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Impacts of Considering Climate Variability on Investment Decisions in Ethiopia

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ABSTRACT

Extreme interannual variability of precipitation within Ethiopia is not uncommon, inducing droughts or floods and often creating serious repercussions on agricultural and non-agricultural commodities. An agro-economic model, including mean climate variables, was developed to assess irrigation and road construction investment strategies in comparison to a baseline scenario over a 12-year time horizon. The motivation for this work is to evaluate whether the inclusion of climate variability in the model has a significant effect on prospective investment strategies and the resulting country-wide economy. The mean climate model is transformed into a variable climate model by dynamically adding yearly climate-yield factors, which influence agricultural production levels and linkages to non-agricultural goods. Nine sets of variable climate data are processed by the new model to produce an ensemble of potential economic prediction indicators. Analysis of gross domestic product and poverty rate reveal a significant overestimation of the country's future welfare by the mean climate model method, in comparison to probability density functions created from the variable climate ensemble. The ensemble is further utilized to demonstrate risk assessment capabilities. The addition of climate variability to the agro-economic model provides a framework, including realistic ranges of economic values, from which Ethiopian planners may make strategic decisions.

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Paul J. Block,[1] Kenneth Strzepek,[1 and 2] Mark Rosegrant,[3] and Xinshen Diao[3]

1. INTRODUCTION

Although Ethiopia is rich in culture, history, and natural resources, it is often remembered more for its disastrous droughts and floods, starving population, and struggling economy. Its heavy reliance on agriculture, combined with its susceptibility to frequent climate extremes, has left it in a precarious position, striving to not only stay on par, but to prevent vast numbers of people from falling deeper into disparity. With 85 percent of the population living in rural areas, agriculture plays an important role in physical and economical survival.

This work is part of an on-going study focusing on relevant and realistic potential investment strategies within Ethiopia. The hope is that these strategies may provide insights into how Ethiopia should best proceed in the years to come, both on regional and country levels, for rural and urban alike. Goals set forth by the Ethiopian government are included explicitly, including plans for development in agriculture, water resources, and roadway infrastructure. To assist in this activity, an agro-economic model was developed by the International Food Policy Research Institute (IFPRI) (Diao et al. 2005.) The model is designed to assess investment strategies and afford recommendations based on forecasts of economic indicators.

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The climate in Ethiopia is generally associated with tropical monsoon-type behavior, experiencing significant June-September rainfall, yet measurably cooler due its high plateau and central mountain range elevations. It is the occurrence of climate extremes, though, both annual and seasonal, which can impact regional economic production, resulting in reduced or negative growth rates. Therefore, due to the importance of climate on the economy of Ethiopia, pertinent climatic variables are incorporated into the agro-economic model. The original version employs average climatic variables, held constant throughout the simulation projection periods. The motivation for this work is to assess whether the inclusion of climate variability in the model, both annually and seasonally, has a significant effect on prospective investment strategies and the resulting country-wide economy. If the effect is remarkable, the implications may be significant, and aid in providing guidance and direction to strategic planners, as well as protection of the investments through wise development decisions.

This paper begins with a brief background on the contemporary move toward modeling with climate variability, followed by a description and validation of climate data employed in the agro-economic model. The original model framework is presented next, after which the methodology for modifying the climatic portion of the model is outlined. Subsequently, the effects of modeling with and without climate variability are compared and discussed, finishing with a summary and discussion.

2. BACKGROUND

A growing number of articles on the influence of including climate variability in models and assessments are appearing in agricultural and economics literature. The general trend in modeling, especially considering the increased ease and decreased processing time, is to include climate variability not only for more representative and descriptive results, but to allow for risk assessment as well (Taylor, et al. 1995; Letson, et al. 2001; Ludena, et al. 2003; Ferreyra, et al. 2001.) Numerous studies indicate that agriculture is particularly sensitive and vulnerable to climate variability, more so than almost any other activity (Dixon, et al. 1999.) Agriculture is often very productive in a multitude of geographic settings under the influence of mean climate variables, but is frequently susceptible to crop failure during extreme climate events (Salinger, et al. 1997.) Additional research has also shown that agriculture is especially vulnerable in developing countries during extreme or semi-extreme events due in large part to the limited infrastructure, and its inability to endure atypical climate fluctuations. Patt (1999), in a paper concerning the treatment of low probability events, claims that extreme climate events often dominate decision making. With this in mind, more climate-varying agriculture models are being built for comparison to mean climate models or even actual field data if available, and are showing that variability is of importance (Mendelsohn et al. 1999).

3. CLIMATIC DATA

The climatic data utilized for inclusion in the agro-economic model is part of the CRU TS 2.0 dataset, obtained from the University of East Anglia, available at http://www.cru.uea.uk/~timm/grid/CRU_TS_2_0.html. It consists of grided data in 0.5-degree by 0.5-degree cells, containing 100 years of monthly data. Much of the data from 1901 – 1960 is synthetic data, and is obtained based on 1961 – 1990 averages and grided anomalies (Block and Rajagopalan 2006.)

As a result of the sparse and spotty precipitation gauges in the region, the upper Blue Nile basin precipitation data from the CRU set (1961-2000) was validated to ensure its spatial and temporal representation, by comparison with two other global precipitation datasets: University of Delaware (UDEL) and CPC merged analysis of precipitation (CMAP). The UDEL data, also in a 0.5-degree by 0.5-degree format, contains monthly data from 1950 – 1999, while the CMAP data, at a resolution of 2.5-degree by 2.5-degree, is available from 1979 – 2000.

The CRU and UDEL data have strong spatial ($R^2 = 0.82$) and temporal ($R^2 = 0.79$) correlations, giving positive indication that the two sets represent precipitation similarly. CMAP data also possesses a strong correlation with CRU data, further bolstering confidence in the CRU dataset (Block and Rajagopalan 2006.) In general, the UDEL and CMAP datasets appear to certify the consistency of the CRU set, and it is therefore deemed acceptable.

4. MODEL FRAMEWORK

The original economy-wide, multi-sector and multi-regional model developed by Diao et al. serves as the foundational model for this study. The model, which comprises Ethiopia's eleven administrative regions and 56 zones, attempts to stimulate growth through agricultural and non-agricultural investment strategies. It is agriculturally focused, with 34 agricultural commodities (cereals, cash crops, and livestock products), yet includes two aggregate nonagricultural commodities as well. Both agricultural production and consumption are defined at the zonal level; the demand side is further disaggregated into rural and urban sectors.

The model was expanded to include an agricultural water extension in order to capture the important links between water demand-supply and economic activity in the agriculture sector. Given its high dependency on rainfall for agricultural production and weak linkages between domestic prices at the regional level and world markets, hydrologic variability has potentially serious impacts on both agriculture and the whole economy. Moreover, with high transportation costs and poor access conditions to distant markets, the local impact of hydrologic variability cannot always be buffered or ameliorated through market links to other regions. There can be significant "threshold" effects whereby prices have to rise above critical values before inducing trade with other regions or fall below a certain level to get access to world markets.

CRITICAL CLIMATE-RELATED EQUATIONS

General multi-market model equations, with brief description, are included in Appendix I (Diaoet al. 2005.) The yield function, representing all agricultural commodities, is of primary interest and re-presented in Equation 1, with further description.

$$Y_{R,Z,i,t} = \mathrm{YA}_{\mathrm{R,Z,i,t}} P_{R,Z,i,t}^{\alpha_{R,Z,i}} \qquad (1)$$

$Y_{R,Z,i}$ is the yield for crop i in zone Z of region R. $P_{R,Z,i}$ is the producer price for the same commodity, i, while $YA_{R,Z,i}$ represents a climate shift parameter. This parameter depends on a climate-yield factor, which has been derived from 100 years of monthly climate data at the zonal level. The climate shift parameter is defined in Equation 2.

$$\mathrm{YA}_{R,Z,i,t+1} = CYF_{R,Z,i,t+1} \cdot \mathrm{YA}_{\mathrm{R,Z,i,t}} \left(1 + g_{Y_{R,Z,i}}\right) \qquad (2)$$

CYF symbolizes the climate-yield factor, and is described in detail in the following section of this paper. *CYF* is crop and zone specific, depending on the drought-tolerant ability of the crop and the local climate condition. g_Y is the annual growth rate in yield productivity, based on historical data, and also varies by zone and crop. For irrigated crops, $\mathrm{YA}_{\mathrm{R,Z,i}}$ is not climate-yield factor dependent, and is assigned a value 50 percent higher than $\mathrm{YA}_{\mathrm{R,Z,i}}$ (producing a full yield) for the same crop depending on rainfall only. This enhancement can be attributed to additional fertilizers and pesticides and better seed a farmer will apply to a crop, due to their confidence in knowing that sufficient water will be available for irrigation, and a good yield will follow, barring any natural disaster.

CLIMATE YIELD FACTOR (CYF) DEVELOPMENT

The development of the climate-yield factor (CYF) is based on procedures summarized in the United Nation's Food and Agriculture Organization's (FAO) Publication 33, Yield Response to Water, and Publication 56, Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. The CYF for each crop in each zone is a single value that attempts to encompass crop location, soil and hydrologic characteristics, planting dates, crop duration, effective precipitation, and evapotranspiration. It is essentially a measure, using all the aforementioned parameters, of the yield potential of rain-fed crops, based on water constraints, for a given crop. Values for CYF range from 0 to 1. A CYF of 1 implies no water constraint (i.e., all required water is available) for the crop. This, of course, does not ensure a full yield, as other variables, such as seed quality, pests, and natural disasters, to name a few, may still reduce the final yield; it only implies that water availability will not reduce the yield. A CYF of 0.8, therefore, indicates that the yield of a crop is reduced to 80 percent of the full potential yield by water constraints alone.

CYF is a function of crop and actual evapotranspiration, as well as Ky, the yield response factor, as outlined in Equation 3.

$$CYF_{S,C} = 1 - Ky_{S,C} \cdot \left(1 - \frac{ETA_{S,C}}{ETC_{S,C}}\right) \tag{3}$$

S refers to either a seasonal or crop stage value; c implies the specific crop considered. Ky values are predefined for each crop-stage and for the season as a whole, and can be found in FAO Publication 33. In general, Ky values below 1 tend to indicate resistance to drought, or drought tolerance, while values above 1 point toward drought sensitivity. It is imperative to analyze both seasonal values as well as crop-stage values, as one detrimental crop-stage could potentially ruin a crop. The CYF is therefore calculated for each crop-stage, including vegetation, flowering, yield, and ripening, and for the season as a whole. Seasonal actual evapotranspiration (ETA) and potential crop evapotranspiration (ETC) or crop-stage ETA and ETC are correspondingly used. Once all the crop-stage and seasonal CYF values are established, the limiting CYF value (i.e., the lowest value) for each crop in each zone is retained. Typically, it is the seasonal CYF that produces the most restrictive value.

Table 1 lists the seven cereal crops for which the CYF is computed, the recommended planting month, and typical harvest month for the Meher (main) cropping season.

Table 1--Cereal crop planting and harvest months

	Meher Season	
Cereal Crop	*Planting Month*	*Harvest Month*
Barley	May	September
Maize	May	October
Millet	June	October
Oats	June	October
Sorghum	May	September
Teff	June	September
Wheat	June	October

These dates were used exclusively throughout the entire country in determining CYF values, although variations certainly exist. The specific months listed were compiled by referencing both the FAO's Early Warning System website (FAO 2004) and FAO Publications 33 and 56.

Although climate-yield factors were computed annually for 100 years, only the *mean* values for each crop are retained and implemented into the model. For each simulation (described in the following section), the same mean CYFs are utilized in each year, implying that the yield for rain-fed areas does not change from year to year based on climate effects. All irrigated areas, which initially only account for just over 2 percent, are assigned a CYF of 1. This methodology is deterministic, dampening out climate variability effects, producing a relatively smooth growing trend, and generating one set of scenario results for each investment strategy.

INVESTMENT STRATEGIES AND SIMULATIONS

Two major strategies, investment in irrigation for agriculture and investment in road construction and maintenance, are simulated in the model. Irrigation investment focuses on providing sufficient water to crops, while road investment allows good access for farmers to transport their agricultural products to a market, both for country-wide use and as an export.

The model brings agricultural supply, demand, and market opportunity issues together to assess the alternatives in investment strategies. The analysis gives a broad picture about agricultural growth and poverty reduction, and reveals some important economic linkages among agricultural sectors, between demand and supply, between exports and domestic markets, and between production and farmer income. It is not the purpose of the model to guide a specific investment decision for any agricultural sector in a precise region. Additionally, the analysis reveals the complexity of economic linkages and trade-offs among different investment goals. Model results are limited to four economic indicators for this study, including total gross domestic product (GDP) growth rate, agricultural GDP growth rate, non-agricultural GDP growth rate, and poverty rate.

The base simulation is considered a "business as usual" simulation, and predicts future conditions if current practices remain unchanged, with no additional infrastructure investments or major policy changes. Its parameters stay within the confines of historical growth rates and utilize mean climate-yield factors for each year. Subsequently, a smooth growth trend occurs over the 12-year (2003 – 2015) simulation.

The irrigation simulation is similar to the base run framework, with the addition of implementing the Irrigation Development Program of the Water Sector Development Plan (WSDP 2002), constructed by the Ethiopian Ministry of Water. Approximately 200,000 hectares of crop area are currently being irrigated in Ethiopia, accounting for just over two percent of all cropland. The new program details the addition of 274,000 hectares of irrigated cropland, more than doubling the current investment. Just under one-half (46 percent) of the newly irrigated crops will be devoted to small-scale projects, and the remainder to large and medium-scale projects. One-half of the newly irrigated cropland is assumed to be cereal crops, and one-half cash crops.

The roads simulation models transportation plans, as drawn up by the Ethiopian government. The goal is to improve road conditions, reduce transportation costs, and increase farmers' accessibility to major markets. Ethiopia's road network currently consists of approximately 3,800 kilometers of paved road and 29,000 kilometers of unpaved, gravel or earth roads. This density is reportedly below the all-African average, and results in 70 percent of all farmers not being within a one-half day's walk of a paved road. The Ethiopian Government's 10-year Road Sector Development Program (RSDP, 1997-2007) includes creating new roads and maintaining existing ones. The first half of the Program (1997-2002) focused on rehabilitating the existing road network with only modest amounts of new road, and was substantially successful. The second half of the program also has a rehabilitation component, but aims to increase the road network by 5,000 to 8,000 kilometers of all types of road. Road construction costs in Ethiopia are highly variable and relatively unknown, due to the extreme terrain and torrential rains. For the purpose of a roads simulation, two fundamental principles are utilized as a surrogate to reflect this infrastructure improvement. The first is to gradually lower the marketing margins between producers and consumers and between surplus and deficit regions over the 12 years, and the second is to increase the productivity of the service sector, also gradually over the same time frame.

The final simulation incorporates irrigation and road investments simultaneously into the model. Both plans, as previously described, are implemented in full, and the simulation reaps the benefits of both. As one might expect, this produces a positive feedback between the agriculture sector and the market/infrastructure sector, improving the potential for positive results. This simulation, as do the previous three, utilizes mean climate-yield factors for all 12 projection years.

5. METHODS FOR CLIMATE MODIFICATIONS IN THE MODEL

The crux of this study lies in exploring the ramifications of including actual variable climate in the agro-economic model. By solely utilizing climate means, year-to-year changes and extreme events are not reproduced or represented explicitly in the model. Alternatively, if the model is run stochastically, an ensemble of potential outcomes is produced. This section outlines appropriate changes to the CYF, the manner in which climate variability is added to the model, and a brief sensitivity analysis exposing the implications of these changes.

FLOOD FACTORS

It is evident from the historical climate record that droughts are not rare, and can be detrimental to agriculture in Ethiopia. But climate extremes in the other direction, an excess of water, are also apparent, and can equally devastate agricultural production and existing infrastructure. Too much precipitation can flood crops, rot or suffocate roots, wash out roads, and instigate an economic situation not entirely different than during drought conditions. The CYFs based on FAO recommendations appropriately model drought conditions, but do not consider conditions when excessive water is applied. Essentially, for an extreme flood event, the respective CYF will still be 1, predicting a full yield due to water considerations. It is imaginable, though, that for excessive water conditions, the CYF should indeed be reduced to values less than 1, causing the model to forecast reductions in economic production.

Literature tends to support the notion of reducing yields of rain-fed crops during flood conditions. Several factors are involved in determining the severity of crop loss, including the timing of flooding during the crop's life cycle, the frequency and duration of flooding, and the air-soil temperatures during flooding (Belford et al. 1985). Lauer (2004) reports damage to maize yields in Wisconsin due to heavy rains causing flooding and ponding in many fields; the impacts to maize growth and development are evident even from short periods of flooding. Lauer also points out that early flooding (a wet spring) may subject plants to greater injury later during a dry summer due to insufficiently developed root systems which are not able to contact available subsoil water. Precipitation/irrigation vs. crop yield curves (Linsley 1992) indicate varying degrees of crop yield losses, dependent upon crop type and location; in all cases, though, yields decrease when applied water is above a threshold value.

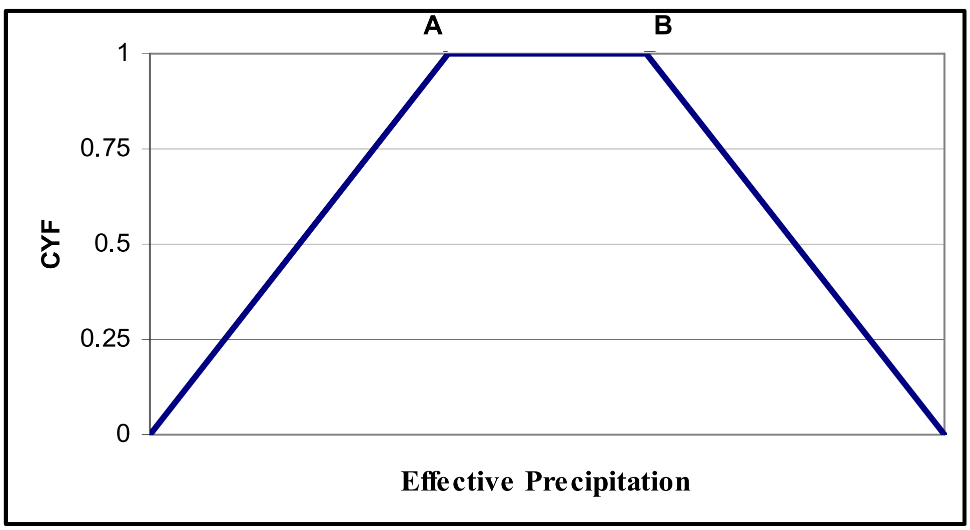
The following combined drought – flood condition occurred in Ethiopia in 1997, as reported on the Famine Early Warning System (FAO 2004):

> ETHIOPIA (1 December) 1997:
> The reduction in production is primarily the result of poor Belg [spring] rains and late, low and erratic rainfall during the Meher [summer] growing season, particularly in lowland areas, exacerbated by unusually heavy rains at harvest time.

To address these issues, a flood factor was developed to appropriately reduce CYF values.

Many of the agricultural, non-agricultural and livestock production terms in the model behave in a similar fashion in response to the quantity of precipitation received. Non-agricultural production and livestock production, specifically for commodities produced in Ethiopia, continue to grow as precipitation levels increase, to an extent; like agricultural production, though, it is also easily imaginable that too much water could tend to cause a loss in infrastructure, and a slowing or reduction in non-agricultural and livestock production. Figure 1 presents a general sketch of the relationship between the climate-yield factor (CYF) and effective precipitation.

Figure 1--General relationship between CYF and effective precipitation



A similar pattern could also be expected for non-agricultural and livestock production. Below point A, more effective precipitation returns a greater yield per crop area. Point A represents a climate-yield factor of 1.0, or the maximum amount achievable. Between points A and B, more effective precipitation produces no more yield, but neither is the yield reduced.

Finally, beyond point B, the effective precipitation has become more than the crop can sustain, and the yield drops. It is conceivable that if the effective precipitation is too large, no yield is possible, resulting in a CYF of 0. This sketch is for illustrative purposes only, and does not infer that the climate-yield factor and effective precipitation form a linear relationship. Rather, this relationship would be specific to each crop, to each climate, and to soil types and conditions, among other factors, and may take on a variety of shapes. Similar statements could be made concerning non-agricultural and livestock production. The figure shows a stylized relationship with an increasing section, a flatter section, and a decreasing section which holds for agricultural and non-agricultural commodities. It is this concept, with some variation, that is exemplified in the flood factor, detailed in the following sections.

Flood Factor – Agricultural Commodities

The flood factor (FF) is essentially a dynamic component that forces a decrease of the CYF if the year is deemed significantly wet, in terms of precipitation. The criterion includes examining the standard normal distribution variable z, for precipitation data, as defined in Equation 4,

$$z = FF = \frac{x - \mu}{\sigma} \tag{4}$$

where x is the observed (actual) monthly precipitation, μ is the mean monthly precipitation, and σ is the standard deviation of the monthly precipitation data, all for a given zone. The flood factor is calculated twice in the evaluation of flooding on agricultural commodities: once during the vegetative/flowering stage, and once during the harvest stage. The exact months of theses two stages are crop specific, but generally correspond with May through July for vegetative/ flowering and August through October for harvest, representing the times when the crop is most vulnerable to flooding, and when the yield is most likely to be shocked negatively. The largest FF value for each of these two crop stages of each year is retained for evaluation. The magnitude of the FF, and its corresponding probabilistic chance of occurring, determines the extent to which the climate-yield factors are affected through a series of CYF reduction equations (not included.)

Flood Factor – Livestock and non-Agricultural Commodities

Livestock and non-agricultural production also exhibit a negative impact from high precipitation and floods, due to damage to infrastructure and linkages to agricultural goods. The same process has been adopted as for the agricultural commodities, taking advantage of the standard normal distribution variable, Equation 4. In this case, though, only the largest FF value from the rainy season months, June through September, of each year is retained for evaluation. This reduction is especially crucial to the road investment scheme, as significant flooding events may damage roads, and pose serious transportation problems.

Based on the aforementioned literature and other available guidelines (Salter, 1967), a very conservative approach has been undertaken in determining an appropriate FF. In no case is any commodity (agricultural or non-agricultural) reduced for a FF less than one standard deviation above the mean. This is essentially analogous to a probabilistic occurrence of less than once in about 6.5 years. Other rubrics are even more conservative. The reasoning for this approach stems from the notion of limited available specific data for varying Ethiopian crops and regions.

A water balance model of soil moisture in a region of the Ethiopian highlands was assessed for comparison with FF occurrence, as prescribed by the rubrics. In general, the average soil condition for a month was at or above full saturation more than twice as often as FFs occurred. Again, this promotes a very conservative estimate, and may well be underestimating the potentially negative effects of flooding conditions on crops.

NEW CLIMATE YIELD FACTORS (CYF) FOR CASH CROPS

In the original model, cash crops, which account for approximately 30 percent of all cultivated lands, were assigned a CYF of 1, leaving them unaffected by climate. New codes were not written to address each cash crop's individual requirements, but rather all cash crops in a zone were assigned a CYF value equal to the maximum cereal crop CYF in that same zone in each year of the simulation. Although this is not a perfect estimation of cash crop CYFs, it does more closely represent an appropriate value based on climate fluctuations, and emphasizes the advantages of irrigated cash crops over rain-fed crops.

INCLUSION OF CLIMATE MODIFICATIONS IN THE MODEL

To include climate modifications and additions, the model was revised to dynamically input a new set of cereal and cash crop CYFs for each year. With the 100 years of available CYF data, nine different 12-year combinations were formed: 1900-1912, 1913-1924, 1925-1936, 1937-1948, 1949-1960, 1961-1972, 1973-1984, 1985-1996, and 1989-2000, representing actual, chronological sets to cover the 100-year span. All 12-year combinations start from the same base year, 2003, for ease of comparison. Each set is run through each simulation (base, irrigation, roads, and irrigation and roads combination) to provide nine sets of results per simulation. These ensembles do not encompass all possibilities, of course, and admittedly correspond to a stylized stochastic process, as opposed to other approaches that generate ensembles using a random or weighting scheme for assimilating months (Prairie et al. 2000), but do offer good insights into the variability and its response on the economy. Additionally, the ensemble may also be compared with historical data and trends, as available in literature.

MODEL SENSITIVITY TO MODIFICATIONS

The modifications and additions to the climate aspect of the model discussed in the previous sections have varying effects on model predictions. Each aspect was evaluated individually to determine its sensitivity on the model. The following sections outline the sensitivity to the implementation of climate variability through dynamic CYFs, and the addition of the flood factor.

Dynamic Climate-Yield Factors

The first portion of the sensitivity analysis involves a comparison of model predictions incorporating mean versus dynamic climate-yield factors. Resulting economic indicators for the base simulation are tabulated in Table 3. Due to their similarity in nature, the irrigation, roads, and irrigation and roads combination simulations are not presented. Table 2 provides necessary terms and abbreviations.

Table 2--Abbreviations of terms

Abbreviation	Actual Term
Means	100-year mean
GDP	gross domestic product
AgGDP	agricultural gross domestic product
NAgGDP	non-agricultural gross domestic product
Irri	Irrigation
FF	flood factor

Table 3-- Base simulation: Economic indicator sensitivity of mean versus dynamic CYF

Simulation - Base					% Difference
		Means of	Range of Var.		Means and
Economic Indicator	Means	Variability*	Min	Max	Means of Var.
GDP growth rate	2.82	2.79	2.34	3.03	-0.9%
Ag GDP growth rate	2.44	2.38	1.61	2.80	-2.2%
NAg GDP growth rate	3.32	3.33	3.25	3.39	0.1%
Poverty rate in 2003 (%)	41.55	41.55	-	-	-
Poverty rate by 2015 (%)	42.98	44.96	40.59	52.22	2.0%

*Mean of Nine-12-year sets

In this comparison, only the initial and final values, from the first and twelfth year, respectively, are utilized. The variability within the 12 years is not addressed here. The Means column utilizes the original 100-year mean climate data, while the Means of Variability column is the average of the nine individual 12-year runs, which incorporate the dynamic CYF. The Range of Variability column simply provides maximum and minimum values from the nine individual sets. Percent differences for relevant economic predictors are also included.

It is interesting to note the convergence of the Means of Variability values to the Mean values. This is both expected and desired, and is true in all simulations. Due to the linearity of the FAO's model in determining CYFs, as outlined earlier, such that CYFs continue to rise toward or remain at 1 as precipitation quantities increase, the Means of Variability should align with the Means. Given enough 12-year sets to run through the model, the Means of Variability will eventually converge to the Mean values. The values for the irrigation, roads, and irrigation and roads simulations obviously differ from those in the base case, as they provide for a better state of welfare for Ethiopia, but nonetheless converge to their respective Mean values. Each variable CYF outcome, though, may defer substantially from the mean CYF outcome.

Flood Factors

For the second part of the sensitivity analysis, the flood factors are introduced. This allows for a comparison of the CYFs both with and without FFs, indicating the implications of including flooding in the model. The results for each of the four simulations are presented in Tables 4 – 7. The Means column is representative of CYFs without FFs, due to the nature of the flood factor equation.

Table 4--Base simulation: CYF with and without flood factors economic indicator comparison

Simulation - Base w FF					% Difference
		Means of	Range of Var.		Means and
Economic Indicator	Means	Variability	Min	Max	Means of Var.
GDP growth rate	2.82	1.78	1.23	2.32	-36.9%
Ag GDP growth rate	2.44	1.47	0.58	2.06	-39.4%
NAg GDP growth rate	3.32	2.17	0.68	2.71	-34.8%
Poverty rate in 2003 (%)	41.55	41.55	-	-	-
Poverty rate by 2015 (%)	42.98	54.77	46.82	65.52	11.8%

* Mean of Nine-12-year sets

Table 5--Irrigation simulation: CYF with and without flood factors economic indicator comparison

Simulation - Irri w FF					% Difference
		Means of	Range of Var.		Means and
Economic Indicator	Means	Variability	Min	Max	Means of Var.
GDP growth rate	4.58	3.66	3.22	4.12	-20.0%
Ag GDP growth rate	4.96	4.21	3.56	4.65	-15.2%
NAg GDP growth rate	4.02	2.85	1.36	3.39	-29.2%
Poverty rate in 2003 (%)	41.55	41.55	-	-	-
Poverty rate by 2015 (%)	36.45	47.62	40.04	58.07	11.2%

* Mean of Nine-12-year sets

Table 6--Roads simulation: CYF with and without flood factors economic indicator comparison

Simulation - Roads w FF					% Difference
		Means of	Range of Var.		Means and
Economic Indicator	Means	Variability	Min	Max	Means of Var.
GDP growth rate	4.29	3.22	2.64	3.75	-24.9%
Ag GDP growth rate	2.60	1.63	0.73	2.22	-37.2%
NAg GDP growth rate	6.21	5.02	3.52	5.57	-19.1%
Poverty rate in 2003 (%)	41.55	41.55	-	-	-
Poverty rate by 2015 (%)	37.04	49.27	40.95	60.84	12.2%

* Mean of Nine-12-year sets

Table 7--Irri/roads simulation: CYF with and without flood factors economic indicator comparison

Simulation -Irri/Rds w FF					% Difference
		Means of	Range of Var.		Means and
Economic Indicator	Means	Variability	Min	Max	Means of Var.
GDP growth rate	5.59	4.64	4.13	5.10	-17.0%
Ag GDP growth rate	5.12	4.36	3.71	4.80	-14.8%
NAg GDP growth rate	6.19	4.99	3.50	5.53	-19.4%
Poverty rate in 2003 (%)	41.55	41.55	-	-	-
Poverty rate by 2015 (%)	32.24	43.58	35.39	54.88	11.3%

* Mean of Nine-12-year sets

Not surprisingly, the Means with Variability for the new CYFs with FFs indicate a substantial decline in the welfare of the country. Flood factors, of course, instigate only negative shocks to the economy, and often create situations from which the country may not be able to rebound within the 12-year simulation. The timing of these flooding events, whether early or late in the 12-year simulation, also plays a significant role. All simulations, therefore, present serious declines when FFs are introduced, each responding in a slightly different manner. Agricultural reductions are more prevalent in the roads simulation, while non-agricultural declines dominate the irrigation simulation. The base simulation is the most deeply effected, while the irrigation/roads simulation drops the least, as expected.

These declining trends, due to the addition of the FF, are in general agreement with historical evidence. Two examples from the recent past include flooding in 1977 and 1996. Seasonl and/or crop stage precipitation over all of Ethiopia for both of these years is greater than one standard deviation above the mean, implying that reductions due to the FF result. According to the FAO's website for agricultural yields of cereals within Ethiopia, declines are evident in the year immediately following the flooding period. In 1977, a yield of 1,036 kg/Ha (kilograms/hectare) was reported; in 1978, 897 kg/Ha, and in 1979, 1,124 kg/Ha, indicating a rebound of yields. The percent decline from 1977 to 1978 was approximately 13 percent. Similarly, flooding in 1996 caused a reduction in yields, dropping from 1,263 kg/Ha in 1996 to 1,140 kg/Ha in 1997, a 10 percent drop. Additional untimely flooding in the following years even further reduced cereal yields until 2001, when they began to rebound. Non-agricultural commodities also dropped in similar fashion during these flooding periods, adding to the overall decline in economic welfare.

6. RESULTS OF MEAN CLIMATE (DETERMINISTIC) VERSUS VARIABLE CLIMATE (STOCHASTIC) MODELING

The sensitivity analysis brings a few key results to the forefront. The addition of climate variability, and the ensuing transformation to a stochastic model, may produce dissimilar results (GDP, poverty rate) compared to the deterministic model for any given run, but the average of all climate variability runs converges to the mean climate results. However, when the flood factor is introduced, the stochastic means no longer converge to the deterministic mean. The variability in the climate-yield factors, in general, does not directly produce this depression, but rather the effects of flooding. The outcomes of a deterministic approach are unaffected by flood factors, as the “observed” precipitation value is always equal to the mean value, resulting in all flood factors equal to zero. Contrarily, for the stochastic approach, flood factors are clearly evident, and reduce the state of the economy, occasionally more than once within a single simulation. If a flood occurs, then, within a simulation, it should be apparent that the economy will rarely return to an economic state equivalent to one for which no floods are accounted.

BASE SIMULATION

A comparison of the deterministic and stochastic approaches in the base simulation, including flood factors, is graphically depicted in Figures 2 and 3.

Figure 2--Base simulation: GDP variable climate sets with deterministic and stochastic means

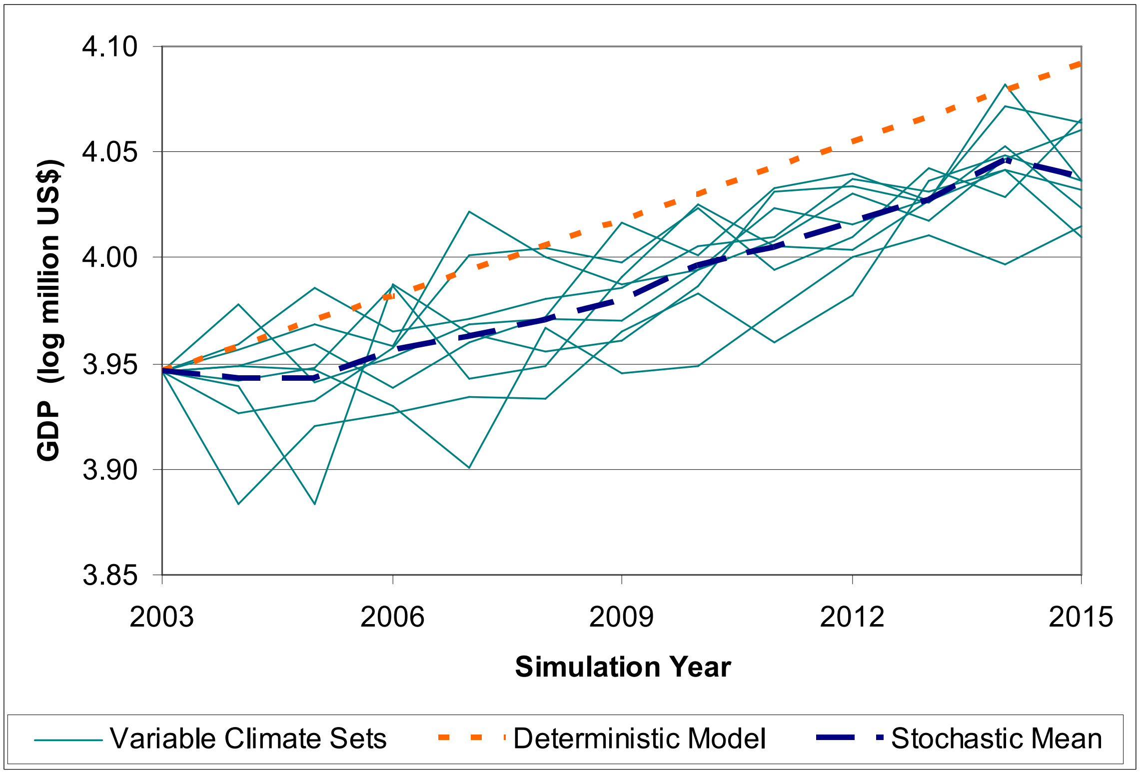
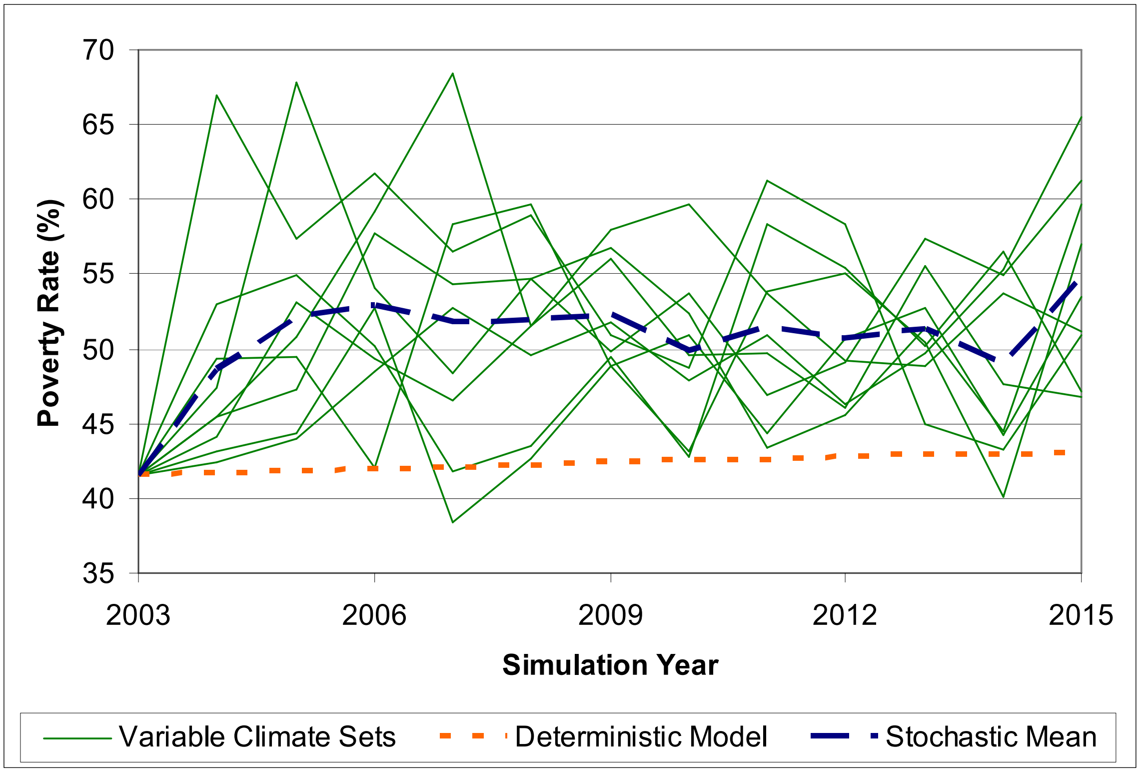


Figure 3--Base simulation: Poverty rate variable climate sets with deterministic and stochastic means



These figures portray the year-to-year fluctuations for GDP (*not* GDP growth rate) in billion US dollars, and poverty rate in percent for the nine variable climate sets; the deterministic result and stochastic mean are also illustrated. In the case of both GDP and poverty rate, the stochastic mean quickly departs from the deterministic line, indicating a lower economic welfare, but follows the same general trend over the 12 years. Even the vast majority of individual variable climate set points lie to one side of the deterministic line, signifying the difficulty in returning to a state of constant growth once a shock to the system has occurred.

INVESTMENT SIMULATIONS

The deterministic and stochastic approaches for the three investment strategies are also analyzed in a fashion similar to the base case. Tables 8 – 10 display a comparison of the two approaches and the nine variable climate set's end-year values, respectively. The values in these tables vary from those in Tables 5 – 7 due to additional model modifications not presented in this report.

Table 8--Irrigation simulation: Means and means of variability comparison

Simulation - Irrigation					% Difference
		Means of	Range of Var.		Means and
Economic Indicator	Means	Variability	Min	Max	Means of Var.
GDP growth rate	3.68	2.73	2.25	3.22	-25.9%
Ag GDP growth rate	3.95	3.13	2.39	3.62	-20.8%
NAg GDP growth rate	3.31	2.14	0.66	2.69	-35.2%
Poverty rate in 2003 (%)	41.55	41.55	-	-	-
Poverty rate by 2015 (%)	39.27	50.50	42.70	61.36	11.2%

Table 9-- Roads simulation: means and means of variability comparison

Simulation - Roads					% Difference
		Means of	Range of Var.		Means and
Economic Indicator	Means	Variability	Min	Max	Means of Var.
GDP growth rate	3.58	2.53	2.00	3.08	-29.4%
Ag GDP growth rate	2.60	1.64	0.75	2.22	-36.8%
NAg GDP growth rate	4.78	3.61	2.11	4.16	-24.5%
Poverty rate in 2003 (%)	41.55	41.55	-	-	-
Poverty rate by 2015 (%)	39.82	51.71	43.37	62.96	11.9%

Table 10--Irrigation/roads simulation: means and means of variability comparison

Simulation - Irri/Roads					% Difference
		Means of	Range of Var.		Means and
Economic Indicator	Means	Variability	Min	Max	Means of Var.
GDP growth rate	4.40	3.43	2.95	3.92	-22.2%
Ag GDP growth rate	4.13	3.29	2.56	3.78	-20.2%
NAg GDP growth rate	4.77	3.59	2.09	4.14	-24.9%
Poverty rate in 2003 (%)	41.55	41.55	-	-	-
Poverty rate by 2015 (%)	36.15	47.74	39.77	58.77	11.6%

In contrast to the base case, both the Means and Means of Variability for the investment simulations have increased due to the growth of irrigated agriculture, better transportation and easier flow of commodities to and from markets, or a combination of the two.

Plots for GDP and poverty rate under the investment simulations appear similar to Figures 2 and 3 for the base case, excepting a generally larger increase for GDP and a lessening of the poverty rate over the 12-year timeframe. Values in 2015, the final year of the simulation, are tabulated in Table 11.

Table 11--Investment simulations: GDP and poverty rates in 2015

	GDP	*(Values in 2015)*		*Poverty Rate*		
		Range of Var. Clim.			Range of Var. Clim.	
Investment	Means	Min	Max	Means	Min	Max
Irrigation	4.13	4.06	4.11	39.3	42.7	61.4
Roads	4.13	4.05	4.10	39.8	43.4	63.0
Combination	4.17	4.10	4.15	36.2	39.8	58.9

As in previous tables, Means refers to the deterministic model; Range of Var. Clim. represents the span of values in the final year from all stocahstic runs. The economic indicators for the roads strategy appear to be nearly on par with the irrigation indicators, showing signs of being only slightly less effective in boosting the Ethiopian economy. As expected, the welfare of the country is at its best under the combination strategy; nonetheless, serious discrepancies still exist between the deterministic means and ranges of variability, although to a lesser degree than for the previous strategies considered.

This analysis underscores the fact that predictions of economic conditions are overestimated when yearly climate variability and flood factors are unaccounted for. The ramifications of this may be severe, as an unexpected decline in the economy is often much more difficult to address than a surprise upswing. The addition of climate variability in the model aids in more sensible predictions and provides a framework, including realistic ranges of economic values, from which Ethiopian planners may make strategic decisions, as discussed in the following section.

RISK ASSESSMENT OF INVESTMENT STRATEGIES

The inclusion of climate variability has the advantage of not only supplying more realistic economic predictions, but also the ability to give some sense of probabilistic risk as well through a stochastic analysis. No investment strategy can ensure economic success, so it is the probabilistic chance of the economy falling within some acceptable range of economic values for a given investment strategy that becomes of interest.

Probability density functions (PDF), assuming normal distribution, for GDP and poverty rates are included in Figures 4 and 5, respectively, under the irrigation investment strategy.

Figure 4—Irrigation simulation: PDF of GDP for 2015

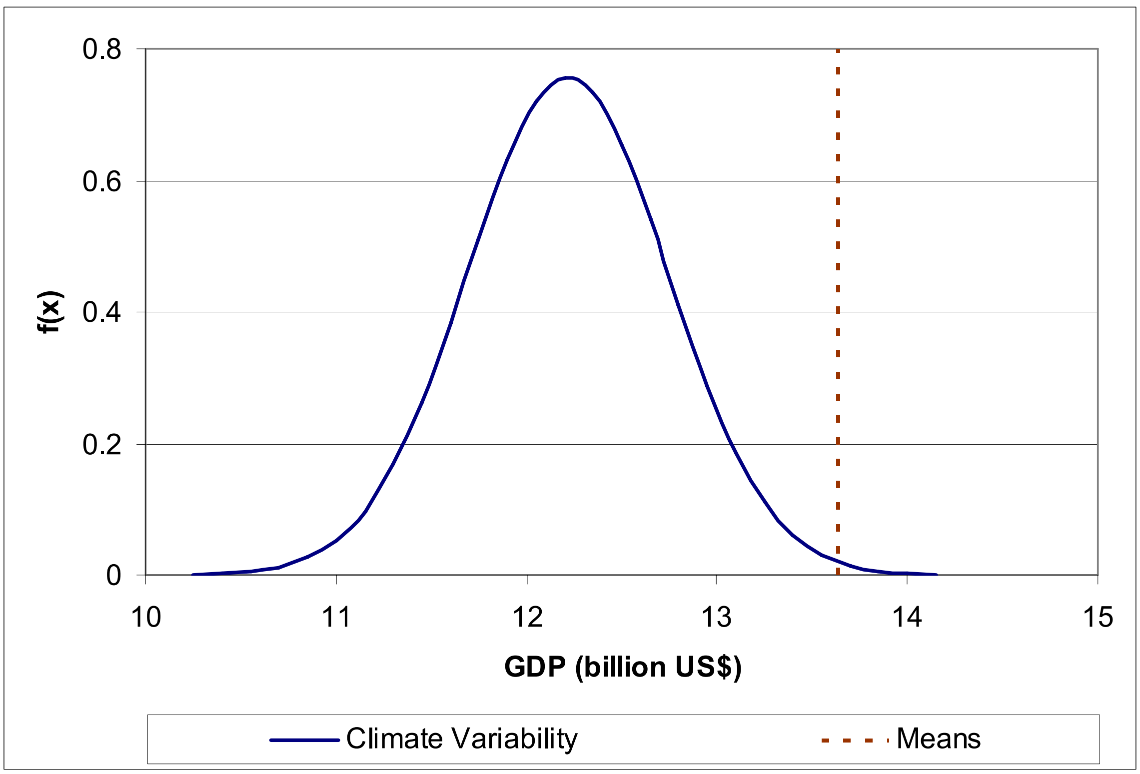
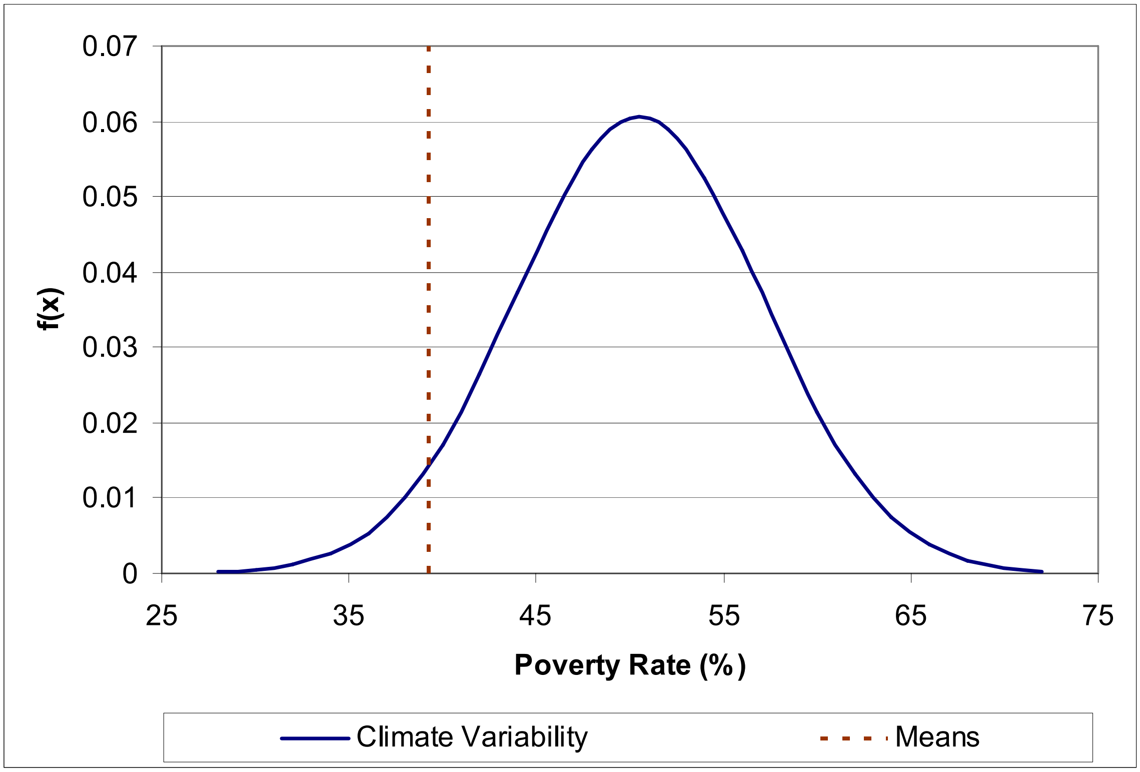


Figure 5--Irrigation simulation: PDF of poverty rate for 2015



The function gives an indication of the probability of a given GDP or poverty rate value occurring in the last year of any variable climate run. The value in the final year from the deterministic approach has also been included as a spike. The figures again give credence to the notion that the deterministic approach is an overestimation of the GDP and an underestimation of the poverty rate at the end of the simulation time period. Plots for the road and combination investments are quite similar and therefore not included here.

The probability of reaching the spike, according to the PDF for the irrigation simulation, is very small: less than 0.4 percent in the GDP case, and just over 4 percent in the poverty case. Assuming this to be true, this implies that if the deterministic approach is used for policy, the predicted GDP will only be attained, on average, approximately once in every 250 years. Similar probabilities result in the road simulation. The PDF of GDP for the combination simulation, though, is shifted further away from the origin, with the mean approximately one billion US dollars greater than for the irrigation scheme. The poverty rate PDF is shifted toward the origin, with the difference in means between the combination strategy and the irrigation strategy at approximately 2.75 percent, translating to almost 2 million people.

An assessment of risk levels for planning purposes naturally flows from the PDF. Table 12 demonstrates sample risk levels and associated GDP and poverty rates for the combination approach.

Table 12--Irrigation/roads simulation: Risk levels for GDP and poverty rate

Irrigation/Roads Simulation for Variable Climate			
Risk Levels for GDP (billion US$)		Risk Levels for Poverty Rate (%)	
μ=13.25	σ=0.579	μ=47.74	σ=6.711
Level of Risk	Associated GDP	Level of Risk	Associated Poverty Rate
50%	13.25	50%	47.74
25%	12.86	25%	52.24
10%	12.51	10%	56.33
1%	11.90	1%	63.38

7. SUMMARY AND DISCUSSION

This research highlights a few important modeling aspects beyond determining which investment strategy may provide the best outlook for Ethiopia's future economy. Average climate parameters, as utilized in the deterministic model, can underestimate the negative effects of climate variability, and do not clearly represent the difficulties in recovering from extreme climate events. Stochastic modeling, with the inclusion of climate variability, helps to alleviate these issues, and appears to be essential and warranted when modeling investment in sectors that are responsive to climate extremes. In the deterministic model, drought effects are modeled appropriately (although partially negated by utilizing average climate parameters), but flood factors, or a reduction in production due to excessive precipitation, are ignored. The inclusion of flood factors in this study not only represents the expected decline in agricultural yields, but also damage to roads and infrastructure, which further perpetuates the decline in agricultural production, trade and other non-agricultural activities. Failure to include flood factors may well result in misleading insights and overestimation of the welfare of the economy. Another benefit of the stochastic approach is the ability to analyze the results from a probabilistic standpoint. This in turn allows for policy decisions to be made and presented in a risk-based frame work.

Table 13 demonstrates expected growth from investments based on GDP growth rates (similar to returns on the investment with the exclusion of costs.)

Table 13--Summary comparison of deterministic vs. stochastic models

Investment Strategy	Growth from Investment	
Irrigation	Deterministic	Stochastic
GDP growth rate	30.5%	53.4%
Ag GDP growth rate	61.9%	112.9%
NAg GDP growth rate	-0.3%	-1.4%
Roads		
GDP growth rate	27.0%	42.1%
Ag GDP growth rate	6.6%	11.6%
NAg GDP growth rate	44.0%	66.4%
Irri & Roads		
GDP growth rate	56.0%	92.7%
Ag GDP growth rate	69.3%	123.8%
NAg GDP growth rate	43.7%	65.4%

In all cases, the percent differences for GDP growth rates between the base case and each investment strategy are greater for the stochastic approach than for the deterministic approach. This is a direct result of adding climate variability and flood factors to the model. The GDP growth rates in the base case, especially for agriculture, are significantly less for the stochastic approach than for the deterministic approach; therefore greater percent difference values for the stochastic results can be expected for a given investment. Clearly, an overall positive growth is expected for any investment, as costs are neglected, but the stochastic approach tends to predict additional growth due to the more realistic prediction of the base case, which is further depressed when climate extremes are included. The table also indicates little similarity in sector response between irrigation and roads investments; the irrigation investment is completely manifested in the agricultural sector, while the roads investment is predominantly driven by the non-agricultural sector, but allows for some agricultural feedbacks.

Overall, as demonstrated in this study, the irrigation investment strategy tends to fare slightly better than the roads investment strategy from a benefit perspective. This is due in part to the fact that additional irrigation has particularly strong impacts on reducing the negative effects on production and farm income of drought. Since drought has a persistent impact on income and food security, prevention or reduction in severity of drought has long term benefits. It is also worthwhile to note that the combination strategy of both irrigation and roads is approximately the sum of the two individual strategies, for both the deterministic and stochastic models, indicating a sense of linearity.

Potential future extensions of this work are numerous. One area for development includes completing more model runs to extend the stochastic ensemble. Additional runs need not be in chronological order, but could follow traditional *K-nearest neighbor* techniques to generate plausible 12-year segments (Prairie, et al. 2000.) The broader ensemble would provide more confidence in accurate PDF and risk assessment levels. A second avenue for future work involves incorporating costs into the agro-economic model, and formulating a true investment analysis considering returns. Ultimately this step will be necessary prior to development of final investment policies in Ethiopia.

APPENDIX I: EQUATIONS IN THE SPATIAL, MULTI-MARKET MODEL OF ETHIOPIA AGRICULTURE

DEMAND FUNCTIONS:

(Zonal level per capita)

$$Dpc_{R,Z,i,t} = \prod_j PC_{R,Z,j,t}^{\varepsilon_{R,Z,j}} GDPpc_{R,Z,t}^{1-\sum_j \varepsilon_{R,Z,j}}$$

Where $Dpc_{R,Z,i}$ is per capita demand for commodity *i* in region *R* and zone *Z*, and $PC_{R,Z,i}$ is consumer price for *i* in region *R* and zone *Z*. j = 1,2,…,36 (including two aggregate nonagricultural goods.) $GDPpc_{R,Z}$ is per capita agricultural and nonagricultural income for region *R* and zone *Z*.

SUPPLY FUNCTIONS:

Yield function (for crops)

$$Y_{R,Z,i,t} = \mathrm{YA}_{\mathrm{R,Z,i,t}} P_{R,Z,i,t}^{\alpha_{R,Z,i}}$$

Where $Y_{R,Z,i}$ is the yield for crop *i* and $P_{R,Z,i}$ is producer price for *i*; $\mathrm{YA}_{\mathrm{R,Z,i}}$ is the shift parameter, which depends on climate-yield factor coefficient derived from 100 years' monthly climate data at zonal level, fertilizer and other input use, and time trend growth rate (varies by zone). For irrigated crops, $\mathrm{YA}_{\mathrm{R,Z,i}}$ does not depend on climate-yield factor and is 50 percent higher than $\mathrm{YA}_{\mathrm{R,Z,i}}$ for the same crops depending on rainfall only.

At this moment, only climate-yield factor coefficients have been developed, and the estimation of other coefficients (for fertilizer and other input use) are in progress. If we choose the mean value of climate-yield factor, the shift coefficient in yield function looks like:

$$\mathrm{YA}_{R,Z,i,t+1} = Kc_{R,Z,i,t+1} \cdot \mathrm{YA}_{\mathrm{R,Z,i,t}}\left(1 + g_{Y_{R,Z,i}}\right)$$

Where *Kc* is mean value of climate-yield factor coefficient with value between 0.5 and 1.0. 1.0 implies that on average there is no shortage in rainfall affecting the yield, and when the coefficient is less than 0.5, the crop fails to grow. *Kc* varies by crops, depending on the drought-tolerant ability of a specific crop and suitability of the climate condition (which varies by zone). g_Y is annual growth rate in yield productivity and varies by zone and crop.

Area function (for crops)

$$A_{R,Z,i,t} = \mathrm{AA}_{\mathrm{R,Z,i,t}} \prod\nolimits_j P_{R,Z,j,t}^{\beta_{R,Z,j}}$$

Where $A_{R,Z,i}$ is the yield for crop i and P_1, P_2, … P_J, is the vector of producer prices; AA is the shift parameter (the trend in area).

Trends in area function:

$$\mathrm{AA}_{R,Z,i,t+1} = \mathrm{AA}_{\mathrm{R,Z,i,t}} \left(1 + g_{A_{R,Z,i}}\right)$$

Where g_A is annual growth rate in area expansion and varies by zone and crop.

Total supply of crops

$$S_{R,Z,i,t} = Y_{R,Z,i,t} \cdot A_{R,Z,i,t}$$

Supply function for livestock and nonagriculture

$$S_{R,Z,i,t}^{LV} = \mathrm{SA}_{\mathrm{R,Z,i,t}}^{\mathrm{LV}} \prod\nolimits_j P_{R,Z,j,t}^{\beta_{R,Z,j}^{LV}}$$

Trends in livestock and nonagricultural supply function

$$\mathrm{SA}_{\mathrm{R,Z,i,t+1}}^{\mathrm{LV}} = \mathrm{SA}_{\mathrm{R,Z,i,t}}^{\mathrm{LV}} \left(1 + g_{S_{R,Z,i}}\right)$$

Where g_S is annual growth rate in productivity and varies by zone and commodity.

g_Y, g_A, and g_S are exogenous variables in the model and are affected by the investment shocks in the scenarios.

RELATIONSHIP BETWEEN PRODUCER AND CONSUMER PRICES

We assume that there are domestic market margins between import parity prices and consumer prices, which is defined by zone; and export parity prices and producer prices, defined also by zone. Moreover, within the country, due to difference in food deficit or surplus, and different distances to the national major market centers, there are price gaps cross regions. To simplify the model, we assume that Addis Ababa is the only market center and the traveling time from Addis Ababa is used as proxy for domestic marketing costs (marking margins). Specifically, we define import/export parity prices as the prices in Addis Ababa markets (if tradable), such that

Import parity prices:

$$PC_{i,t}^{Addis} = \left(1 + Wmargin_i\right) \cdot PWM_i$$

where *Wmargin* is the marketing margins between CIF prices and Addis Ababa consumer prices. If commodity *i* importable, this equation holds. Consumer's prices in the other zones with food surplus are:

$$PC_{R,Z,i,t} = \left(1 - Dgap_{R,Z,i}\right) \cdot PC_{i,t}^{Addis}$$

and consumer's prices in the other zones with food deficit or balanced food are:

$$PC_{R,Z,i,t} = \left(1 + Dgap_{R,Z,i}\right) \cdot PC_{i,t}^{Addis}$$

Where *Dgap* is domestic price gap between consumer prices in Addis Ababa and in other regions and such gap varies by zone according to the distance to Addis Ababa. In general, for food surplus regions, producer prices are lower than that in Addis Ababa, while in food deficit or balanced regions, consumer prices are higher than that in Addis Ababa.

Export parity prices:

$$P_{i,t}^{Addis} = \left(1 - Wm\arg in_i\right)\cdot PWE_i$$

where P is producer prices and PWE is the FOB prices and the equation holds only when commodity i is exportable. There is marketing margins between producer and consumer prices, i.e.,

$$PC_{i,t}^{Addis} = \left(1 + Dm\arg in_i^{Addis}\right)\cdot P_{i,t}^{Addis}$$

and similarly for other zones:

$$PC_{R,Z,i,t} = \left(1 + Dm\arg in_{R,Z,i}\right)\cdot P_{R,Z,i,t}$$

Where *Dmargin* is domestic marketing margins between producer and consumer prices and varies according to distances to Addis Ababa.

EXPORTS AND IMPORTS

Trade (either exports or imports) is determined by the difference between Addis Ababa's prices and import/export parity prices, i.e., if

$$P_{i,t}^{Addis} = \left(1 - Wm\arg in_i\right)\cdot PWE_i;\ E_{i,t} > 0,$$

E_i is exports of commodity i; if

$$PC_{i,t}^{Addis} = \left(1 + Wm\arg in_i\right)\cdot PWM_i;\ M_{i,t} > 0,$$

M_i is imports of commodity i; if

$$PC_{i,t}^{Addis} < \left(1 + Wm\arg in_i\right)\cdot PWM_i \text{ or } P_{i,t}^{Addis} > \left(1 - Wm\arg in_i\right)\cdot PWE_i$$

both E_i and M_i are zone and commodity i is in autarky.

REGIONAL CROP DEFICIT AND SURPLUS

The model can identify which zones are food crop deficit or surplus, but cannot identify trade flows among the zones. That is, total deficit and surplus are cleared (balanced) at the national market and there is no regional market. A regional food crop *i*'s deficit/surplus is defined as

$$DEF_{R,Z,i,t} = Dpc_{R,Z,i,t} \cdot PoP_{R,Z,t} - S_{R,Z,i,t}$$

Positive means deficit.

BALANCE OF DEMAND AND SUPPLY AT THE NATIONAL LEVEL

$$\sum_{R,Z} S_{R,Z,i,t} + M_{i,t} - E_{i,t} = \sum_{R,Z} Dpc_{R,Z,i,t} \cdot PoP_{R,Z}$$

GDP AND PER CAPITA ZONAL INCOME FUNCTION

$$GDP_{R,Z,t} = \sum_j P_{R,Z,j,t} \cdot S_{R,Z,j,t} \;\; j = 1,2,\ldots,36 \text{ (including nonagriculture)}$$

Income per capita:

$$GDPpc_{R,Z,t} = \frac{GDP_{R,Z,t}}{PoP_{R,Z,t}}$$

REFERENCES

Bedient, P. B., and W. C. Hubert. 2002. *Hydrology and floodplain analysis*. 3rd Edition. Upper Saddle River, N.J.: Prentice Hall.

Belford, R. K., R. Q. Cannell, and R. J. Thompson. 1985. Effects of single and multiple water loggings on the growth and yield of winter wheat on clay soil. *Journal of Science and Food Agriculture* 36:142-156.

Benjamin, Jack R., and C. Allin Cornell. 1970. Probability, statistics, and decision for civil engineers. New York, N.Y.: McGraw-Hill Book Company.

Block, P. and B. Rajagopalan. 2006. Interannual variability and ensemble forecast of Upper Blue Nile Basin Kiremt season precipitation." *Journal of Climatology.* In review.

Conway, D. Ethiopia: The warning signs of famine. BBC News, November 19, 2002.

CROPWAT, Version 4.3. Rome: Food and Agriculture Organization of the United Nations. DATE

Dalton, M.G. The welfare bias from omitting climatic variability in economic studies of global warming. *Journal of Environmental Economics and Management* 33: 221-239.

Diao, X. and A. Nin Pratt with M. Gautam, J. Keough, J. Chamberlin, L. You, D. Puetz, D. Resnick, and B. Yu. 2005. *Growth options and poverty reduction in Ethiopia, A spatial, economywide model analysis for 2004–15.* DSG Discussion Paper No. 20, Washington, D.C. International Food Policy Research Institute.

Dixon, Bruce L., and Kathleen Segerson. 1999. Impacts of Increased Climate Variability on the Profitability of Midwest Agriculture. *Journal of Agricultural and Applied Economics* 31: 537-549.

FAO. 1998. Crop Evapotranspiration: Guidelines for computing crop water requirements. fao irrigation and drainage. Paper No. 56. Rome: Food and Agriculture Organization of the United Nations (FAO).

FAO. 1984. Yield Response to Water. FAO Irrigation and Drainage Paper No. 33. Rome: FAO.

FAO/GIEWS. 2004. *Food and Agriculture in Ethiopia*. http://www.fao.org. Global Information and Early Warning System. Rome: FAO

Ferreyra, R. A., G. P. Podesta, C. D. Messina, D. Letson, J. Dardanelli, E. Guevara, and S. Meira. 2001. A linked-modeling framework to estimate maize production risk associated with ENSO-related climate variability in Argentina. *Agricultural and Forest Meteorology* 107: 177-192.

GAMS 2.0.26.8. 2004. General Algebraic Modeling System. Washington, D.C.

Hogg, R. V., and J. Ledolter. 1992. *Applied statistic for engineers and scientists*, 2nd Edition. New York: Macmillan Publishing Company.

Holland, W. R., S. Joussaume, and F. David. 1999. Modeling the earth's climate and its variability. Amsterdam, the Netherlands: Elsevier Science B.V.

Kane, S., J. Reilly, and J. Tobey. 1992. Climate change on world agriculture. *Climate Change* 21:17-35.

Lauer, J. 2004. Flooding impacts on corn growth and yield, *Wisconsin Crop Manager* 11 (12): 63-64.

Letson, D., G. Podesta, C. Messina, and A. Ferreyra. 2001. ENSO forecast value, variable climate and stochastic prices. American Agricultural Economics Annual Meeting Presentation. August 5-8, Chicago, Illinois.

Linsley, R., J. Franzini, D. Freyberg, and G. Tchobanoglous. 1992. Water-resources engineering, 4th Edition. New York, N.Y.: McGraw-Hill Inc.

Ludena, C. E., K. McNamara, P. A. Hammer, and K. Foster. 2003. Development of a stochastic Model to evaluate plant growers' enterprise budgets. American Agricultural Economics Annual Meeting Presentation. July 27-30, Montreal, Canada.

Mendelsohn, R., W.D. Nordhaus, and D. Shaw. 1994. The impact of global warming on agriculture: A Ricardian approach. *American Economics Review* 84: 753-771.

Mendelsohn, R., and J. Neuman. 1999. The impact of climate change of the United States economy. Cambridge, UK: Cambridge University Press.

Patt, A.G. 1999. Extreme outcomes: The strategic treatment of low probability events in scientific assessments. *Risk Decision and Policy* 4: 1-15.

Prairie, J., B. Rajagopalan, U. Lall and T. Fulp. A stochastic nonparametric technique for space-time disaggregation of streamflows. *Water Resources Research*. In review.

Rogers, C. 2004. *Development of a climate yield factor to assess climate-based risk to rainfed agriculture in Ethiopia: Description of methodology and results of Ethiopian climate data analysis.* Washington, D.C. International Food Policy Research Institute.

Rosegrant, M., X. Cai, and S. Cline. 2002. *World, water and food to 2025: Dealing with scarcity.* Washington, D.C.: International Food Policy Research Institute.

Salinger, M.J., R Desjardins, M.B. Jones, M.V.K. Sivakumar, N.D. Strommen, S. Veerasamy and Wu Lianhai. 1997. Climate variability, agriculture and forestry: An update. Technical Note No. 199. Geneva, Switzerland: World Meteorological Organization. http://www.wmo.ch/web/catalogue/New%20HTML/frame/engfil/841.html

Salter, P. J., and J.E. Goode. Crop responses to water at different stages of growth. Commonwealth Agricultural Bureaux, Farnham Royal, Bucks, England, 1967.

Taylor, R.G., and R.A. Young. 1995. Rural-to-urban water transfers: measuring direct foregone benefits of irrigation water under uncertain water supplies. *Journal of Agricultural and Resource Economics* 20: 247-262.

Valdivia, C., and R. Quiroz. 2003. Coping and adapting to increased climate variability in the Andes. American Agricultural Economics Annual Meeting Presentation. July 27-30, Montreal, Canada.

EPT DISCUSSION PAPERS

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