Working Paper

Addressing the issue of Uncertainty within the Egyptian agricultural sector

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Abstract

In this paper we use the static EASM model of the Egyptian agricultural sector and stochastic programming methodology to explore what level of uncertainty Egyptian decision makers presently perceive regarding the value of their produce on international markets. We also investigate how Egyptian cropping patterns might change in response to changing annual water availability and a changing perception of uncertainty.

Key words: Economics, environment, stochastic programming

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1. Introduction

There is an ever increasing need and awareness to manage the world's freshwater supply in an intelligent manner [Pos92], [Gle93], [BJS93]. The world population continues to show exponential growth, clearly giving rise to an increased use of water within many economic sectors. This increasing population will continue to require more and more productivity from the agriculture sector, while at the same time other sectors will also demand a portion of a relatively fixed annual water supply. Industry will continue to demand processing and cooling water (although potentially and hopefully at a smaller rate), while urban areas will require more and more water to meet the demands of the growing population. Even with water conserving strategies, new requirements are likely to cause a continual increase in water demands.

The agricultural sector is perhaps one of the most vulnerable with regards to these increased demands, especially within arid climates where there is a greater dependency on irrigation to grow crops. Egypt is a good example of the problems facing the agricultural sector around the world. Located in an arid climate, (annual average potential evapotranspiration and precipitation are 1700 and 26 mm/year respectively), Egypt's dependence on its sole water source, the Nile, is paramount [Sha85]. With an approximate 1993 population of 55 million and a growth rate of about 2.3% [BS92], wise decision making and management regarding the consumption of its approximate 55.5 milliards[1] of water is critical for Egypt. Currently most of the consumed[2] demand is in the form of evapotranspiration losses (approximately 60% of the 55.5 milliards) from the irrigation of agricultural commodities. Because the agricultural sector is such a large consumer of Egypt's water, it is felt that any work which tries to understand the agriculture sector can only help in improving the use of Egypt's limited water. Much has been written on ways in which Egypt can reduce consumed water use and still maintain a strong agricultural market [RoH94], [Bis91], [EGY86]. Often, this work centers around technological and managerial improvements or incentives such as improved irrigation technologies, better control of hydraulic structures, improved on farm management strategies, government intervention, the use of economic instruments, etc. One objective of this paper is to look at

[1]milliard 10^9 m^3

[2]Consumed losses are those that are lost to the atmosphere and can be counted as lost in the national water balance

the agricultural sector from a different angle, not by answering the common how or what kinds of questions, but by trying to address the question of why. Why does the current Egyptian agricultural sector appear the way it does? A second objective is to compare the solutions of a deterministic versus a stochastic model of the Egyptian agricultural sector under varying levels of annual water availability and to examine the differences in the results.

The question of why is addressed using a stochastic agricultural sector model of Egypt (adapted from the Egyptian Agricultural Sector Model, EASM) combined with a scenario analysis approach which applies a set of perceived and uncertain international markets. It is argued that the current perceptions of uncertainty (or lack thereof) with regards to the international market of agricultural commodities gives rise to the current national production of agricultural commodities within Egypt. By using a scenario approach, combined with uncertain international markets, market equilibrium can be achieved without applying non-agronomic constraints. But why go through the effort of modifying a deterministic model to produce a stochastic program?

There are definite advantages of using a stochastic instead of a deterministic approach. Deterministic models are forced to match observed equilibrium through hard constraints. Take for example the cotton sector. Often regarded as one of Egypt's strongest export crops, this commodity has continued to shown a decline over the past 15 years despite government attempts to maintain quotas through planting requirements[3] [FAO94]. If one applies a deterministic model, the only way of achieving the observed equilibrium based on present prices is to apply policy and import/export quantity constraints within the model [OHS92]. An analysis of the shadow prices on the base equilibrium is all that is needed to point to the fact that cotton production would rise significantly if the policy constraint were removed. A very intuitive result. If stochastic programming is used, these constraints can be removed and substituted with perceptions of the domestic value of cotton and its international marketability.

Normally there is great aspiration for a sectoral model such as the EASM. Given enough detail, it is hoped that the model can answer detailed questions about policy, development, cropping patterns, water allocation, etc. Often, however, results are suspect and little attention is given to the details. Models become platforms for discussion. Therefore it can be argued that large economic planning models are not created to give quantitative results, but are developed to help the decision makers ask questions and create a platform for dialogue. This is an additional advantage of the stochastic programming approach because it opens a new vector of questions that were hidden when only using a deterministic model.

This paper is an attempt to approach the issue of the Egyptian agricultural sector from a different perspective by:

1. Developing an alternative methodological approach to modeling the Egyptian agricultural sector using stochastic programming.

2. The creation of a set of scenarios within the stochastic model which give insight into the current perception of risk and uncertainty in the global market of agricultural

[3]The authors recognize that there is currently a free market reform within the agricultural sector of Egypt and a move away from required planting.

commodities and their implied economic value.

3. The removal of policy and import/export constraints and the use of the scenario approach to achieve market equilibrium and the reproduction of the observed, base year agricultural output.

2. Perceptions of Risk and Uncertainty within the Agricultural Market - Scenario Generation

What creates the general structure of an agricultural sector of a country? One decisive driving factor could be the comparative advantage offered by the climate of a region. This is observed in such places as Columbia which grows coffee, the state of Florida in the southeastern U.S. with an excellent climate for orchards, or Ghana with its dominant cocoa bean market to name a few. These regions have "put all their eggs in one basket" realizing that they are effective monopolies of the market and therefore have a great deal of control and power. Countries without this comparative advantage often focus on policies of food security and self sufficiency by broadly diversifying their crops. The make-up of these agricultural markets within this type of country are often dictated by the desire to minimize overall risks to the society, i.e. high food prices, famines, etc. Some agricultural policies (which often translate into water policies) seem far fetched, but given perceptions of uncertain futures might not be that ludicrous. Since we are focusing on Egypt we will mention two examples from the Middle East, Saudi Arabia and Libya. These countries agricultural policies are often regarded as "illogical", but if one addresses the issues of risk and uncertainty, it might be possible to answer why they have developed into their present form. Saudi Arabia, a rather harsh desert community which currently mines groundwater for food production, is wheat self sufficient in spite of the fact that the production costs are four times the international market price and are likely non-sustainable [Pos92]. To simply state this fact and argue that the Saudi policy is "wrong" is really not addressing the issues. Better questions might be; why do they have this current policy? What are the perceived risks and future scenarios that Saudi Arabia is hedging against? Are they trying to avoid being controlled by the major world food brokers of the west? Libya is a similar example. They have just completed the great man made river, costing them billions of dollars [Pos92], [Pea92]. They have effectively swapped oil for water; water which will be used to grow food crops that can be obtained on the world market for a fraction of the cost. Why are they desperate to achieve food self sufficiency? What possible futures are they perceiving and how are they hedging against the possible outcomes of these different scenarios?

Egypt is a country without a unique comparative advantage[4] and it appears that the present agricultural make-up of Egypt has been created over a long history of social and cultural conditions which are unique to this country. When one understands these components, it is possible to gain a better understanding of water use and agricultural

[4] It might be argued that cotton has been a crop of comparative advantage to Egypt; however the past few decades has shown a large reduction in Egyptian exports of cotton which indicates a loss in this comparative advantage.

form within this country. A brief, overall makeup of the Egyptian agricultural sector is given in order to show the development of various scenarios defined later in the paper. This is not meant to be a detailed synthesis. A majority of the Egyptian agriculture is made up of a large number of land tenants holding small amounts of land. These are often subsistence farmers trying to produce food for themselves as well as a basket of marketable commodities for sale on the local market. These farmers often own a few livestock such as buffalo, cattle, or goats. The Egyptian farmer highly values his small herds for meat and milk production. This is evident by simply observing the large amounts of animal fodder grown on valuable land and with valuable water[5] . At the same time, the government sector continually demands cotton production for national employment and export as well as sugarcane for use in labor intensive factories throughout the country. High valued cash crops such as winter fruits and vegetables are not produced with much efficiency and there appears to be a high degree of uncertainty with regards to their international marketability. Rice is grown in abundance in the northern portion of the Nile Delta, where it can be used advantageously to reclaim land and at the same time provide a valuable agricultural commodity. Maize is also grown for both human and animal consumption throughout Egypt, as are wheat and barley. Egypt's primary imports are grain crops (wheat, maize, etc.) which are often obtained below world market prices through low interest loans and/or food aid. Egypt has become highly dependent upon these food imports to meet a large and increasing portion of its food requirement. All this and more gives rise to the present agricultural practices within Egypt. These different elements are interpreted and combined to create the scenarios that are used within the stochastic program.

3. The deterministic Egyptian Agricultural Sector Model (EASM)

The EASM is a multi-market mathematical programming model of the Egyptian agricultural sector which represents technology by means of activity analysis. It is formulated as a partial-equilibrium model utilizing a quadratic objective function of consumer and producer surplus while maintaining a linear constraint set. The EASM simulates domestic production and demand, processing, and import supply and export demand using the "small country"[6] assumption. The EASM was first developed by Kutcher [Kut81] in the context of a UNDP funded, World Bank managed water resource master planning study aimed at rationalizing a proposed sequence of water resource investments. The motivation for this work centered around the concern that water availability would become a pressing concern to Egypt as it approached the 21st century. In this model, the agricultural lands of Egypt were broken into 15 aggregate canal command areas throughout the entire country of Egypt. Twenty five crops, along with their production possibilities were included in the model. Livestock was exogenous; specified as a fixed herd with a given feed requirement. In the early 1980's, Dr. Bayoumi Attia of the Ministry of Public

[5]Although it should be noted that there is no direct charge to the farmer for the use of water in Egypt.

[6]The small country assumption is that Egypt can import and export any quantity without affecting world market prices

Works and Water Resources reformulated the model in the GAMS (General Algebraic Modeling System; [BKM92]) language and reworked the model to include the three main zones in Egypt; Upper and Middle Egypt and the Nile Delta. These three zones were then mapped to 5 main physical regions of Egypt: Middle, Eastern, and Western Delta, Middle Egypt, and Upper Egypt. McCarl [MAQ89] directed a market liberalization study and issued a useful manual documenting the state of the EASM in 1989. Humphries and Attia [HuA91] updated the model, endogenizing the livestock herd and Strzepek, et. al [SOSY94] updated a portion of the data set and included the poultry market within the model, and reformulated the marketings costs and subsidy component. For this study the EASM has been simplified to ease the computational burden required for multiple scenario analysis of stochastic programming. The number of crops has been reduced to 15; the months have been removed and converted to the three main growing seasons of summer, winter and nili; and the regions have been reduced from 5 to 2 (Upper Egypt and the Nile Delta).

4. Optimization under Uncertainty

Any model that attempts to describe a large-scale system of human agents making decisions that mazimize some figure of merit (e.g. utility, profits, etc) must invariably wrestle with the question of uncertainty. That is, in these systems human decision makers must commit themselves to courses of action without knowing ahead of time what the payoff from their effort will be. Obvious examples of this can be found in finance where investment options are weighed according to both the level and uncertainty of expected return. This same process also occurs in the agriculture sector of an economy. Farmers must make planting decisions before it is clear what weather conditions will prevail during the growing season or what price they can expect to receive for their produce at harvest time. In both of these examples, the presence of uncertainty leads to changes in how decisions are made. Specifically, agents decide on strategies that are robust against a variety of futures, not just one. This is termed hedging behavior. This type of problem lends itself very well to an existing branch of optimization theory called stochastic programming.

One of stochastic programmings model formulations is the 2-stage stochastic program with recourse [BeD55], [BiL88], [DaM61], [HiS91], [SlW69], [ErF93]. In this model there are two vectors of decisions. One, the first stage decision, corresponds to a decision made before some uncertain event occurs (typically modeled as a random variable(s)). This decision may be accompanied by immediate costs ("first stage" costs) which are known with certainty at the time of the decision. The second decision vector corresponds to decisions made once the uncertain event has occured and in light of the new information this provides. The second decision vector is chosen in such a way as to minimize a second stage cost associated with the first stage decision, the actual outcome of the uncertain event and, of course, the second stage decision. In this respect, the second stage recourse decision can itself be considered uncertain as it is a function (argument minimizer of second stage cost) of both the first stage decision (deterministic) and the uncertain event (random).

Formally, let $x \in X$ represent the first stage decision with X being some feasible region and let $D(x)$ be the associated known cost. If we assume the random variables in our problem, $r = (r_1, \ldots, r_N)$, have finite support, then one realization of the random variables is a scenario $s^i = (r_1^i, \ldots, r_N^i)$ $i = 1, \ldots, S$ with an associated probability p^i. The second stage cost is, then, the function

$$\begin{aligned} C(s^i, x) &= \min c(s^i, x, y^i) \\ \text{subject to} & \\ & y^i \in Y(s^i, x) \end{aligned}$$

where the second stage decision, $y^i(x)$, may be restricted to lie within a feasible region that varies with the first stage decision and scenario. For any particular first stage decision x then, a finitely supported distribution of costs

$$D(x) + C(s^i, x) \; i = 1, \ldots, S$$

results. To establish which particular distribution (a function of x) is most desirable, we mention only the simple minimum expected value criteria. Thus, the first stage decision which we term optimal is found by solving the following problem:

$$\begin{aligned} \min \quad & D(x) + \sum_{i=1}^{S} p^i * C(s^i, x) \\ \text{subject to} & \\ & x \in X. \end{aligned}$$

In the next section, we explore how we applied this general methodology to the earlier described deterministic EASM model.

5. Stochastic EASM model of Egyptian Agriculture

As previously described, the EASM model contains a detailed description of the agricultural sector of Egypt, both with regards to the variety of commodities, the regional distribution of production, the relationship between Egypt and the rest of the world via international markets, and the role the Nile plays in Egypts agricultural output. At the present though, it does not explicitly incorporate the impact of uncertainty on the kinds of decisions made within the Egyptian agricultural sector.

It is our goal to incorporate uncertainty, principally as regards the international price of agricultural commodities that are both exported and imported by Egypt. We will use this revised model in two ways. Firstly, we hope to be able to reproduce observed 1987 national cropping patterns without relying on the many exporting, importing and cropping pattern constraints used in the original deterministic model that mimic official Egyptian quotas and trade policy. Rather, we hope that by picking our scenarios and associated likelihoods carefully we can drive the solution of the unconstrained stochastic model to the observed solution. This will give us valuable information regarding the risk in international markets that Egyptian decision makers presently perceive and why they pursue the agricultural policies they do. Given this information about the present, we can then turn to our next question. Namely, how might Egyptian policy decisions change given a shift in their hypothesized perception of risk and/or a change in the availability of water from the Nile. We stress that our primary goal in this exercise is not to determine specific policies that Egypt should pursue, but rather to explore the use of stochastic programming as a means of understanding Egyptian agricultural decision making behavior.

Clearly, much more uncertainty than we are attempting to model is present in the Egyptian economy. We have not tried to deal with uncertainties in domestic demand or price elasticity or uncertainties in production costs and inputs for different crops and livestock to name just a few. We feel, though, that a close inspection of international commodity market price uncertainty will be very beneficial to Egypt as so much of its domestic consumption comes from abroad. We now describe the stochastic version of the EASM model.

5.1 Stochastic Modeling Details

The principal uncertainties that we want to include within the model are the international market prices of commodities that Egypt imports and exports. This means that in the 2-stage stochastic programming format presented in the previous section, export and import prices are modeled as the finitely supported random variables

$$s^i = (pr^i(c)) \ i = 1, \ldots, S, \ c = 1, \ldots, C$$

where each scenario has likelihood p^i, S is the number of scenarios and C is the number of traded commodities. It should be noted here that for this problem we do not suppose that there actually exists a well defined distribution governing the random prices of all agricultural goods traded internationally nor that, even if there did exist such a distribution, Egyptian decision makers would subscribe to it and make decisions based on it. What we do assume is that Egyptian decision makers do perceive a variety of possible price futures which we call scenarios and that they weight those scenarios according to the likelihood with which they think they will occur. They may or may not change those perceptions over time based on observed price trends. We assume that all decisions relating to domestic agricultural production

$$x(c,r) \ c = 1, \ldots, C, \ r = 1, \ldots, R$$

where R is the number of agricultural regions in Egypt are made prior to knowledge of the prices that will be offered for the countries output or the prices that will be required to secure its imports. We feel that this approximates well the lag in price information that policy makers have at the start of the planting season when cropping decisions are made. Thus, these agricultural production decisions play the role of the first stage decisions. The second stage decisions made once Egypt knows its domestic production and the price structure of internationally traded agricultural commodities are the quantities of commodities to import and export

$$y_m^i(c), y_e^i(c) \ i = 1, \ldots, S, \ c = 1, \ldots, C.$$

These decisions are feasibly made (e.g. exports do not exceed production) and contribute to national consumption of all commodities

$$n^i(c) \; i = 1, \ldots, S, \;\; c = 1, \ldots, C.$$

in such a way as to maximize the difference between consumer and producer surplus given the agricultural production decisions that have already been made and the given price structure. The stochastic version of the original quadratic deterministic problem is as follows.

$$\max \; -\sum_{c,r} I(c,r) * x(c,r) + \sum_{i=1}^{S} p^i * (\sum_{c} (\alpha(c) + \frac{\beta(c)}{2} n^i(c)) n^i(c)) + (\sum_{c} (pr^i(c) y_e^i(c))) - (\sum_{c} (pr^i(c) y_m^i(c)))$$

$$\begin{array}{rcl} & \text{subject to} & \\ n^i(c) & = & \sum_r yd(c,r)x(c,r) - y_e^i(c) + y_m^i(c) \text{ forall } c \\ \sum_{c,r} R_f(c,r)x(c,r) & \leq & \bar{\mathrm{R}}_f \text{ forall } f \\ \sum_{c,r} A_n(c,r)x(c,r) + \sum_c B_n^e(c)y_e^i + \sum_c B_n^m(c)y_m^i & \leq & 0 \text{ forall } i,n \\ x(c,r), y_e^i(c), y_m^i(c), n^i(c) & \geq & 0 \text{ forall } c,r,i \end{array}$$

where $I(c,r)$ is the vector of costs associated with the production of and $yd(c,r)$ is the expected yield from a unit area planted in commodity c within region r. $\alpha(c)$ and $\beta(c)$ are the domestic price and elasticity parameters of commodity c. $R_f(c,r)$ is the amount of limited resource f used per unit area planted in c and $\bar{\mathrm{R}}_f$ is the total amount of that resource available, and arrays A_n, B_n^e and B_n^m account for all agronomic constraints that bind the system.

To summarize, the problem this model attempts to simulate is how Egyptian decision makers decide which crops to produce how much of in order to position the country to earn the highest expected national surplus given uncertainty in the value of imports and exports that they perceive at the start of the planting season.

6. Stochastic Analysis

As stated before, the scenarios and associated likelihoods that we have developed are not based on any actual data on randomly varying international commodity prices or hypothesized stochastic processes that govern this behavior but are artificial constructs designed to simulate hedging behavior. This is because the purpose of this study is not to determine "proper" government price support programs or trade barriers given the best data available on the distributions governing price fluctuations. The purpose is to attempt to model the current behavior of decision makers in Egypt and determine a potential perception of uncertainty that would drive them to make the kinds of allocations of resources that they actually do while behaving in a manner that is logically consistent with the theory of competitive equilibrium that the model is based on.

In this section we discuss the set of scenarios and associated likelihoods that do, in fact, drive the unconstrained stochastic version of the deterministic model to the observed 1987 cropping patterns. This will require a discussion of the problems foundations in inverse nonlinear programming theory and the necessary assumptions we were required to make in order to make the problem well defined (under the assumption that a set of scenarios and associated probabilities is a potential solution when it is an ϵ-solution). We then discuss how, given the same hypothesized perception of price uncertainty, these cropping patterns change as the availability of water declines and, conversely, how for the same flows of water the cropping patterns change as the hypothesized perception of uncertainty changes.

6.1 Inverse Nonlinear Programming

Our version of the EASM model is a 2-stage stochastic quadratic programming problem in which the quadratic component of the objective function contains only second stage variables, no mixed terms and no uncertain parameters. Abstracting from the actual variables of the problem, we get the following

$$U(c_2^i, p^i, \bar{x}, \bar{y}) = \max \qquad c_1^t x + \sum_{i=1}^{S} p^i (\frac{1}{2}(y^i)^t M y^i + c_2^i y^i) \tag{6.1}$$

$$\begin{aligned} \text{subject to} & & \qquad\qquad (6.2)\\ \pi : A_1 x &\leq b_1 \\ \sigma^i : A_2 x + B y^i &\leq b_2 \text{ forall } i = 1, \dots, S \\ x, y &\geq 0 \end{aligned}$$

where

$$(\bar{x}, \bar{y^i}) \in \text{Argmax}_{(x,y^i) \in X} U(c_2^i, p^i, x, y^i) \tag{6.3}$$

and X is the feasible set described by the constraints in 6.2. As the set of $(\bar{x}, \bar{y^i})$ optimal for each (c_2^i, p^i) is convex, we can easily create a function $F(c_2^i, p^i)$ from the parameter space $(c_2^i, p^i), i = 1, \dots, S$ into the solution space (x, y^i) such that $F(c_2^i, p^i) = (\hat{x}, \hat{y^i})$ where

$$(\hat{x}, \hat{y^i}) = \text{Argmin } ||(\bar{x}, \bar{y^i})||^2$$

with $(\bar{x}, \bar{y^i})$ defined as in 6.3.

Let $F_x(c_2^i, p^i)$ be the projection of this function into the x subspace. The projected mapping is, of course, well-defined for any value of S and those choices of c_2^i for which a feasible solution of 6.2 exists.

Our goal is to reproduce approximately the observed cropping patterns (x^*) in the base year 1987. To do this we must find $(c_2^i, p^i) i = 1, \dots, S$, such that

$$F_x(c_2^i, p^i) \in B_\epsilon(x^*).$$

This requires constructing an inverse mapping from the data space back into the parameter space. This type of problem has already been studied and lies within the general field of inverse mapping problems [Sab87],[Tar87].

The difficulty with the particular parameter space in this problem is that the space of all scenarios and associated likelihoods is a space of infinite dimensions. Any solution in the problem space $\hat{x}$ will surely be the image of an infinitely sized and infinitely dimensioned set in the parameter space. This makes any inverse mapping ill-defined. To limit the parameter space to a finite number of dimensions, a finite set of scenarios must be chosen (i.e. we define the parameter space for only one value of S and one set of c_2^i, $i = 1, \ldots, S$). Thus, now we have a mapping from a finite dimensional parameter space into a finitely dimensioned data space. Unfortunately, the inverse mapping will most likely still be ill-defined. Worse yet, the pullback of the ϵ ball surrounding x^* will very likely not even be convex. As a result, our inverse mapping modified by the addition of a regularization term will not give us a unique solution as it will be difficult, in general, to find that norm for which there exists a unique minimizer. Nevertheless, for our purposes any member of the set of minimizers with respect to the standard l_2 norm will do. We claim this because the vectors of parameters we are choosing from represent vectors of probabilities and, hence, lie in the S dimensional simplex. Regularizing using this norm will give us the set of probability vectors that are closest (in the sense of the l_2 distance) to the centroid of the simplex (i.e. each scenario weighted as equally as possible). This is exactly what we want as we desire to, if anything, overestimate the uniformity of the distribution in order to obtain an upper bound on the hypothesized perception of uncertainty.

For the work in this paper we did not implement an algorithm to search for the type of solution just described. Instead we relied on an intuitive understanding of the model in order to search for a set of probabilities, given a finite set of scenarios, that would give us the observed cropping patterns we needed. We intend to revisit this question again, though, in a future paper.

6.2 Present Perception of Uncertainty

As previously mentioned, the original deterministic model had a variety of policy constraints binding cropping, import and export behavior in the model. This is sensible given that the model was expected to reproduce present cropping trends given present policy, import and export prices. This deterministic model cannot be used, though, to explore how a perception of uncertainty might give rise to the observed official policies in the first place.

Our first task in developing the data base for a stochastic model to more adequately understand the perceived uncertainty behind the present policy was to develop a finite number of scenarios which could believably represent the world view of an Egyptian decision maker. The criteria we settled on for making this decision was to choose scenarios that were representative of the state of agricultural commodity prices in past years. We felt that this was appropriate because most decision makers future perceptions of world events are shaped largely by past events. To supplement this first criteria, we also investigated how, given the 1987 international commodity prices, the cropping pattern of the deterministic model would differ from observed patterns if we removed the policy constraints.

The past data on Egyptian agricultural production indicates that seed cotton, livestock and the meat and milk produced from it, and livestock's fodder, berseem, have traditionally been the high priced commodities central to Egypt's agricultural output. In

Observed	Modeled
6888	0

Table 1: Livestock Production ('000 head) - Deterministic

more recent years, the world market price of cotton has started to slowly decline as substitute sythetic fibers eat away at its market share. The price of meat and milk, though, has remained high. Also more recently, the international price of vegetables has begun to rise, making it competitive with the more traditional crops. Just how competitive is suggested by the results for agricultural produce, given 1987 prices, in the unconstrained deterministic model which are pictured in figure 1 while the total numbers of animals raised in thousands of head are indicated in table 1. Given the actual 1987 international

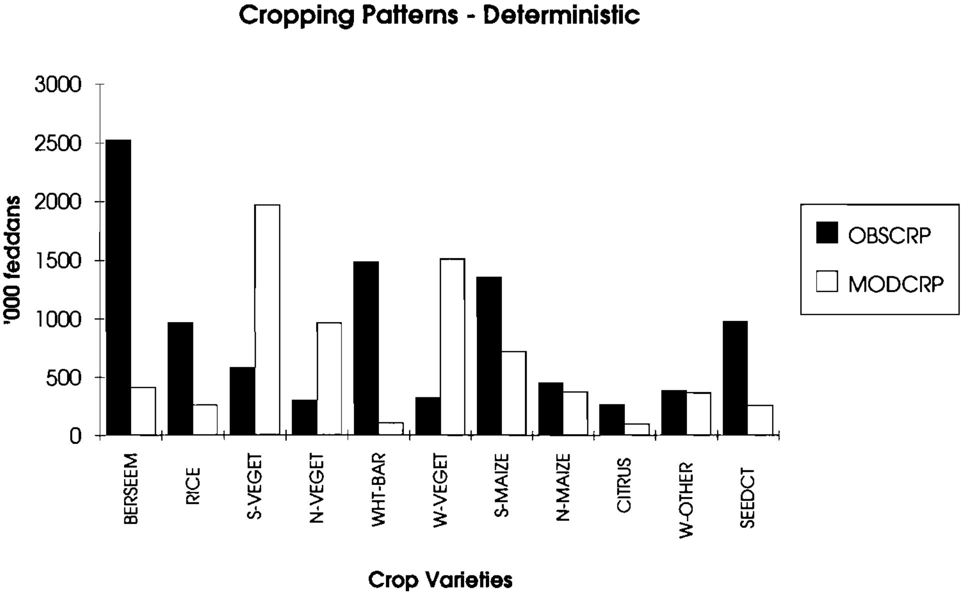

Figure 1: Deterministic unconstrained results

price data and no uncertainty, the cropped area of vegetables in all seasons would be substantially greater than actually occured while the production of all other commodities, most notably seed cotton, livestock (which is dropped completely) and livestock's attending feed, berseem, would decline. Of course, Egyptians do not make the cropping decisions pictured in this figure because they base their decisions on more than just the observed 1987 prices.

Both the present and past states of the international commodity market over time suggest a number of different price scenarios that decision makers might weight in their decision making. In particular, we summarize these different states of prices in nine simple scenarios. In eight of the scenarios we set the price of both meat and milk to twice the level and the price of cotton to a little over half of the level of 1987 prices. These choices reflect the relative stability of meat and milk as high priced commodities in Egypt and the steady decline of cotton as an export item over time. In these same scenarios we attempt

Scen.	Price Mult. - Meat and Milk	Price Mult. - Seed Cotton	Price Mult. - other commodities	Prob.
1	2.0	0.525	1.00	0.01
2	2.0	0.525	0.90	0.15
3	2.0	0.525	0.60	0.15
4	2.0	0.525	0.40	0.65
5	2.0	0.525	1.50	0.01
6	2.0	0.525	2.00	0.01
7	2.0	0.525	2.50	0.01
8	2.0	0.525	3.00	0.00999
9	1.0	1.00	1.00	0.00001

Table 2: Scenarios

to reflect the greater historical variability of alternative commodity prices by having the prices of all other commodities range from as low as forty percent to as high as three times the observed price [FAO94]. In the last scenario we set the prices of meat, milk and seed cotton along with all other commodities to the actually observed 1987 prices.

The scenarios and associated likelihoods that led to a close approximation of actual 1987 cropping patterns are listed in table 2. The newly constructed stochastic program with the 9 scenarios produced the results pictured in figure 2 and table 3. These results

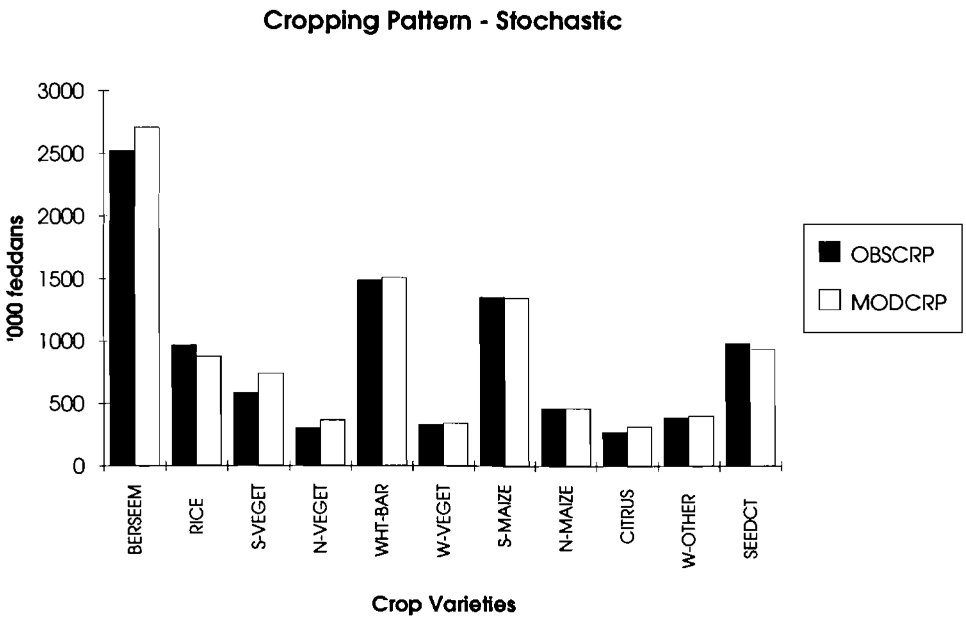

Figure 2: Stochastic unconstrained results

reproduce observed national cropping patterns very closely. In fact, the average weighted error of the stochastic model is only 6%, in contrast to the 11% error for the original **constrained** deterministic (results in figure 3 and table 4.) model and 70% for the **unconstrained** deterministic model. The error of 6% we consider to be quite acceptable

Observed	Modeled
6888	6823

Table 3: Livestock Production ('000 head) - Stochastic

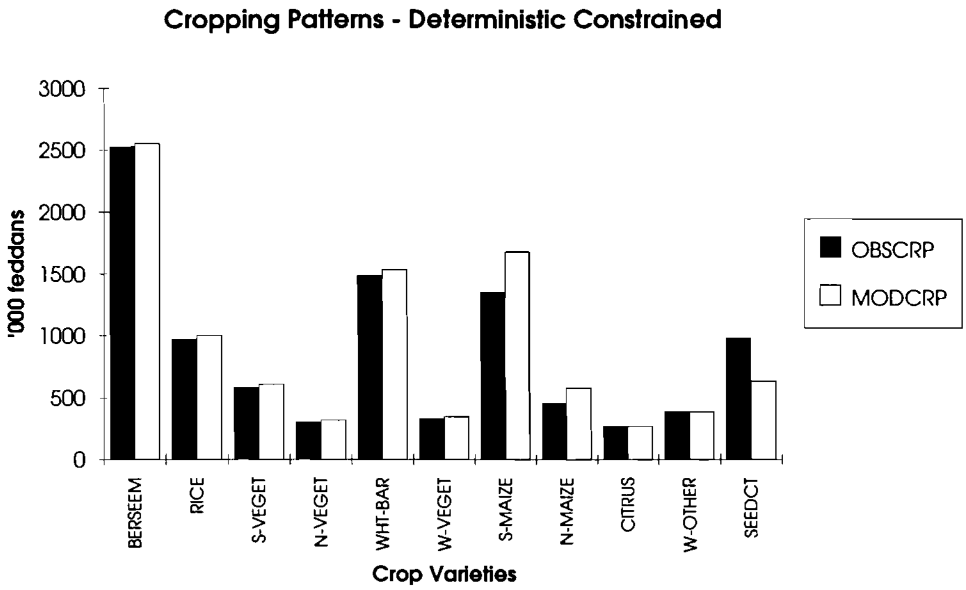

Figure 3: Deterministic constrained results

Observed	Modeled
6888	6665

Table 4: Livestock production ('000 head) - Deterministic constrained

given the overall uncertainty in the model as a whole.

It would appear from these results that the hypothesized Egyptian decision maker of our model whose decisions parallel so closely the actual patterns found in Egypt actually perceives very little uncertainty in international commodity markets. He consistently sees meat and milk as very valuable (twice as valuable as they actually end up being), and all other crops as relatively inexpensive. In fact, he perceives with 80% likelihood that the price of all other crops will be no more than 0.60 of the prices they actually attain. This hypothesized perception of uncertainty about international commodity prices makes the observed cropping patterns optimal and helps to explain why current policy regarding agricultural subsidies, taxes, export and import barriers is as it is.

In the next section we explore how, given this perception of uncertainty, the stochastic models prediction of cropping patterns differs from that of the original constrained deterministic model under various water availability scenarios.

6.3 Low Water Scenarios

On average, Egypt has approximately 55.5 milliards of water annually available from the Nile to meet all its water needs. In the short run, this is subject to some variability each year because of droughts that periodically effect the region, although this type of problem has been drastically mitigated since the construction of the High Aswan dam. In the long run, though, Egypt's water supply will almost likely decline. This is chiefly because the Nile, before reaching Egypt, runs through a number of other African nations. These nations presently use only a small percentage of the water in the basin, but could conceivably use a great deal more if they were to develop their agricultural industry in any substantial way. In fact, it has been estimated that the country of Ethiopia, by simply planting orchards along its portion of the rivers path, could reduce the flows of water to Egypt substantially. In addition, research on global change caused by increasing concentrations of carbon dioxide and other trace chemicals in the upper atmosphere is already suggesting that rain fall in this part of the world might very well be adversely affected. Both of these facts suggest that an analysis of the relationship between cropping patterns, water availability, and price uncertainty is well worth performing.

We investigated this question for both the deterministic constrained and stochastic models for seven reduced water availability scenarios ranging from 90% of current supplies down to only 40%. The results are displayed in figures 4 and 5. Each model tells its own story of Egyptian cropping behavior in an increasingly water scarce environment.

In the stochastic model, domestic production of livestock supporting fodder, berseem and wht-bar, generally declines as stocks of water decrease, falling to about a third of its present production in the last scenario. At the same time, livestock production itself declines and then abruptly increases again as Egypt begins to import large quantities of feed from abroad. It pays for this fodder by culling its herds and selling the meat and milk overseas. Vegetable production and export also becomes an increasingly important part of Egypt's overall agricultural output. Rice, a water intensive crop, drops precipitously to only a fifth of its present level at 80% water supplies and then disappears all together once water supplies drop below that. Cotton's importance as an export seems to be inversely proportional to that of livestock. When it is at its highest, livestock production is at its

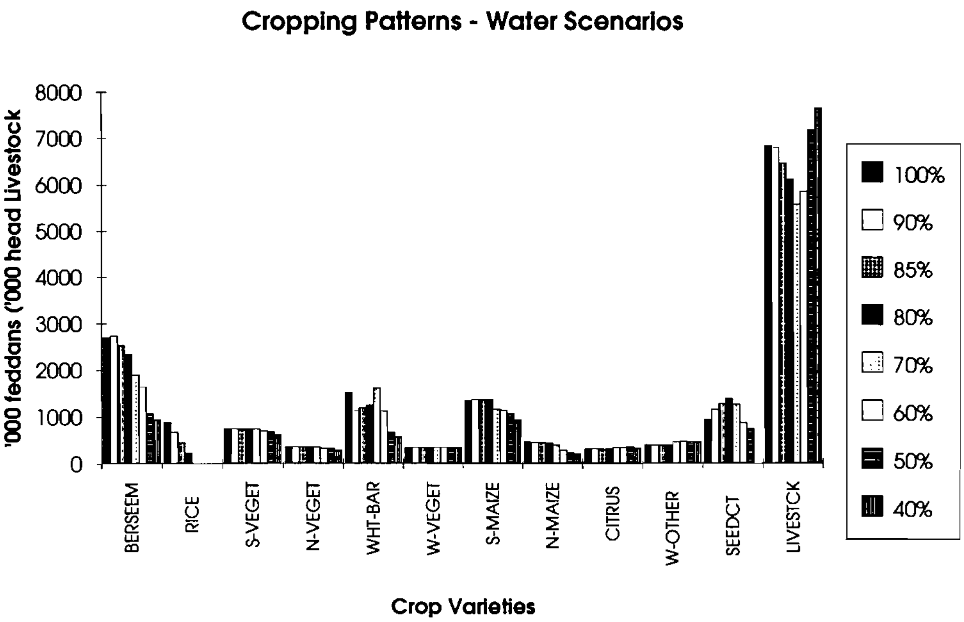

Figure 4: Cropping Patterns under Different Water Supply Scenarios - Stochastic

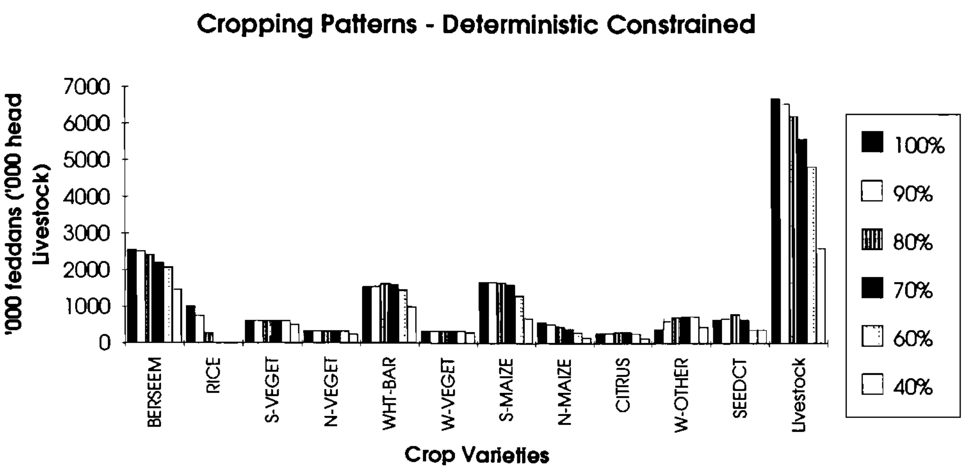

Figure 5: Cropping Patterns under Different Water Supply Scenarios - Deterministic

lowest and vice versa.

Although the deterministic models results share some similarities with those of the stochastic model, they are also different in some important ways. For example, the deterministic model suggests that livestock will become a progressively less and less important part of agricultural activity as the acreage of its support crops, berseem and wheat, dwindles. This is because constraints in the deterministic model, necessary for its calibration, limit the import of fodder for livestock. This results in a completely different picture of the largest component of Egypts agricultural activity.

These seven water scenarios and the results from the stochastic and deterministic model runs demonstrate the fundamentally new kinds of information that a stochastic model can provide. The stochastic results suggest that even if the present perception of price uncertainty, which clearly favors the maintenance of large herds of livestock, continues into a low water future, inputs to livestock maintenance, principally produced by Egypt at present, will increasingly come from overseas. This would require a fundamental restructuring of the way Egypt produces meat and milk. Away from the traditional small herd fed on the farmers beerseem field and towards the factory style feed lot supported by imported fodder from water rich nations. This is a much different result than that suggested by the deterministic model. Namely, a declining livestock industry fed principally on decreasing quantities of domestically produced fodder (i.e. no fundamental change in how the industry is run). Both models do agree, though, that despite Egypt's traditional comparative advantage in the production of cotton based products, reduced water supplies along with continuing competition from sythetic fibers will make this product less and less important to Egypt's economy. They also agree that vegetables will make up an ever increasing percentage of total agricultural output.

What is most important to note about this experiment is not the specific numbers, but the fundamentally different picture of the future that each model produces. The two models provide different kinds of information and, for this reason, should both be studied to more completely understand the impact of water scarcity on Egyptian agricultural output.

In the next section we focus on the stochastic model and look more at the question of how a change in the perception of uncertainty might affect cropping decisions even in the absence of a change in water supplies.

6.4 Changing Perceptions of Uncertainty

Our work so far has indicated that a stochastic model with low price variance models the current agricultural cropping situation at a national level in Egypt quite well. From this we surmise that decisions are presently made under the perception that, at least as regards international commodity prices, there is little uncertainty. Clearly, though, perception of uncertainty by decision makers is not a constant. Events in the world can cause a perception of certainty to quickly change. For example, consider the events of 1990 and early 1991. Previous to Iraq's invasion of Kuwait, oil prices were relatively stable. With the invasion, many oil traders perceived a great deal of uncertainty regarding Iraq's intensions, both with regards to future oil production in Kuwait, and the Iraqi armies possible expansion into Saudi Arabia. This uncertainty caused oil futures to quickly rise

Scen.	Prob. Highly Uncertain	Prob. Moderately Uncertain
1	0.125	0.121
2	0.125	0.125
3	0.125	0.225
4	0.125	0.325
5	0.125	0.101
6	0.125	0.101
7	0.125	0.01
8	0.12499	0.00999
9	0.00001	0.00001

Table 5: Alternate Scenario Weightings

which resulted in price spikes. The point is that the perception of the reality, whether it is true or not, is what decision makers act upon, and this perception is subject to radical change depending on many factors. Consider the case of Egypt. The set of scenarios and associated likelihoods that we chose models a perception of great confidence in the continued strength of markets for meat and milk, and pessimism over anticipated prices for all other commodities. How might cropping patterns change if this perception was to change?

We experimented with two other weightings of the scenarios to see how solutions changed. In one we weighted all scenarios approximately equally except for number nine which we left at 0.00001. This represented the maximum uncertainty regarding the future given the 9 scenarios we had picked. For the other we chose weights for our scenarios that generated a moderately higher variance. The two vectors of weightings are listed in table 5. The cropping results from the original distribution and the two alternatives is shown in figure 6. The differences between the solutions that result when the original distribution is used and when the distribution of moderately higher variance is used are minimal. In the latter, production of seed cotton is dropped. What is most remarkable is the tremendous change that occurs once all scenarios are weighted approximately the same. There is essentially a complete reversal in the cropping pattern. Berseem and wht-bar, both cropped heavily in the original solution, become insignificant. Livestock holdings, so central to the economy in the previous weighting, disappear. Taking their place are all varieties of vegetables. Egypt becomes a huge producer of vegetables, exporting all its surplus and using its foreign exchange to import the grains, meat, milk, sugar and citrus that it needs.

Again we stress that these results point to the importance that perception of uncertainty plays in agricultural decision making. A change in this perception can lead to a fundamentally new kind of agricultural policy.

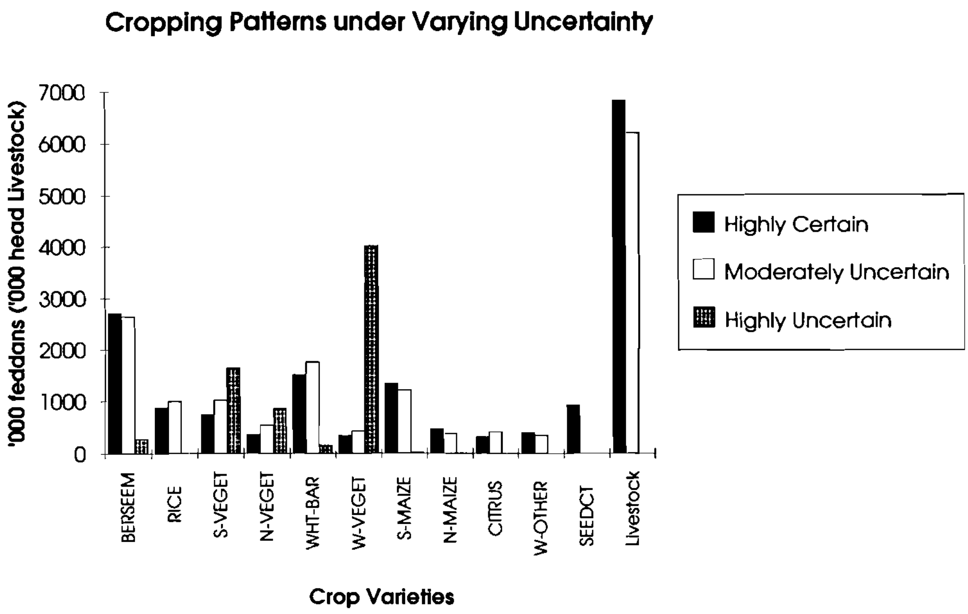

Figure 6: Cropping Patterns under Different Perceptions of Uncertainty

7. Conclusion

Egyptian decision making regarding the crops they grew in the 1987 season is based on a perception of future prices that is strikingly different from the realized international prices of that year. Our modeling efforts indicate that a set of nine scenarios with small variance adequately reproduces cropping patterns for the 1987 season. These scenarios show that Egyptians made their cropping decisions based on a perception that the value of meat and milk would be much higher than reflected by the actual world market prices for that year. At the same time, they perceived that all other commodities would, with high probability, have values that were just over half what the actual market prices turned out to be.

Continuing this analysis into different low water futures, we see that, given no change in perception of price uncertainty, the stochastic model produces results strikingly different from those of the old deterministic model. In particular, it suggests that rather than withering, Egypts meat and milk industry, now heavily dependent on inefficiently grown domestic feeds, will expand and come to rely increasingly on fodder from water rich trade partners. Both models agree that Egypt will move away from high water use crops like rice and begin heavy cultivation of high value vegetable crops for export to Europe and other demand centers.

Finally, the stochastic model suggests that, even if Egypt suffers no loss of water supply, its cropping patterns are subject to tremendous change if decision makers begin to perceive a distribution of future international prices that has greater variance.

In closing we feel that, by using stochastic programming methodology, we have captured an important behavioral aspect of Egyptian decision making not detectable using traditional deterministic programming techniques. Namely, the influence that a perception of uncertainty can have on the production, tax and trade decisions that impact a nations agricultural system.

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