			
captl	Capital	x		x		
lndcr	Crop land				x	
lndfl	Fallow land				x	
lndps	Pasture land				x	
water	Water					x

Table 4 describes the agents and/or institutions identified in the SAM. Mostly these represent the traditional final demand accounts, households, government, investment, stock building and the rest of the world. Note that these agents are a subset of a larger set of Armington agents, indexed by *aa*, that includes all activities. Agents are further subdivided into Armington agents (that excludes the rest of the world), households and other final demand agents.

Table 4: Institutions/agents (*in*)

		Non-production Armington agents (*af*)	Households (*hh*)	Other final demand (*fd*)
rhdc1	Rural households first decile	x	x	
rhdc2	Rural households second decile	x	x	
rhdc3	Rural households third decile	x	x	
rhdc4	Rural households fourth decile	x	x	
rhdc5	Rural households fifth decile	x	x	
uhdc1	Urban households first decile	x	x	
uhdc2	Urban households second decile	x	x	
uhdc3	Urban households third decile	x	x	
uhdc4	Urban households fourth decile	x	x	
uhdc5	Urban households fifth decile	x	x	
govnt	Government	x		x
invst	Investment	x		x
delst	Stock building	x		x
rowld	Rest of the world			

The SAM includes three additional accounts for closure—all related to various taxes—as detailed in table 5.

Table 5: Other SAM accounts

prdtx	Production tax
indtx	Indirect tax
imptx	Import tax

As mentioned above, agricultural activities are identified spatially—in a given agro-ecological zone—and by water access. Table 6 describes the spatial dimensions of the model. There is a subset (*zr*) of z that excludes the national zone.

Table 6: Agro-ecological zones (*z*)

aezfvrbl	Most favorable agricultural zone
aezintrm	Intermediate agricultural zone
aezsthpr	Poor Southern agricultural zone
aezestpr	Poor Eastern agricultural zone
aezatlas	Mountainous agricultural zone
aezsahrn	Saharan agricultural zone
aeztotal	National total*

Note: * The national zone encompasses all non-agricultural activities and is not a user of water.

Table 7 identifies the four sources of water—large scale hydro, other irrigation (that is a mixture of smaller scale hydro such as ponds, catchment basins and river intake and ground water) and rain-fed. The fourth category is simply not-applicable and is used for the national activities.

Table 7: Water sources (*w*)

hydir	Large scale hydro
othir	Other irrigation
rnfed	Rain fed
ntapp	Not applicable

A final set used in the model is the distinction between rural and urban factor markets—used exclusively for the allocation of labor and capital supply, i.e. the so-called national factors. The set is indexed by *ru*. Table 8 provides the details and the mapping between the zones and the rural and urban aggregations.

Table 8: Rural and urban aggregate regions (*ru*)

	Rural	Urban
aezfvrbl	x	
aezintrm	x	
aezsthpr	x	
aezestpr	x	

aezatlas	x	
aezsahrn	x	
aeztotal		x

5.2 Model Specification

Production specification

Production, as in many CGE models, is specified as a series of nested CES functions the objective of which is to emulate the substitution and complementarity relations across inputs—both factors and goods and services. The specification used in the model is currently relatively simple but is likely to be modified—particularly as regards the demand for water.

In essence, the current structure has two nests. All non-factor inputs are assumed in constant proportion to output (though substitution is allowed in principle). And all factor inputs are substitutes with each other in a single nest. The first node aggregates a bundle of all intermediate goods, *ND*, and the value added bundle, *VA*, to form output. A CES technology is used, but typically, the top level substitution elasticity, s^p, is 0, implying a fixed proportion, or Leontief technology. Equations (P-1) and (P-2) provide the demand functions for the aggregate bundles. Their respective prices are *PND* and *PVA*. The unit cost of production is given by *PX*. Technology improvement is allowed at this level of aggregation, with each bundle have a separate efficiency parameter given respectively by l^n and l^v. The a parameters are the CES share parameters and calibrated to the base year data. The unit cost can be derived from the CES dual price function, equation (P-3). Finally, the output price, *PP*, is equal to the unit cost adjusted for an output tax/subsidy, t^p, equation (P-4).

(P-1) $$ND_{a,w,z} = \alpha^{nd}_{a,w,z} \frac{XP_{a,w,z}}{\lambda^n_{a,w,z}} \left(\frac{\lambda^n_{a,w,z} PX_{a,w,z}}{PND_{a,w,z}} \right)^{\sigma^p_{a,w,z}}$$

(P-2) $$VA_{a,w,z} = \alpha^{va}_{a,w,z} \frac{XP_{a,w,z}}{\lambda^v_{a,w,z}} \left(\frac{\lambda^v_{a,w,z} PX_{a,w,z}}{PVA_{a,w,z}} \right)^{\sigma^p_{a,w,z}}$$

(P-3) $$PX_{a,w,z} = \left[\alpha^{nd}_{a,w,z} \left(\frac{PND_{a,w,z}}{\lambda^n_{a,w,z}} \right)^{1-\sigma^p_{a,w,z}} + \alpha^{va}_{a,w,z} \left(\frac{PVA_{a,w,z}}{\lambda^v_{a,w,z}} \right)^{1-\sigma^p_{a,w,z}} \right]^{1/(1-\sigma^p_{a,w,z})}$$

(P-4) $$PP_{a,w,z} = \left(1 + \tau^p_{a,w,z}\right) PX_{a,w,z}$$

The second level CES nest has two nodes that determine on the one hand the demand for non-factor goods and services, i.e. intermediate demand and on the other hand the demand for factors of production. Equation (P-5) describes the demand for intermediate goods, *XAP*. The price of Armington goods is homogenous across all end-users and is given by the variable PA^t. End-users have a specific sales tax, t^{Ap}. The substitution elasticity of this CES node is s^n, typically assumed to be 0, and a^{io} are the CES share parameters. Equation (P-6) then provides the price of the *ND* bundle, *PND*, using the standard CES dual price expression.

(P-5) $$XAP_{c,a,w,z} = \alpha^{io}_{c,a,w,z} ND_{a,w,z} \left(\frac{PND_{a,w,z}}{(1+\tau^{Ap}_{c,a,w,z}) PA^t_c} \right)^{\sigma^n_{a,w,z}}$$

(P-6) $$PND_{a,w,z} = \left[\sum_c \alpha^{io}_{c,a,w,z} \left[(1+\tau^{Ap}_{c,a,w,z}) PA^t_c \right]^{1-\sigma^n_{a,w,z}} \right]^{1/(1-\sigma^n_{a,w,z})}$$

The opposite node determines the demand for factors of production, *XF*, with a price *PF*, as described in Equation (P-7). The CES substitution elasticity is s^v with share parameters a^{fp}. The model allows for factor- and activity-specific factor productivity improvement provided by variable l^{fp}. The price of the value added bundle, *PVA*, is provided in equation (P-8).

(P-7) $$XF_{fp,a,w,z} = \alpha^{fp}_{fp,a,w,z} \frac{VA_{a,w,z}}{\lambda^f_{fp,a,w,z}} \left(\frac{\lambda^f_{fp,a,w,z} PVA_{a,w,z}}{PF_{fp,a,w,z}} \right)^{\sigma^v_{a,w,z}}$$

(P-8) $$PVA_{a,w,z} = \left[\sum_{fp} \alpha^{fp}_{fp,a,w,z} \left[\frac{PF_{fp,a,w,z}}{\lambda^f_{fp,a,w,z}} \right]^{1-\sigma^v_{a,w,z}} \right]^{1/(1-\sigma^v_{a,w,z})}$$

Each activity *a* is allowed to produce one or more commodity *c*, i.e. the model allows for a multi-output production structure. For example, the sugar sector could produce a mixture of sugar for food and ethanol. The multi-output structure is specified using a CET transformation function where the producer maximizes revenues subject to being on a CET transformation frontier. Equation (P-9) determines the output of *X* which represents the quantity of commodity *c* produced by activity *a*, the price of which is *P*. The transformation elasticity is given by w^s with share parameters g^p. The model allows for perfect transformation in which case the law of one price holds. The aggregate price of output of activity *a* is simply the CET aggregation of the component commodity prices, equation (P-10). The latter is replaced by a simple aggregation expression in terms of the volumes if there is perfect transformation.

$$\text{(P-9)} \qquad \begin{cases} X_{a,c,w,z} = \gamma^{p}_{a,c,w,z} XP_{a,w,z,t} \left(\dfrac{P_{a,c,w,z}}{PP_{a,w,z}} \right)^{\omega^{s}_{a,w,z}} & \text{if} \quad \omega^{s}_{a,w,z} \neq \infty \\ P_{a,c,w,z} = PP_{a,w,z} & \text{if} \quad \omega^{s}_{a,w,z} = \infty \end{cases}$$

$$\text{(P-10)} \qquad \begin{cases} PP_{a,w,z} = \left[\sum_{c} \gamma^{p}_{a,c,w,z} \left(P_{a,c,w,z} \right)^{1+\omega^{s}_{a,w,z}} \right]^{1/(1+\omega^{s}_{a,w,z})} & \text{if} \quad \omega^{s}_{a,w,z} \neq \infty \\ XP_{a,w,z} = \sum_{c} X_{a,c,w,z} & \text{if} \quad \omega^{s}_{a,w,z} = \infty \end{cases}$$

Finally, a single commodity can also be produced by outputs from various activities. This is one way to deal with trade and transport margins where a single commodity produced from activity *a* is combined with trade and transport services to 'produce' a commodity *c*. A different example, representative of a homogeneous commodity, is electricity that might be produced using different technologies, for example hydro and thermal. The law-of-one price might hold in this case and the output from the two streams is simply aggregated. Equation (P-11) represents the supply of commodity *c* from activity *a*, *X*. A CES specification is used to aggregate output from multiple activities, with potentially an infinite substitution elasticity. In this case the law-of-one price must hold. *XS* represents the aggregated commodity from the multiple activity streams, with a price *PS*. Equation (P-12) represents the aggregation. In the case of a finite elasticity the primal aggregation function is replaced by the dual price aggregation expression. With an infinite elasticity, the streams are simply added together.

$$\text{(P-11)} \qquad \begin{cases} X_{a,c,w,z} = \alpha^{c}_{a,c,w,z} XS_{c,w,z} \left(\dfrac{PS_{c,w,z}}{P_{a,c,w,z}} \right)^{\sigma^{c}_{c,w,z}} & \text{if} \quad \sigma^{c}_{c,w,z} \neq \infty \\ P_{a,c,w,z} = PS_{c,w,z} & \text{if} \quad \sigma^{c}_{c,w,z} = \infty \end{cases}$$

$$\text{(P-12)} \qquad \begin{cases} PS_{c,w,z} = \left[\sum_{a} \alpha^{c}_{a,c,w,z} \left(P_{a,c,w,z} \right)^{1-\sigma^{c}_{c,w,z}} \right]^{1/(1-\sigma^{c}_{c,w,z})} & \text{if} \quad \sigma^{c}_{c,w,z} \neq \infty \\ XS_{c,w,z} = \sum_{a} X_{a,c,w,z} & \text{if} \quad \sigma^{c}_{c,w,z} = \infty \end{cases}$$

National commodity supply

National commodity supply is the aggregation of regionally-produced commodities. A two nested CES specification is implemented to 'produce' national commodities—with the option to assume commodity homogeneity. The first nest aggregates commodities at the regional level, i.e. commodities produced using different technologies as identified by the source of water—large-scale hydro, ground water, rain-fed and other. Equation (S-1) depicts the first order condition for demand for commodity *c* in region *z* using water technology *w*, *XSW*, with a price *PSW*. The aggregate supply at the regional level is given by *XSR*, with an aggregate price *PSR*. Equation (S-2) then provides the aggregate price, or in the case of a homogeneous commodity, total regional supply is simply the sum of supplies across the water technologies.

$$\text{(S-1)} \quad \begin{cases} XSW_{c,w,z} = \alpha^{cr}_{c,w,z} XSR_{c,z} \left(\dfrac{PSR_{c,z}}{PS_{c,w,z}} \right)^{\sigma^{cr}_{c,z}} & \text{if} \quad \sigma^{cr}_{c,z} \neq \infty \\ PSW_{c,w,z} = PSR_{c,z} & \text{if} \quad \sigma^{cr}_{c,z} = \infty \end{cases}$$

$$\text{(S-2)} \quad \begin{cases} PSR_{c,z} = \left[\sum_{w} \alpha^{cr}_{c,w,z} \left(PSW_{c,w,z} \right)^{1-\sigma^{cr}_{c,z}} \right]^{1/(1-\sigma^{cr}_{c,z})} & \text{if} \quad \sigma^{cr}_{c,z} \neq \infty \\ XSR_{c,z} = \sum_{w} XSW_{c,w,z} & \text{if} \quad \sigma^{cr}_{c,z} = \infty \end{cases}$$

The second CES nest is the aggregation of regional commodity supplies, *XSR*, into total national supply XS^t. Equation (S-3) determines the demand for regional commodities, *XSR*, and equation (S-4) describes the aggregation of regional commodities into national commodity supply, XS^t, where the dual CES price expression replaces the primal CES aggregation function in the case of a finite elasticity.

$$\text{(S-3)} \quad \begin{cases} XSR_{c,z} = \alpha^{ct}_{c,z} XS^t_c \left(\dfrac{PS^t_c}{PSR_{c,z}} \right)^{\sigma^{ct}_c} & \text{if} \quad \sigma^{ct}_c \neq \infty \\ PSR_{c,z} = PS^t_c & \text{if} \quad \sigma^{ct}_c = \infty \end{cases}$$

$$\text{(S-4)} \quad \begin{cases} PS^t_c = \left[\sum_{z} \alpha^{ct}_{c,z} \left(PSR_{c,z} \right)^{1-\sigma^{ct}_c} \right]^{1/(1-\sigma^{ct}_c)} & \text{if} \quad \sigma^{ct}_c \neq \infty \\ XS^t_c = \sum_{z} XSR_{c,z} & \text{if} \quad \sigma^{ct}_c = \infty \end{cases}$$

Income distribution

National income is derived from a number of sources—factor returns (labor, capital, land and water), transfers from abroad and internal transfers. Equation (Y-1) describes national income derived from factor returns, *YFact*. It is the sum across all activities (*a*), zones (*z*) and technologies (*w*). Households (in the current version of the model) are only identified at the national level. Total household income, *YH*, is derived from four sources (equation Y-2): 1) a share of factor income, where the matrix of shares is given by f^f; 2) transfers from the government, some share of total government transfers to households *GTRH*; 3) intra-household transfers, *HTRH*; and 4) transfers from the rest of the world, *ROWTRH*. The latter is fixed in foreign currency terms. Disposable income, *YD*, is equal to total income less direct taxes. The rate of direct taxation in the base year, k^h, is calibrated using data from the SAM. A national adjustment factor, c^t, is used in specific closures of the model to achieve certain targets. For example, in the standard fiscal closure of the model, government expenditures, either in volume terms or as a share of GDP, are fixed and the government balance (savings) is also fixed. The direct tax adjustment factor is then endogenous and scales (uniformly) the schedule of direct taxes across households.[12] Total intra-household transfers, *HTRH*, are fixed as a proportion of disposable income (equation Y-4), with their distribution to individual households given by the share matrix f^h (see equation Y-2). Household saving, S^h, is also fixed as a share of disposable income (equation Y-5).[13] Total expenditure on goods and services, *YC*, is simply the residual of subtracting transfers and savings from disposable income (equation Y-6).

(Y-1) $$YFact_{fp} = \sum_a \sum_w \sum_z PF_{fp,a,w,z} XF_{fp,a,w,z}$$

(Y-2) $$YH_h = \sum_{fp} \phi^f_{h,fp} YFact_{fp} + CPI.\phi^g_h GTRH + \sum_{h'} \phi^h_{h,h'} HTRH_{h'} + ER.ROWTRH_h$$

(Y-3) $$YD_h = (1 - \chi^t \kappa^h_h) YH_h$$

(Y-4) $$HTRH_h = \chi^{trh}_h YD_h$$

(Y-5) $$S^h_h = \alpha^{sav}_h YD_h$$

(Y-6) $$YC_h = YD_h - HTRH_h - S^h_h - ER.HTRROW_h$$

12 This assumption has direct distributional implications. An alternative would be to allow for either an additive adjustment factor, or an adjustment that is progressive in nature.

13 Alternative closure rules are also possible, with the savings rate endogenous to achieve a specific target, for example a given investment level. A national adjustment factor would have to be introduced to link the one savings instrument with its target.

Equation (Y-7) describes total government revenue, *GREV*, largely composed of revenues generated by commodity and income taxes, but also including factor revenues and transfers from abroad. Equation (Y-8) defines real government savings that in the standard closure is fixed. Government expenditures on goods and services, YC_{Gov}, equals government revenues less transfers to households and the rest of the world and government savings. The transfers are fixed. Equation (Y-10) is the investment/savings identity. Aggregate investment in nominal terms, YC_{Inv}, is equal to available savings—households, government and foreign—less expenditures on stock building activities.

(Y-7)
$$\begin{aligned} GREV = & \underbrace{\sum_{fp}(1-\sum_{h}\phi^{f}_{h,fp})\, YFact_{fp}}_{\text{Income from value added}} + \underbrace{ER.ROWTRG}_{\text{Transfers from rest of the world}} \\ & + \underbrace{\sum_{a}\sum_{w}\sum_{z}\tau^{p}_{a,w,z}PX_{a,w,z}XP_{a,w,z}}_{\text{Production taxes}} + \underbrace{ER.\sum_{c}\tau^{m}_{c}WPM_{c}XM^{t}_{c}}_{\text{Tariff revenues}} \\ & + \underbrace{\sum_{c}\sum_{a}\sum_{w}\sum_{z}\tau^{Ap}_{c,a,w,z}PA^{t}_{c}XAP_{c,a,w,z}}_{\text{Taxes on intermediate consumption}} + \underbrace{\sum_{c}\sum_{af}\tau^{Af}_{c,af}PA^{t}_{c}XA_{c,af}}_{\text{Taxes on final consumption}} \\ & + \underbrace{\sum_{c}\left(\tau^{dt}_{c}PD^{t}_{c}XD^{t}_{c}+\tau^{mt}_{c}PM^{t}_{c}XM^{t}_{c}\right)}_{\text{Commodity taxes}} + \underbrace{\chi^{t}\sum_{h}\kappa^{h}_{h}YH_{h}}_{\text{Direct household taxes}} \end{aligned}$$

(Y-8) $$S^{g} = CPI.RS^{g}$$

(Y-9) $$YC_{Gov} = GREV - CPI.GTRH - S^{g} - ER.GTRROW$$

(Y-10) $$YC_{Inv} = \sum_{h}S^{h}_{h} + S^{g} + ER.S^{f} - YC_{Stb}$$

Final demand

The final demand agents are indexed by *af* and include households (*h*), government (*Gov*) and investment (*Inv*) and stock building (*stb*). In the current version of the model a CES expenditure function is assumed for all agents.[14] Equation (D-1) determines the (Armington) demand for commodity *c* across all agents *af*, where *XC* is the aggregate volume of demand, *PC* is the aggregate expenditure price index, and the national Armington price, PA^{t}, is adjusted by a commodity and agent specific sales tax, t^{Af}. Equation (D-2) defines the aggregate expenditure price index, *PC*. Equation (D-3) is an identity equating nominal expenditures to the product of the aggregate price index and the aggregate volume index. In the case where nominal expenditures are endogenous to the model (such as household expenditures) the equation is used to define the

[14] In the next version, household expenditures will be replaced with a nested LES/CES structure that enables a richer set of income and price elasticities.

aggregate volume index. In the case where the volume index is exogenous (such as government expenditures in the default closure), the equation defines nominal expenditures. Equation (D-4) defines the national consumer price index, *CPI*, where the weights across commodities and households, j, sum to 1.

(D-1) $$XA_{c,af} = \alpha^{fd}_{c,af} XC_{af} \left(\frac{PC_{af}}{(1+\tau^{Af}_{c,af})PA^t_c} \right)^{\sigma^f_{af}}$$

(D-2) $$PC_{af} = \left[\sum_c \alpha^{fd}_{c,af} \left[(1+\tau^{Af}_{c,af})PA^t_c \right]^{1-\sigma^f_{af}} \right]^{1/(1-\sigma^f_{af})}$$

(D-3) $$YC_{af} = PC_{af} XC_{af}$$

(D-4) $$CPI = \sum_c \sum_h \varphi_{c,h} (1+\tau^{Af}_{c,h}) PA^t_c$$

Allocation of national output and trade specification

At this stage the model specification is quite conventional. The small country assumption is assumed for world prices. National production is allocated between domestic export markets assuming a CET transformation function. National absorption is allocated between goods produced domestically and imports using a CES specification, consistent with the so-called Armington assumption of products differentiated by region of origin.

Equation (T-1) equates the domestic price of exports, PE^t to the world price, *WPE*, multiplied by the exchange rate *ER*. The domestic price of imports, PM^t, is equal to the world price, *WPM*, times the exchange rate, and augmented by the import tariff given by t^m, equation (T-2).

(T-1) $$PE^t_c = ER.WPE_c$$

(T-2) $$PM^t_c = ER(1+\tau^m_c)WPM_c$$

Equations (T-3) through (T-5) describe the allocation of domestic production using the CET specification. With a finite elasticity, domestic and export supply, respectively XD^t and XE^t, are determined using the CET first order conditions, where XS^t is total supply with price PS^t, and the respective component prices are given by PD^t and PE^t. Equation (T-5) represents the aggregation of domestic and export sales where the CET dual price expression is employed in the case of a finite elasticity. The specification allows for homogeneous commodities and the law-of-one-price.

$$\text{(T-3)} \qquad \begin{cases} XD_c^t = \gamma_c^d XS_c^t \left(\dfrac{PD_c^t}{PS_c^t} \right)^{\omega_c^x} & \text{if} \quad \omega_c^x \neq \infty \\ PD_c^t = PS_c^t & \text{if} \quad \omega_c^x = \infty \end{cases}$$

$$\text{(T-4)} \qquad \begin{cases} XE_c^t = \gamma_c^e XS_c^t \left(\dfrac{PE_c^t}{PS_c^t} \right)^{\omega_c^x} & \text{if} \quad \omega_c^x \neq \infty \\ PE_c^t = PS_c^t & \text{if} \quad \omega_c^x = \infty \end{cases}$$

$$\text{(T-5)} \qquad \begin{cases} PS_c^t = \left[\gamma_c^d \left(PD_c^t \right)^{1+\omega_c^x} + \gamma_c^e \left(PE_c^t \right)^{1+\omega_c^x} \right]^{1/(1+\omega_c^x)} & \text{if} \quad \omega_c^x \neq \infty \\ XS_c^t = XD_c^t + XE_c^t & \text{if} \quad \omega_c^x = \infty \end{cases}$$

Aggregate Armington demand XA^t is allocated between domestically produced goods and imports. Equation (T-6) defines aggregate Armington demand, XA^t. It is the sum of demand across all activities and final demand agents—under the assumption that each agent has the same preferences between domestically produced goods and imports. Equations (T-7) through (T-9) describe the Armington demand system. Demand for domestically produced goods, XD^t, and imports, XM^t, are price-sensitive shares of aggregate Armington demand using the standard CES formulation. The component prices, PD^t and PM^t, are adjusted by commodity taxes, t^{dt} and t^{mt}. Equation (T-9) describes the aggregate Armington price, PA^t. It is worthy to note that the model specification assumes implicitly market equilibrium. On the export and import side this is due to the small country assumption, in which case actions by the national economy have no influence on the terms of trade. On the domestic goods market, equilibrium is subsumed because the XD^t used in equation (T-3) is the same as that used in equation (T-7). In fact, that used in equation (T-3) determines supply and that used in equation (T-7) determines demand. They could be identified separately with an additional equation added to insure supply/demand equilibrium.

$$\text{(T-6)} \qquad XA_c^t = \sum_a \sum_w \sum_z XAP_{c,a,w,z} + \sum_{af} XA_{c,af}$$

$$\text{(T-7)} \qquad XD_c^t = \alpha_c^d XA_c^t \left(\frac{PA_c^t}{(1+\tau_c^{dt})PD_c^t} \right)^{\sigma_c^m}$$

(T-8) $$XM_c^t = \alpha_c^m XA_c^t \left(\frac{PA_c^t}{(1+\tau_c^{mt})PM_c^t}\right)^{\sigma_c^m}$$

(T-9) $$PA_c^t = \left[\alpha_c^d \left((1+\tau_c^{dt})PD_c^t\right)^{1-\sigma_c^m} + \alpha_c^m \left((1+\tau_c^{mt})PM_c^t\right)^{1-\sigma_c^m}\right]^{1/(1-\sigma_c^m)}$$

Factor markets

The current version of the model identifies four primary factors of production—labor, capital, land and water. There are markets for two sources of water—large-scale hydro and ground water. These are identified with separate activities and thus the same index is used for both. The labor and capital markets are national in scope, though potentially with internal barriers that can create price wedges across activities and regions. The market for land is region-specific, as is the market for water. These are detailed further below.

National factors

The supply of labor and capital is handled through a series of nested CET supply functions. The top nest allocates these two factors between rural and urban supply. By default, the six agro-ecological zones are considered to be rural—since they only produce agricultural commodities, and the urban sector is associated with the rest of the activities, i.e. those produced at the national level. The second nest allocates labor and capital across the zones. In the case of rural labor and capital, it is allocated across the six agro-ecological zones. In the urban area there is only a single zone, so in some sense this nest is redundant but it does allow for flexibility in re-arranging the markets. The final nest allocates capital and labor across individual activities, where an activity is identified with a pair of indices (*a*,*w*), i.e. each activity identified with a specific water technology.

Equations (F-1) and (F-2) represent the allocation of national labor and capital between rural and urban activities. The variable *XFRU* represents supply to each one of the respective zones (rural and urban), with an aggregate price of *PFRU*.[15] The variable XF^t represents national supply of the respective factors with an aggregate price given by PF^t. Even with perfect transformation, i.e. with perfect mobility of labor and capital across the two zones, factor prices may differ, due for example to differences in the cost of living. The g^{ru} parameter, which is calibrated to base year price wedges, is fixed. With perfect mobility, all factor prices move in unison, however the price wedge remains constant. The elasticity of transformation is given by w^{ru}.

[15] The index *nfp* covers national factors, i.e. labor and capital and is a subset of the set *fp*. The index *ru* is an index of the set defined by {*rural*, *urban*}.

$$\text{(F-1)} \quad \begin{cases} XFRU_{nfp,ru} = \alpha^{ru}_{nfp,ru} \dfrac{XF^t_{nfp}}{\gamma^{ru}_{nfp,ru}} \left(\dfrac{PFRU_{nfp,ru}}{\gamma^{ru}_{nfp,ru} PF^t_{nfp}} \right)^{\omega^{ru}_{nfp}} & \text{if} \quad \omega^{ru}_{nfp} \neq \infty \\ PFRU_{nfp,ru} = \gamma^{ru}_{nfp,ru} PF^t_{nfp} & \text{if} \quad \omega^{ru}_{nfp} = \infty \end{cases}$$

$$\text{(F-2)} \quad \begin{cases} PF^t_{nfp} = \left[\sum_{ru} \alpha^{ru}_{nfp,ru} \left(\dfrac{PFRU_{nfp,ru}}{\gamma^{ru}_{nfp,ru}} \right)^{1+\omega^{ru}_{nfp}} \right]^{1/(1+\omega^{ru}_{nfp})} & \text{if} \quad \omega^{ru}_{nfp} \neq \infty \\ XF^t_{nfp} = \sum_{ru} \gamma^{ru}_{nfp,ru} XFRU_{nfp,ru} & \text{if} \quad \omega^{ru}_{nfp} = \infty \end{cases}$$

At the next stage, aggregate supply by broad zone (rural and urban) is allocated across the six agro-ecological zones and the national zone. By default, there is only one zone (the national zone) mapped to the urban index. Equations (F-3) and (F-4) describe this allocation. The variable *XFZ*, with a price *PFZ*, represents the total supply of national factors to zone *z*, where each one of the zones is mapped to either the rural or urban aggregate. The transformation elasticity is given by w^z, and similar to above, the parameter g^z reflects base year price wedges across zones.

$$\text{(F-3)} \quad \begin{cases} XFZ_{nfp,z} = \alpha^{z}_{nfp,z} \dfrac{XFRU_{nfp,ru}}{\gamma^{z}_{nfp,z}} \left(\dfrac{PFZ_{nfp,z}}{\gamma^{z}_{nfp,z} PFRU_{nfp,ru}} \right)^{\omega^{z}_{nfp,ru}} & \text{if} \quad \omega^{z}_{nfp,ru} \neq \infty, z \in ru \\ PFZ_{nfp,z} = \gamma^{z}_{nfp,z} PFRU_{nfp,ru} & \text{if} \quad \omega^{z}_{nfp,ru} = \infty, z \in ru \end{cases}$$

$$\text{(F-4)} \quad \begin{cases} PFRU_{nfp,ru} = \left[\sum_{z \in ru} \alpha^{z}_{nfp,z} \left(\dfrac{PFZ_{nfp,z}}{\gamma^{z}_{nfp,z}} \right)^{1+\omega^{z}_{nfp,ru}} \right]^{1/(1+\omega^{z}_{nfp,ru})} & \text{if} \quad \omega^{z}_{nfp,ru} \neq \infty \\ XFRU_{nfp,ru} = \sum_{z \in ru} \gamma^{z}_{nfp,z} XFZ_{nfp,z} & \text{if} \quad \omega^{z}_{nfp,ru} = \infty \end{cases}$$

The finally nest allocates the aggregate supply at the zone level across the different activities within the zone where each activity is identified by a pair of indices (*a*,*w*). The variable *XF* therefore represents the supply of the factor to the activity identified with three indices (*a*,*w*,*z*). The model directly substitutes out the market equilibrium condition and the *XF* identified in equations (F-5) and (F-6) is identical to the *XF* identified in the factor demand equation as given by (P-7), with the equilibrium price of *PF*. The parameter g^f represents base year price wedges and the transformation elasticity is given by w^f.

$$\text{(F-5)} \qquad \begin{cases} XF_{nfp,a,w,z} = \alpha^s_{nfp,a,w,z} \dfrac{XFZ_{nfp,z}}{\gamma^f_{nfp,a,w,z}} \left(\dfrac{PF_{nfp,a,w,z}}{\gamma^f_{nfp,a,w,z} PFZ_{nfp,z}} \right)^{\omega^f_{nfp,z}} & \text{if} \quad \omega^f_{nfp,z} \neq \infty \\ PF_{nfp,a,w,z} = \gamma^f_{nfp,a,w,z} PFZ_{nfp,z} & \text{if} \quad \omega^f_{nfp,z} = \infty \end{cases}$$

$$\text{(F-6)} \qquad \begin{cases} PFZ_{nfp,z} = \left[\sum_a \sum_w \alpha^s_{nfp,a,w,z} \left(\dfrac{PF_{nfp,a,w,z}}{\gamma^f_{nfp,a,w,z}} \right)^{1+\omega^f_{nfp,z}} \right]^{1/(1+\omega^f_{nfp,z})} & \text{if} \quad \omega^f_{nfp,z} \neq \infty \\ XFZ_{nfp,z} = \sum_a \sum_w \gamma^f_{nfp,a,w,z} XF_{nfp,a,w,z} & \text{if} \quad \omega^f_{nfp,z} = \infty \end{cases}$$

Market for land

Aggregate arable land, *TLand*, is fixed within each one of the agro-ecological zones. It is allocated across land-types using a top-level CET nest to determine land supply by type of land, *XFZ*, indexed by *lnd*.[16] The variables *PTLand* and *PFZ* represent respectively the aggregate price of land in zone *z* and the price of land-type *lnd* in zone *z*. The parameter g^z represents the initial price wedge across land types and w^t is the transformation elasticity.

$$\text{(F-7)} \qquad \begin{cases} XFZ_{lnd,z} = \alpha^z_{lnd,z} \dfrac{TLand_z}{\gamma^z_{lnd,z}} \left(\dfrac{PFZ_{lnd,z}}{\gamma^z_{lnd,z} PTLand_z} \right)^{\omega^t_z} & \text{if} \quad \omega^t_z \neq \infty \\ PFZ_{lnd,z} = \gamma^z_{lnd,z} PTLand_z & \text{if} \quad \omega^t_z = \infty \end{cases}$$

$$\text{(F-8)} \qquad \begin{cases} PTLand_z = \left[\sum_{lnd} \alpha^z_{lnd,z} \left(\dfrac{PFZ_{lnd,z}}{\gamma^z_{lnd,z}} \right)^{1+\omega^t_z} \right]^{1/(1+\omega^t_z)} & \text{if} \quad \omega^t_z \neq \infty \\ TLand_z = \sum_{lnd} \gamma^z_{lnd,z} XFZ_{lnd,z} & \text{if} \quad \omega^t_z = \infty \end{cases}$$

Each type of land (*lnd*) is then allocated across all the activities in the zone as identified by the pair of indices (*a*,*w*). This provides the land supply variable *XF* with a price *PF* identified with each activity *a* using water technology *w* in zone *z*. Similar to labor and capital, the equilibrium condition is substituted away. The parameter g^f measures base year price wedges for land across activities and the transformation elasticity is given by w^f.

[16] In the current version of the model there are three types of land—crop land, pasture land, and fallow land. The latter two are used exclusively in the livestock sectors.

$$
\text{(F-9)} \quad \begin{cases} XF_{lnd,a,w,z} = \alpha^s_{lnd,a,w,z} \dfrac{XFZ_{lnd,z}}{\gamma^f_{lnd,a,w,z}} \left(\dfrac{PF_{lnd,a,w,z}}{\gamma^f_{lnd,a,w,z} PFZ_{lnd,z}} \right)^{\omega^f_{lnd,z}} & \text{if} \quad \omega^f_{lnd,z} \neq \infty \\ PF_{lnd,a,w,z} = \gamma^f_{lnd,a,w,z} PFZ_{lnd,z} & \text{if} \quad \omega^f_{lnd,z} = \infty \end{cases}
$$

$$
\text{(F-10)} \quad \begin{cases} PFZ_{lnd,z} = \left[\displaystyle\sum_a \sum_w \alpha^s_{lnd,a,w,z} \left(\dfrac{PF_{lnd,a,w,z}}{\gamma^f_{lnd,a,w,z}} \right)^{1+\omega^f_{lnd,z}} \right]^{1/(1+\omega^f_{lnd,z})} & \text{if} \quad \omega^f_{lnd,z} \neq \infty \\ XFZ_{lnd,z} = \displaystyle\sum_a \sum_w \gamma^f_{lnd,a,w,z} XF_{lnd,a,w,z} & \text{if} \quad \omega^f_{lnd,z} = \infty \end{cases}
$$

Market for water

Surface water is allocated in three stages, within each AEZ. The first allocation is for urban populations, meeting their notional demand from aggregate supplies at administered prices. After this, surface water is allocated to priority crops, @@[these need to be specified, but AEZ].

Once the administered allocation is complete, the remaining surface water is allocated according to a market mechanism. This takes the form of a single nest. For each period, marketable the supply of water of type *w* in zone *z*, has a price *PFWT*.[17] It is allocated to the different activities *a* within the water-zone identified by the pair (*w*,*z*) to give water supply *XF* with a price *PF* (also the equilibrium price). The parameter γ^f identifies the base year price wedge across activities and ω^w is the transformation elasticity.

$$
\text{(F-11)} \quad \begin{cases} XF_{wat,a,w,z} = \alpha^s_{wat,a,w,z} \dfrac{XFWT_{wat,w,z}}{\gamma^f_{wat,a,w,z}} \left(\dfrac{PF_{wat,a,w,z}}{\gamma^f_{wat,a,w,z} PFWT_{wat,w,z}} \right)^{\omega^w_{wat,w,z}} & \text{if} \quad \omega^w_{wat,w,z} \neq \infty \\ PF_{wat,a,w,z} = \gamma^f_{wat,a,w,z} PFWT_{wat,w,z} & \text{if} \quad \omega^w_{wat,w,z} = \infty \end{cases}
$$

$$
\text{(F-12)} \quad \begin{cases} PWAT_{wat,w,z} = \left[\displaystyle\sum_a \alpha^s_{wat,a,w,z} \left(\dfrac{PF_{wat,a,w,z}}{\gamma^f_{wat,a,w,z}} \right)^{1+\omega^w_{wat,w,z}} \right]^{1/(1+\omega^w_{wat,w,z})} & \text{if} \quad \omega^w_{wat,w,z} \neq \infty \\ XFWT_{wat,w,z} = \displaystyle\sum_a \gamma^f_{wat,a,w,z} XF_{wat,a,w,z} & \text{if} \quad \omega^w_{wat,w,z} = \infty \end{cases}
$$

17 Because water is always identified by the pair (*w*,*z*), there is no distinction made across water types, i.e. there is a single index ‘wat’ in the set ‘wat’. In principle one could identify different types of water within each one of the technologies, for example different types of ground water—differentiated for example by salinity or some other qualifier.

At the same time, individual farm enterprises/households can exploit ground water (G) with their own on-site technologies.[18] We assume this water is nonmarketable, but is a perfect substitute for marketed water. The cost of groundwater depends on pumping technology, energy prices, and the depth of the water table. To model these, we consider first the stock of ground water available in the current year (G_t), which is defined dynamically at the beginning of a period as

(3) $G_t = G_{t-1} + I_t - G_{t-1}^{gh} - G_{t-1}^{oi} - Mun$

In particular, G_t equals the previous period's stock (G_{t-1}), plus new intake (I_t, all water inflow/outflow expect irrigation outtake), less outtake for irrigation (including grande hydraulique G^{gh}, other irrigation G^{oi}, and Municipal):

The new intake is a combination of two sources— natural flows (rainfall/drainage by the river/outflow to the see) and return irrigation:

(4) $I_t = R_t + \alpha_t (G_t^{gh} + G_t^{oi})$

where α_t is the annual return rate—assumed to be around 20%. The cost of pumping depends on the depth of the ground water, the latter depends on the change in volume of ground water:

(5) $\Delta D_t = \beta_t \Delta G_t$

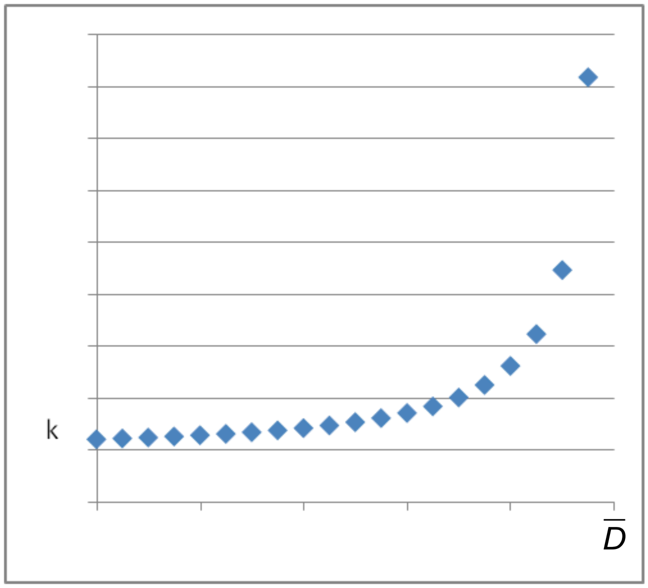
where β_t is a calibrated coefficient. The cost of pumping might then take the form:

(6) $w_t = C(k_t, \overline{D}, G_t)$

The price of pumping rises as the ground water depth approaches its maximum $\overline{D}$. The variable k_t represents some markup over the price of pumping for conveyance cost. This cost function is generally represented by an inverse logistic function, with lower bound (at D=0) equal to minimum conveyance cost and becoming unbounded at the maximum depth (see e.g. Figure 8).

[18] We are very grateful to Benedicte Augeard for insights on ground water extraction costs.

Figure 1: Schematic Water Extraction Cost Curve



Macro and dynamic equations

The macroeconomic and dynamic equations are used in the dynamic version of the model. The dynamic version of the model has two phases. The first phase is the dynamic calibration of the baseline. Certain key assumptions are made regarding dynamic variables—labor and population supply, investment/savings and productivity to produce a baseline or business-as-usual (BaU) scenario. Typically developing the BaU entails some 'dialogue' with the model. The analyst will have some priors on the macro evolution of the economy and use the model to back-out key behavioral or technical parameters. For example, it is typical to exogenize per capita GDP growth in the baseline and let the model solve for the relevant TFP factor that achieves that growth rate (subject to all of the other exogenous assumptions). The analyst will look at the plausibility of the BaU results and revise some key assumptions to achieve a satisfactory baseline. The second phase represents undertaking policy or alternative scenarios where some key variables calculated in the BaU scenario are now fixed, such as productivity, and other variables—such as tax policies or water supply—are shocked and the results of which are analyzed and compared with the BaU outcomes.

Equations (M-1) and (M-2) define respectively nominal and real GDP at market prices, *GDP* and *RGDP*. The prices represent the difference between the two expressions—current in the first case and constant in the second [should we convert to chain indices?]. Equation (M-3) defines the GDP deflator at market price, *PGDP*. Equation (M-4) is an identity describing the growth of real GDP, given by g^y. In the BaU, g^y may be exogenous and it is a common productivity factor (described below) that is endogenous to achieve a given growth target. In shock scenarios the variable g^y would normally be endogenous. Equation (M-5) defines the GDP shares of domestic absorption, c^y. These shares are fixed in some closures—for example the government expenditure to GDP share or the investment to GDP share.

(M-1)	$GDP = \sum_c \sum_{af} (1+\tau^{Af}_{c,af}) PA^t_c XA_{c,af} + \sum_c PE^t_c XE^t_c - ER \sum_c WPM_c XM^t_c$
(M-2)	$RGDP = \sum_c \sum_{af} (1+\tau^{Af}_{c,af,0}) PA^t_{c,0} XA_{c,af} + \sum_c PE^t_{c,0} XE^t_c - ER \sum_c WPM_{c,0} XM^t_c$
(M-3)	$PGDP = GDP / RGDP$
(M-4)	$RGDP = (1+g^y) RGDP_{-1}$
(M-5)	$\chi^y_{af} = YC_{af} / GDP$

The next set of equations relates to GDP from the supply side, i.e. GDP at factor cost. Equations (M-6) and (M-7) define respectively nominal (*GDPFC*) and real (*RGDPFC*) GDP at factor cost. Notice that GDP at factor cost is measured in efficiency units. In the case of nominal GDP this is irrelevant because the efficiency parameters offset each other. In the case of real GDP they do not.[19] [If we move to chain indices we would have to re-introduce the efficiency parameter in the price factor. This may improve the consistency of growth between MP and FC]. Equation (M-8) defines the GDP price deflator, *PGDPFC*. There are two things to note. First, there is a wedge between the two definitions of GDP due to the existence of indirect taxes. We have chosen to ignore these in the definition of GDP at factor cost. Also, in part due to this wedge and in part due to the inherent problems in defining volume indices, the growth rate of GDP at market price may deviate (slightly) from the growth rate of GDP at factor cost. The two definitions, adjusted for indirect taxes, are identical in nominal terms.

(M-6)	$GDPFC = \sum_{fp} \sum_a \sum_w \sum_z PF_{fp,a,w,z} XF_{fp,a,w,z}$
(M-7)	$RGDPFC = \sum_{fp} \sum_a \sum_w \sum_z PF_{fp,a,w,z,0} \lambda^f_{fp,a,w,z} XF_{fp,a,w,z}$
(M-8)	$PGDPFC = GDPFC / RGDPFC$

The dynamics are driven by a number of exogenous assumptions. First, aggregate labor supply and population are exogenous and grow according to the UN (medium

[19] In principle we should divide PF_0 by λ_0, but the latter is initialized at 1 in the base year.

variant) population projection. Labor supply growth is equated to the growth of the population cohort bounded by the 15 to 64 year age group, i.e. the working age population. Capital supply is fixed within a period, but between periods is the sum of two components (equation M-9). The first component is the previous period's capital stock with a depreciation adjustment. The second component is the previous period's volume of investment. The model's capital stock is normalized so that it equals the base year's aggregate remuneration, i.e. in the base year it represents the aggregate rate of return to the non-normalized capital stock. In the absence of an independent estimate of the base year capital stock a base year rate of return, RoR_0 is assumed, i.e. the non-normalized, or true value of the base year capital stock is given by $XFT_{Captl,0}/ RoR_0$.[20] In equation (M-9), this relation is carried through but multiplied out and thus the RoR_0 factor is applied to the volume of investment.

(M-9) $$XFT_{Captl} = (1-\delta)XFT_{Captl,-1} + RoR_0 XC_{Inv,-1}$$

(M-10) $$\lambda^f_{l,a,w,z} = (1+\pi_{a,w,z} + g^l)\lambda^f_{l,a,w,z,-1} \quad \text{if} \quad (a,w,z) \in Endog(a,w,z)$$

Equation (M-10) describes productivity dynamics in the BaU scenario exclusively. First, all of the other productivity parameters in the model are assumed to be exogenous (though not necessarily constant). Second, activities are clustered into three sets. The first set is for activities where factor productivity is fully exogenous. Typically this is the assumption for the agricultural sectors where there is significant knowledge about agricultural productivity. The activities with endogenous productivity are divided into two—those with high productivity and this with low. Typically manufacturing productivity is higher than productivity in the services sector. Equation (M-10) provides the productivity factor, for labor alone, in those activities with endogenous productivity. Growth in productivity has two components. One is the economy-wide labor productivity growth, g^l, which is uniform across all activities. With a given GDP target in the BaU scenario, there must be a single instrument to achieve the target. The other factor, p, is a wedge that differentiates productivity growth across activities. The factor p is exogenous with default value of 2% in the manufacturing sectors and 0% elsewhere. Equation (M-10) is part of the model only in the BaU scenario and only for activities with endogenous productivity growth (that is user-determined). In shock scenarios, labor productivity is exogenous and updated at the beginning of each period.

To summarize, the baseline is predicated on the following list of assumptions:

[20] RoR0 could also be derived in the base year with a known estimate of the value of the non-normalized capital stock, as calculated for example from the perpetual inventory methodology.

1. Labor and population growth are exogenous.
2. Capital accumulates through the process of savings, investment and depreciation.
3. Currently aggregate water and land availability are fixed at base year levels.
4. Productivity in the agricultural sectors is exogenous and uniform across all inputs (i.e. the l^n and l^v parameters grow at identical user-specified rates).
5. Productivity in the other sectors is endogenous and is only labor-augmenting. There is a uniform labor productivity factor that is endogenous to achieve a given growth in per capita GDP. In addition, there is a sector specific productivity shifter, p, which allows for inter-sectoral productivity wedges—normally with higher productivity in manufacturing than in services.
6. Government expenditures in volume terms grow at the rate of GDP growth. The household direct tax rate is adjusted uniformly across households to achieve the government expenditure target—with the government balance fixed in real terms.
7. Investment in savings driven.

In the shock scenarios, productivity is fully exogenous and set to the values calculated in the baseline. As well, government expenditures in volume terms are fixed to BaU levels, though the household direct tax schedule remains endogenous to achieve the fixed government balance.

5.3 Dynamics

The time interval between model solutions is allowed to vary. Typically annual time periods are used in the early periods—in part to line up key macro aggregates with observed data and in part to allow the model to smooth out potential disequilibria in the early periods. When extending to the longer term horizon, where in particular there is more uncertainty about longer term trends, it is typical to solve the model over longer time intervals, for example five years. In this case, some of the dynamic equations need to be modified to handle the longer time intervals. Most of these extensions are straightforward, though there are some exceptions. The following details the equations that require modification.

Equation (M-4) can readily be extended to time intervals greater than 1 under the assumption of constant (compound) annual growth in the intervening years. The capital accumulation equation requires a bit more algebra since the accumulation function depends on assumptions about investment in the intervening years. It is relatively straightforward to show that the following expression must hold for the capital accumulation equation between period *t-n* and *t*:

$$XFT_{Captl,t} = (1-\delta)^n XFT_{Captl,t-n} + RoR_0 \sum_{j=1}^{n} (1-\delta)^{j-1} XC_{Inv,t-j}$$

If we assume further that investment growth is constant in the intervening years, i.e.:

$$XC_{Inv,t} = (1+\gamma^I) XC_{Inv,t-1}$$

Then the formula above collapses to:

$$XFT_{Captl,t} = (1-\delta)^n XFT_{Captl,t-n} + RoR_0 XC_{Inv,t-n} \frac{(1+\gamma^I)^n - (1-\delta)^n}{\gamma^I + \delta}$$

The ratio in the expression above can create numerical problems. The expression is transformed to an expression that is more stable numerically, though requires and auxiliary expression and variable, *InvGFact*, defined in equation (M-9a). The expression in brackets evaluates to the sum of the depreciation rate and the growth rate of investment, say somewhere around 10%, so the ratio is on the order of magnitude of 10. This is then substituted into equation (M-9b) to provide the capital accumulation equation. Finally, equation (M-10) is relatively simply extended by assuming constant compound growth in productivity.

(M-4) $$RGDP_t = (1+g^y)^n RGDP_{t-n}$$

(M-9a)	$InvGFact_t = RoR_0 \left[\left(\frac{XC_{Invst,t}}{XC_{Invst,t-n}} \right)^{1/n} - 1 + \delta_t \right]^{-1}$
(M-9b)	$XFT_{Captl,t} = (1-\delta)^n \left[XFT_{Captl,t-n} - InvGFact_t XC_{Inv,t-n} \right] + InvGFact_t XC_{Inv,t}$
(M-10)	$\lambda^f_{l,a,w,z,t} = (1 + \pi_{a,w,z,t} + g^l_t)^n \lambda^f_{l,a,w,z,t-n} \quad \text{if} \quad (a,w,z) \in Endog(a,w,z)$