Uncertain Yields in Sectoral Welfare Analysis: An Application to Global Warming

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Abstract

Agriculture operates in an uncertain environment. Yields, prices, and resource usage can change dramatically from year to year. However, most analyses of the agricultural sector, at least those using mathematical programming methods, assume decision making is based on average yields, ignoring yield variability. This study examines how explicit consideration of stochastic yield outcomes influence a sector analysis. We develop a model that can be used for stochastic sector analysis. We extend the risk framework developed by Hazell and others to incorporate discrete yield outcomes as well as consumption activities dependent upon yield outcomes. An empirical application addresses a comparison between sector analysis with and without considerations of the economic effects of yield variability in a global warming context.

Keywords: agricultural sector analysis, global warming, partial equilibrium models, stochastic programming.

Introduction

The utility of mathematical programming models in comparative statics analyses of the agricultural sector has long been recognized. The conceptual basis was originally detailed in Samuelson. Later, Takayama and Judge expanded the concept, developing quadratic programming models for multiproduct equilibria. Successive contributors to the literature are legion (see McCarl and Spreen; Norton and Schiefer; Martin; and Willett for reviews and tutorials).

Risk and uncertainty are pervasive in agriculture (Boisvert and McCarl). Sectoral models that ignore farmers' responsiveness to risk and uncertainty may thus be suspect, which will be discussed in a following section. Consequently, Hazell and Scandizzo (1974, 1975, 1977) addressed the problem of including risk in the form of yield variability into sector models. Hazell and Scandizzo (HS) developed two risk formulations and Hazell and Pomareda (HP) contributed a third.

The first HS model (1974) was based on average price expectations and a risk measure based

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on lagged gross margin variance. This formulation has been used in Simmons and Pomareda; Pomareda and Samayoa; and Weimar and Hallam among others. In 1977 HS developed a revenue expectations formulation where price and yield expectations were jointly formed, but limited the interaction between price formation and risk to own price elasticity terms. HP extended the HS (1977) formulation to permit cross price elasticities from integrable demand functions using an iterative solution approach.

All three of the Hazell and associates' models preclude behavior influenced by anything other than average market price or the level of revenue variability. Thus, for example, the average of exports, feed use and domestic consumption do not vary given bumper crops or droughts.

There has been a considerable amount of both theoretical and applied work on the incorporation of risk and uncertainty in conditional normative agricultural models. These efforts draw upon Dantzig's stochastic programming with recourse (SPR) and Cocks's and Rae's (1971a, 1971b) development of discrete stochastic programming. Apland and Hauer have recently surveyed agricultural applications in this arena. All of the studies cited in their survey apply SPR to farm-level decision making. In general, modelers have found that farm decisions differ from the deterministic, single outcome case when a vector of discrete parameter values is considered.

The first objective of this paper is to expand existing partial equilibrium approaches to consider discrete outcomes under alternative states of nature. The resulting SPR model extends sectoral risk formulations by including: (1) situations where segments of the sector (consumers, feeders, and processors) can alter enterprise levels in response to stochastic outcomes, while other segments (producers) plan according to revenue expectations; and (2) consideration of yield risk for commodities which may be sold as intermediate inputs (e.g., where raw sugar is sold to a sugar refinery which, in turn, produces refined sugar which has a demand curve.) The formulation assumes that producers make acreage decisions before actual prices and yields are known, although yield distributions and demand curves are known. Subsequently, a realized distribution of total production and prices will result. Processing and consumption decisions are made conditional on those discrete outcomes by state of nature.

A second objective of the paper is to test the SPR setting by evaluating the potential effects on the U.S. food system of projected climatic changes associated with global warming. Our methodology will be similar to that in Adams et al., but will also examine yield variability effects. Results of the stochastic sequential model will be contrasted with results obtained using average yields.

The Hazell and Associates Models

The SPR model is conceptually similar to the HS and HP models. Thus, it is worthwhile to briefly review those models. The assumptions of the HS sector model are: 1) yields are the sole source of risk (endogenous prices will be random due to random total production); 2) producers operate in a competitive environment, form revenue expectations and maximize expected profits; and 3) producers make decisions before prices and yields are known.

HS formalize the linear demand version of their model as:

$$\begin{aligned} &\text{Max} \quad E[\mathbf{x}'\mathbf{N}(\boldsymbol{a} - 0.5\boldsymbol{BNx})] - \boldsymbol{c}'\boldsymbol{x} \\ &\textit{subject to} \quad \boldsymbol{Dx} \le \boldsymbol{b} \\ &\qquad \boldsymbol{x} \ge \mathbf{0} \end{aligned} \tag{1}$$

where E[ ] is the expectation operator, **x** is a vector of production levels, **N** is a diagonal matrix of stochastic yields, **a-BNx** is a set of quantity dependent demand equations, **c** is a vector of unit activity costs, **D** is a matrix of resource usage coefficients, and **b** is a vector of resource endowments. This objective function maximizes the average area under the demand curve less the cost of production.

HS (1975, 1977) and HP manipulate the objective function in (1) to obtain:

$$\mathbf{x}'\mathbf{E[N]a} - 0.5\ \mathbf{x}'\mathbf{E[NBN]x} - c'\ x$$
$$= \mathbf{x}'\mathbf{E[N]}\ (\mathbf{a} - 0.5\mathbf{BE[N]x}) - 0.5\mathbf{x}'\mathbf{V(NBN)x} - \mathbf{c}'\mathbf{x} \tag{2}$$

where $\mathbf{x}'\ \mathbf{V(NBN)x}$ is the revenue variance associated with production plan **x**. Although it is possible to include risk averse behavior in their formulation, calculations of per acre net returns and avoidance of monopolistic behavior requires an iterative procedure.

Including Adaptive Behavior and Derived Demands

Incorporation of adaptive behavior and derived demands by the processing sector into the HS model may be accomplished by using two stage or discrete stochastic programming with recourse (SPR), as developed by Dantzig, generalized by Cocks, and used in Lambert and McCarl (1985, 1989), and McCarl and Parandvash[1]. The resultant formulation includes market clearing rows for each state of nature with objective function expectations explicitly calculated by considering revenue outcomes under each discrete state of nature. In addition, processing activities are included for each state of nature. The resultant model is:

Max

$$CSPS = E \quad \left(\int p(q)dq - g'y\right) - c'x$$
$$= \sum_{s=1}^{N}\{\theta_s \left(\int p(q_s)dq_s - g'y_s\right)\} - c'x \tag{3a}$$

subject to

$$q_s + Hy_s - N_s x \le 0 \textit{ for all } s,\ [\pi_{1s}] \tag{3b}$$
$$My_s \le e \textit{ for all } s,\ [\pi_{2s}] \tag{3c}$$
$$Dx \le b, \quad [\pi_3] \tag{3d}$$
$$q_s, \quad y_s, \quad x \ge 0 \tag{3e}$$

where the state of nature dependent variables are: $\mathbf{q}_s$, a vector of final goods sold resulting either directly from farm production ($\mathbf{N}_s\mathbf{x}$) or processing ($\mathbf{Hy}_s$) under state of nature s; and $\mathbf{y}_s$, a vector of processing levels which uses some or all of primary production (through $\mathbf{Hy}_S$ when $\mathbf{H} > 0$) and produces goods (when $\mathbf{H}<0$). The deterministic variable **x** depicts a vector of production levels chosen prior to knowledge of state of nature. **x** produces stochastic output ($\mathbf{N}_S\mathbf{x}$) and uses resources (**Dx**). The other parameters for the model are: θ_s, the probability of state of nature s occurring; **p(q)** the inverse demand curve; **g**, a vector of per unit processing costs; **H**, a matrix of product usage and final good supply by the processing activities; **M** a matrix of resource usages by the processing activities; $\mathbf{N}_s$ a matrix of yields under state of nature s by crop and production possibility **x**; **D** a matrix giving resource usage by **x**; and **e** and **b**, the resource endowments. For later discussion, vectors of shadow prices $(\boldsymbol{\pi}_{1s}, \boldsymbol{\pi}_{2s}, \boldsymbol{\pi}_3)$ associated with each block of constraints are identified to the left of the equations.

There are three major differences between the stochastic model (3) and the HS/HP formulations:

1. Explicit outcomes under each state of nature enter the model rather than using analytically derived expected value and variance parameters. For example, vectors of production under each state of nature are entered while total production and prices for each particular final good by state of nature are contained in the output.

2. Primary products may enter final demand or be used in the processing sector. $\mathbf{q}_s$ accumulates the quantity of output that is directly sold to final demand. The component of (3) dealing with the primary commodities $\mathbf{Hy}_s$ depicts both the quantity produced that is used as an intermediate input to processing (when $\mathbf{H} > 0$) and the supply of processed goods sold to final demand (when $\mathbf{H} < 0$). In such a model, risk may be depicted for intermediate commodities which are not subject to final demand. For example, raw sugar is an input for

refining and its price is derived from market conditions facing sugar refineries. The HS/HP family of models could not directly handle riskiness in such cases since the explicit demand curve parameters required to form the HP objective function (2) are not present or are only applicable to part of the production.

3. Processing ($\mathbf{y}_s$) and consumption ($\mathbf{q}_s$) are state of nature dependent, but production ($\mathbf{x}$) is not. Thus, processing and consumption levels are dependent upon production conditions, whereas primary production decisions are based on an expectation across the yield outcomes.

Optimality Conditions for the SPR Sectoral Model

The SPR sector model possesses optimality conditions that are only slightly different from the standard optimality conditions associated with price-endogenous sectoral models (McCarl and Spreen). Final demand product prices are dependent upon state of nature. Given the Lagrangian of model (3) $L(\mathbf{q}_s, \mathbf{y}_s, \mathbf{x}, \pi)$ where π are the Lagrange multipliers, then

$$\frac{\partial \mathbf{L}}{\partial \boldsymbol{q}_s} = \theta_s \, [\boldsymbol{a} - \boldsymbol{B}\boldsymbol{q}_s] - \pi_{1s} \leq 0 \tag{4}$$

The π_{1s} is related to state of nature dependent output prices ($\mathbf{p}_s$) for commodities which are consumed at a nonzero level ($\mathbf{q}_s > 0$). Namely if $\mathbf{q}_s > 0$ then

$$\pi_{1s} = \theta_s \, [\mathbf{a} - \mathbf{B}\mathbf{q}_s] \tag{5}$$

Defining p_s as the demand curve price under state of nature s, $\mathbf{p}_s = \mathbf{a}\text{-}\mathbf{B}\mathbf{q}_s$, and substituting gives

$$\pi_{1s} = \theta_s \, \mathbf{p}_s \qquad \text{or} \qquad \mathbf{p}_s = \pi_{1s}/\theta_s. \tag{6}$$

Thus, state of nature dependent prices are obtained by dividing the vector π_{1s} by the probabilities θ_s.

Production levels $\mathbf{x}$ are determined by the following optimality condition:

$$\frac{\partial \mathbf{L}}{\partial \boldsymbol{x}} = -\boldsymbol{c} + \sum_s \boldsymbol{N}_s \pi_{1s} - \boldsymbol{D}'\pi_3 \leq 0 \tag{7}$$

If $\mathbf{x}$ is positive, the above equations can be manipulated to show that average revenues from the production of $\mathbf{x}$ will be equated with the per unit variable and resource costs. Thus, the model assumes that producers of the primary product choose x such that expected unit revenues equal marginal costs. This is the same behavioral assumption underlying the risk neutral version of Hazell and Scandizzo (1977).

Nonzero levels of the processing activities under each state of nature, $\mathbf{y}_s$, satisfy the following conditions:

$$\frac{\partial L}{\partial y_s} = -\theta_s \boldsymbol{g} - \boldsymbol{H}'\pi_{1s} - \boldsymbol{M}'\pi_{2s} = 0 \quad \textit{for all } s, \tag{8}$$

which can be manipulated to yield $\mathbf{-H'p_s = g + M}\ \pi_{2S}/\theta_s$.

Interpretation of (8) requires further definition of terms. Processing activities ($\mathbf{Y}$) use intermediate goods and result in final goods that face explicit demands. If we create two new matrices, the intermediate goods matrix $\mathbf{H}_I$ and the output matrix $\mathbf{H}_O$, where we can define:

$\mathbf{H}_I = h(i,j)$ if $h(i,j) > 0$ $\quad$ $\mathbf{H}_O = h(i,j)$ if $h(i,j) < 0$
$\quad = 0$ otherwise $\quad\quad\quad\quad\quad = 0$ otherwise

Then $\mathbf{H}_I - \mathbf{H}_O = \mathbf{H}$ and the Kuhn-Tucker conditions for processing require

$$\mathbf{H}'_O\mathbf{p}_s \leq \mathbf{g} + \mathbf{M}'\pi_{2s}/\theta_s + \mathbf{H}'_I\mathbf{p}_s \quad \text{for all s.} \tag{9}$$

That is, the marginal revenue from processing ($\mathbf{H}'_O\mathbf{p}_s$) must be less than or equal to the marginal cost under each state of nature. Marginal cost consists of the direct costs ($\mathbf{g}$), the opportunity cost of processing resources ($\mathbf{M}'\ \pi_{2s} /\ \theta_s$), and the value of intermediate goods used ($\mathbf{H}'_I\mathbf{p}_s$).

A Theoretical Investigation of why Risk Should Matter

Before developing empirical results a theoretical investigation of the implications of using SPR versus a model based on mean values is in order. Assume for simplicity a linear demand curve and a deterministic model of the form

$$\begin{aligned} \text{Max} \quad & \int(\alpha - \beta q)\,dq - \delta x \\ & q - \phi x = 0 \\ & q, \quad x \geq 0 \end{aligned} \tag{10}$$

where x and q are single variables, the demand curve is $(\alpha - \beta \mathbf{q})$, δ is the cost of producing x, and ϕ is yield. After integration the model becomes

$$\begin{aligned} \text{Max} \quad & \alpha q - 1/2\beta q^2 - \delta x \\ & q - \phi x = 0 \\ & q, \quad x \geq 0 \end{aligned} \tag{11}$$

Now if we introduce uncertainty in yield (θ) we can set up the SPR model in the form

$$\text{Max} \quad \int_{y_1}^{y_2} \theta(\phi)(\alpha\phi X - 1/2\beta\phi^2 X^2)\,d\phi - \delta X \tag{12}$$

where θ is the probability distribution of yield, while y_1, and y_2 are the limits of integration on yield. On the other hand, if we assume the model clears at average yield we get

$$\text{Max} \quad \alpha\bar{\Phi}x - 1/2\beta\bar{\Phi}^2 x^2 - \delta x \tag{13}$$

where $\bar{\Phi}$ is a mean yield. These functions potentially involve different levels of x because of the nonlinear terms in the objective function. If we assume θ (ϕ) is a uniform distribution then the optimal x value is

$$x_{spr} = \frac{3(\alpha(y_1 + y_2)/2 - \delta)}{\beta(y_1^2 + y_1 y_2 + y_2^2)} \tag{14}$$

$$x_{mean} = \frac{4(\alpha(y_1 + y_2)/2 - \delta)}{\beta(y_1 + y_2)^2} \tag{15}$$

Empirical trials also show x varies under distributions with a more central tendency. Thus we should expect a difference between the stochastic results and the deterministic ones when means of the yield distribution differ between models. Furthermore, state of nature dependent processing and consumption markets may increase the potential difference in results.

A Case Study: Yield Variability and Global Warming

We now examine the results of a sectoral analysis in which yield variability enters through states of nature dependent on crop yields. The case study involves agricultural sector analysis of the implications of global warming as our case study. Increasing concentrations of carbon dioxide (CO_2) trapped within the earth's atmosphere prevents the escape of solar radiation, thus leading to possible increases in global temperatures and changes in precipitation. Global climate change (GCC) is expected to alter the growing environment for agricultural products, affecting yields, regional production characteristics, and resource usage (Adams et al.).

Agricultural sector analyses of GCC have generally relied upon Kokoski and Smith's theoretical argument that fairly large, single-sector welfare effects may be adequately measured in a partial-equilibrium setting.[2] Although a small number of researchers have investigated GCC in a global setting (Tobey, Reilly and Kane; Reilly and Hohmann), most research has concentrated on impacts on single countries under the assumption of trade-neutral impacts resulting from GCC. These studies have provided deterministic analyses of GCC impacts on agricultural productivity, income distribution, expected prices, and resource allocation (Adams, Glyer and McCarl; Onal and Fang; Kaiser; Sherony, Knowles, and Boyd; Rosenzweig et al.; Rosenberg and Crosson). No study, to our knowledge, has been done on the effects of GCC induced changes in yield variability.

The SPR model allows assessment not only of the expected impacts of GCC, but also price, production, and regional impacts under stochastic crop yield outcomes. An overview of the model is presented below. Additional details are found in He.

Empirical Model Formulation

The global climate change analysis is based upon the U.S. agricultural sector model (ASM) developed by McCarl and associates (see Chang et al. for a recent description). The resulting model, SPRASM (Stochastic Programming with Recourse Agricultural Sector Model), was aggregated to the 10 USDA agricultural production regions, with processing and consumption dependent on state of nature.

An additional modification in SPRASM incorporates state-of-nature dependent stock withdrawals and additions. An equation was added for each commodity that equates expected stock additions and withdrawals. A cost of 10% of the commodity price was added for stock withdrawals.

Stochastic yield data before GCC were derived as the residuals from a set of trend models estimated by Thaysen for each crop region using 1977 to 1989 observations. Residuals were added to the 1990 base year observations to give 13 equally likely yield outcomes resulting from weather or other stochastic factors. Use of the discrete, empirical yield distributions, derived from the observed year to year yield outcomes, preserves both interregional and intercrop correlation.

Base Model Calibration

A two-step calibration procedure was used to replicate 1990 supply and demand conditions:

1. The base model was solved with crop acreage and stock additions/depletions fixed at their 1990 levels. The SPRASM yield distribution was also adjusted by a crop-dependent scalar to force the 1990 state-of-nature crop production results to correspond to observed levels.

2. Given the production and stock levels, the domestic consumption quantities were adjusted to approximate actual 1990 prices (adjustments were generally in the 1-2% range). The constraints holding 1990 acreage and stock levels were then removed and an optimal solution was found.

Production levels for all crops and prices for most crops were within 1% of actual values after the second calibration step. Thus, the calibration was judged adequate for further analysis of the importance of considering yield distributions when analyzing GCC.

Developing the GCC Scenarios

Following Adams et al.,[3] forecasts of likely climate changes came from two models of atmospheric circulation, the NASA/Goddard Institute of Space Studies (GISS) model and the Princeton Geophysical Fluid Dynamics Laboratory (GFDL) model. Climate parameters reported in Adams et al. were used (assuming passive fertilization from enhanced CO_2 levels) in the Erosion/Productivity Impact Calculator (EPIC) crop simulation model to simulate mean and standard deviations for crop yields and irrigation water use both with and without climate change. EPIC results were used to simulate yield distributions for wheat, corn, cotton, grain sorghum, and soybeans. Yield distributions for the remaining crops were adjusted by the average GCC induced changes for the five crops analyzed using EPIC. Pasture and grazing land usage coefficients in the livestock budgets were also divided by the average yield change under the assumption that forage growth is also affected by GCC.

State-of-nature dependent yields were developed based on the 13 observations to maintain intercrop and interregional correlations using the formula:

$$\begin{aligned} \boldsymbol{obs}_s^1 &= \boldsymbol{mean}^o \left(\frac{\mu_{GCC}}{\mu_{base}}\right) \\ &+ \left(\boldsymbol{obs}_s^o - \boldsymbol{mean}^o\right)\left(\frac{\sigma_{GCC}}{\sigma_{base}}\right) \end{aligned} \tag{16}$$

where subscript s is the state-of-nature, $\boldsymbol{obs}_s^o$ and $\boldsymbol{obs}_s^1$ are state-of-nature dependent crop yields before and after GCC, **mean°** is the average crop yield before climate change, while μ_{base}, μ_{GCC}, σ_{base}, and σ_{GCC} are EPIC generated means and standard deviations of crop yield observations at the base and under GCC. Thus, the mean yield after GCC is adjusted by the percentage change in the mean of the simulation models under pre- and post-GCC CO_2 levels. Similarly, the deviations under each of the 13 states are adjusted by the percentage change in the EPIC standard deviation.[4]

Agronomic Impacts of GCC

The results for crop yields were constructed using a CO_2 sensitive version of EPIC. The EPIC crop yield simulations indicate mixed results after GCC, with the magnitude of the change depending on crop, geographic location, and irrigation status (See He). Yields generally increase except in some southern regions. Lower yields are observed under the GFDL scenario than the GISS scenario, a result that is consistent with Adams et al. Both scenarios exhibit significant regional differences in the variability of crop yields.

Regional crop water use requirements in the SPRASM model are adjusted by the percentage change in simulated irrigation water use under the GCC scenarios. Water supply is also altered. Following Adams et al., pre-GCC water supplies are multiplied by the expected percentage change in irrigation water supply following GCC. Under GISS, water supply is expected to decrease in all regions except the Mountain area. Conversely, water supply increases under the GFDL scenario in all regions except the Southern Plains.

Results

The primary focus of this paper is to compare the results of a stochastic partial equilibrium mathematical programming model with results obtained under deterministic assumptions. Consequently, the stochastic SPRASM model is solved using the agronomic and resource usage results arising under the GISS and the GFDL scenarios. The stochastic results are then compared with solution values obtained using mean crop yield outcomes.

Stochastic Results

Table 1 presents price and production solutions under the BASE, GISS, and the GFDL scenarios.[5] Generally, both GCC scenarios result in increased crop production. Production increases result from changes in yields, acreage planted, and/or irrigated acreage. Aggregate production changes are small for most crops, but are over 10% for barley, sugarcane, and sugar beets under both scenarios and for silage under the GISS scenario.

The model also yields stochastic welfare distributions. Table 2 presents the impact of GCC on the means and standard deviations of economic welfare results. Welfare changes from climate warming are small. Generally, the results exhibit parallel changes in both mean and variance under the GISS and GFDL climate scenarios. Domestic consumers' surplus increases slightly on average with 10% decreases in standard deviation. On the producer side, decreases in average producers' surplus of about 14% are predicted with a 6 to 9% decrease in variation. GISS climatic conditions are more favorable for producers' welfare. An increase in average foreign welfare with less variation is also observed. Finally, the average level of total economic surplus is predicted to decrease 0.07% and 0.06% under GISS and GFDL scenarios with decreasing variation.

The stochastic results may also be compared with previous U.S. and world GCC studies. The economic consequences of global warming as forecast here are in general smaller than most previous studies. The world study by Rosenzweig et al. shows the same direction of production and price change under the GISS climate scenario, but a smaller change under the GFDL climate scenario. Adams et al., in their U.S. deterministic study concluded positive welfare effects under the GISS scenario, but negative effects under the GFDL climate scenario.

Deterministic Results

The deterministic analyses were conducted by using the same data as in the stochastic model for all items except yields. The yields were set at the mean of the yields in the stochastic data. Stock additions and removals were excluded. In doing so, the objective function in (1) becomes:

$$\text{Max} \quad \text{CSPS}(q) = \int \mathbf{p}_s(\bar{\boldsymbol{q}})d\bar{\boldsymbol{q}} - \boldsymbol{g}'\text{E}(\boldsymbol{y}) - \boldsymbol{c}'\boldsymbol{x} \qquad (17)$$

where $\bar{\mathbf{q}}$ is the expected production, $\mathbf{E}(\mathbf{q})$.

Table 1. The Impact of GCC on Commodity Prices and Production from SPR Runs

		BASE		GISS				GFDL			
Commodity	Units	Mean	Std[d]	Mean	Percent Change[a]	Std	Percent Change[a]	Mean	Percent Change[a]	Std	Percent Change[a]
I. Prices											
Cotton	bales	409.26	17.12	395.93	-3.26	17.89	4.50	404.69	-1.12	17.63	2.98
Corn	bu	2.46	0.13	2.39	-2.85	0.12	-7.69	2.39	-2.85	0.12	-7.69
Soybeans	bu	5.02	0.30	4.76	-5.18	0.21	-30.00	4.80	-4.38	0.23	-23.33
Wheat	bu	2.98	0.16	2.83	-5.03	0.16	0.00	2.85	-4.36	0.15	-6.25
Sorghum	bu	2.24	0.12	2.18	-2.68	0.11	-8.33	2.18	-2.68	0.11	-8.33
Rice	cwt	10.64	0.37	11.26	5.83	0.39	5.41	10.52	-1.13	0.39	5.41
Barley	bu	1.75	0.16	1.64	-6.29	0.09	-43.75	1.65	-5.71	0.11	-31.25
Oats	bu	1.21	0.34	1.06	-12.40	0.17	-50.00	1.14	-5.79	0.19	-44.12
Silage	tons	14.62	13.03	13.39	-8.41	4.83	-62.93	13.23	-9.51	4.80	-63.16
Hay	tons	70.2	13.12	68 99	-1.72	8.90	-32.16	67.33	-4.09	7.16	-45.43
Sugarcane	1000 lbs	242 64	11.93	245.21	1.06	11.86	-0.59	243 79	0.47	12.55	5.20
Sugarbeets	1000 lbs	242.64	11.93	245.21	1.06	11.86	-0.59	243.79	0.47	12.55	5.20
Nonfed Beef	cwt	160.47	1.06	159.97	-0.31	0.73	-31.13	159.90	-0.36	0.67	-36.79
Fed Beef	cwt	280.72	0 76	279.22	-0.53	2 93	285.53	278.59	-0.76	3 22	323.68
Poultry	GCAU	272.75	10.12	266.84	-2.17	9.74	-3.75	267.25	-2.02	9.78	-3.36
II. Production[b]											
Cotton	bales	12.32	0.89	12.71	3.17	1.0	12.36	12.45	1.06	1.01	13.48
Corn	bu[c]	6.71	0.59	6.58	-1.94	0.41	-30.51	6 68	-0.45	0.42	-28.81
Soybeans	bu	2042.73	153.61	2088.51	2.24	48.41	-68.49	2077.82.	1.72	61.33	-60.07
Wheat	bu	2331.18	140 25	2474.17	6.13	208.23	48.47	2458 04	5.44	165.09	17.71
Sorghum	bu	845.28	76.28	940.46	11.26	76.96	0.89	868.49	2.75	77.19	1.19
Rice	cwt	138.05	4.17	137 14	-0.66	5.11	22.54	139.43	1.00	4.17	0.00
Barley	bu	374 48	38 03	491 75	31.32	52.07	36.92	487.48	30.18	50.27	32.19
Oats	bu	627.12	53.43	620.9	-0.99	50.59	-5.32	601 57	-4.07	45.21	-15 38
Silage	tons	90.34	4 61	100.11	10.81	37.75	718.87	96 45	6.76	3 60	-21.91
Hay	tons	161.88	6.63	162 07	0.12	5.86	-11.61	166 19	2.66	5.45	-17.80
Sugarcane	1000 lbs	6 28	0 28	5.09	-18.95	0.20	-28.57	5 07	-19.27	0.23	-17.86
Sugarbeets	1000 lbs	6.00	0.22	7.14	19.00	0 25	13.64	7.20	20.00	0.27	22.73
Nonfed Beef	cwt	88 28	0.46	88.50	0.25	0.32	-30 43	88 53	0 28	0.29	-36.96
Fed Beef	cwt	146 34	0.35	147.05	0 49	1.38	294.29	147.34	0.68	1.52	334.29
Poultry	GCAU	45.01	0.67	45.4	0.87	0.67	0.00	45 37	0.80	0.66	-1.49

[a] All percentage changes are measured in terms of the change from the base
[b] Production units are in millions of the units listed, if not noted otherwise
[c] Corn is in billions.
[d] Std is an abbreviation for standard deviation

Table 2. Impact of Global Climate Change on Welfare from SPR Runs (in billion 1986 dollars)

	Climate Scenarios						Percentage Change			
	BASE		GISS		GFDL		GISS		GFDL	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Domestic C.S	932 85	1 32	934 22	1.18	934 36	1.19	0 15	-10.94	0.16	-10 05
Domestic P S.	18.52	1.05	15.95	0 98	15.90	0.95	-13 91	-6 29	-14 15	-8 82
Total Foreign Surplus	77 11	0.50	77.64	0.49	77 56	0.50	0 68	-2.51	0.59	-0.34
Total Social Surplus	1028.49	1.41	1027.80	1.21	1027.82	1.26	-0.07	-14 65	-0.06	-10 70

Note. Mean gives the average result.
Std gives the standard deviation of the result
C.S stands for consumers' surplus
P.S. stands for producers' surplus

The deterministic model was used to generate results for the BASE, GISS, and GFDL climate scenarios. Table 3 presents percentage changes in prices and production levels as a result of GCC. Price movements are mixed under both climate scenarios but are similar to the stochastic results.

Welfare changes are generally smaller than under the stochastic model (table 4). Consumers and foreign interests gain more in the stochastic model while producers lose more. The significance of these changes will be formally tested in the next section.

Statistical Comparison of Results

Since the deterministic and stochastic models exhibit different production, price, and welfare solutions, a t-test was done comparing the stochastic analysis results with those from the deterministic analysis. The null hypothesis is that the mean of the stochastic change equals the deterministic change. Table 5 provides the test results on welfare changes under each climate scenario. Both t-values lie more than 2 standard errors below the assumed deterministic results, which leads to the rejection of the null hypothesis at

Table 3. Percentage Changes in Commodity Prices and Production in Deterministic Runs

	Prices		Production	
Commodity	GISS	GFDL	GISS	GFDL
Cotton	-1.88	-1.31	2.10	1.46
Corn	0.00	-0.48	-1.94	-0.90
Soybeans	-5.60	-5.60	2.29	2.25
Wheat	-3.74	-4.28	1.24	2.62
Sorghum	0.00	-0.52	7.01	-8.00
Rice	8.68	3.98	-2.10	-0.99
Barley	0.97	0.48	10.63	11.23
Oats	-4.59	-2.75	4.74	0.75
Silage	-17.44	-15.46	6.35	3.44
Hay	-2.77	-2.79	-0.32	0.49
Sugarcane	2.01	2.10	-6.13	-6.67
Sugarbeet	2.01	2.10	3.96	4.40
Nonfed Beef	-0.81	-0.72	0.66	0.58
Fed Beef	-0.56	-0.52	0.49	0.46
Poultry	-0.77	-0.95	0.30	0.39

Table 4. Aggregate Economic Effects of GCC on Welfare in deterministic Runs (in 1986 dollars)

	Climate Scenario Results			Percentage change	
Economic Surplus	BASE	GISS	GFDL	GISS	GFDL
	(billion dollars)			(percent)	
Domestic C.S.	937.17	938.14	938.15	0.10	0.10
Domestic P.S.	19.67	18.07	18.03	-8.13	-8.34
Total Foreign Surplus	79.61	79.95	79.99	0.43	0.48
Total Social Surplus	1036.45	1036.16	1036.17	-0.03	-0 03

Table 5. T-test Results for Test of Whether Change of Total Social Welfare from Climatic Warming in the SPR Analysis is Equivalent to that in the Deterministic Analysis

	Change from BASE	
t-test components	GISS	GFDL
	(billion dollars)	
Sample Mean SPR Change	-0.685	-0.664
Sample Standard Deviation of SPR change	0.560	0.607
Deterministic Solution Change	-0.29	-0.28
Degrees of Freedom	12	12
t-value	-2.543	-2.281

Table 6. T-test Results of the Hypothesis that Change in Crop Price and Production Solutions From SPR Analysis is Equivalent to that from Deterministic Analysis

	Cotton		Corn		Soybeans		Wheat		Sorghum	
	GISS	GFDL	GISS	GFDL	GISS	GFDL	GISS	GFDL	GISS	GFDL
I. Production Change from Base Solution										
Mean of SPR Change	0.39	0 13	-0 13	-0.03	45.78	35 09	142.99	126 86	95.19	23 21
Sample Standard Deviation of SPR Change	0 16	0.15	0.19	0.18	125.21	118 82	76 36	28 94	4.42	3 16
Change from Deterministic Solution	0.33	0 23	-0 15	-0.07	46 22	45.27	35.53	74.98	62 13	-70 85
t-value	1 35	-2 40	0 38	0.80	-0 01	-0.31	5.07	6.46	1 92	107 31
II Price Change from Base Solution										
Mean of SPR Change	-13 33	-4.57	-0.07	-0.06	-0 26	-0 21	-0 15	-0 13	-0 06	-0 06
Sample Standard Deviation of SPR Change	2.85	2.25	0.04	0 04	0 24	0.23	0.07	0.06	0.04	0 04
Change from Deterministic Solution	-6 04	-4 21	0.00	-0.01	-0.28	-0.28	-0.07	-0.08	0 00	-0.01
t-value	-9.22	-0 58	-6 31	-4.51	0 30	1 10	-4.12	-3 00	-5 41	-4.51

Note: There are 12 degrees of freedom and the critical t-value for 95% equals 1 782

the 2.5% significance level. This indicates that the deterministic results tend to be more optimistic appraisals of GCC effects on total social welfare.

Furthermore, table 6 provides t-test results on changes in prices and production levels of major crops between the stochastic and deterministic results with those from the deterministic ones. Over half of the t-values were found to be significantly different from the assumed deterministic results. Again, for most crops, changes in stochastic prices and production levels are significantly different from changes in the deterministic results.

Concluding Comments

The utility of welfare analysis of technical, environmental or policy changes using partial equilibrium mathematical programming sector models is well-documented. However, such analyses have largely been done in a deterministic manner. Here we follow the general idea posed in Hazell and Scandizzo's risk models and appraise the difference that use of a stochastic method makes in the sectoral analysis. In doing this a risk model was developed incorporating stochastic programming with recourse. This is an expansion on the expected revenue model of HS. The model allows equilibria to be determined wherein processing and demand levels are conditional upon the yield outcomes.

The empirical application of the sectoral model incorporated changes in yield variability resulting from projected global climate change. Historical crop yield data were used to construct a yield distribution and EPIC simulations were used for forecasting yield changes under two climate change scenarios. Comparison of the stochastic results with a deterministic formulation demonstrated that production, price, and welfare values are significantly different between the two models. The deterministic model projected smaller total social welfare effects resulting from GCC. Furthermore, the informational content of SPRASM results is greater, allowing hypothesis testing under alternative environmental or policy scenarios. However, the results are basically identical in sign and direction with significantly, but not terribly, different quantitative results. As a consequence we cannot really conclude that the stochastic model is preferred to the deterministic approach for sectoral analysis, especially given the time and effort involved in developing the stochastic results. More research in different empirical settings is needed to resolve the model superiority question. Finally, we conclude that, based on the climate and crop response models used, trade-neutral global climate change will have a slight negative impact on U.S. food consumers and foreign interests, with losses to producers' welfare of 8-14 percent.

References

Adams, R.M., J.D. Glyer, and B.A. McCarl. "The Economic Effects of Climate Change on U.S. Agriculture: A Preliminary Assessment." *Report to Congress on the Effects of Global Climate Change.* Washington DC: U.S. Environmental Protection Agency, 1988.

Adams, R.M., C. Rosenzweig, R.M. Peart, J.T. Ritchie, B.A. McCarl, J.D. Glyer, R.B. Curry, J.W. Jones, K.J. Boote, and L.H. Allen. "Global Climate Change and U.S. Agriculture" *Nature.* 345(1990):219-224

Apland, J., and Hauer, G. "Discrete Stochastic Programming: Concepts, Examples and a Review of Empirical Applications." Staff Paper 93-21, Department of Agricultural Economics, University of Minnesota, September, 1993.

Boisvert, R.N. and B.A. McCarl. "Agricultural Risk Modeling Using Mathematical Programming." Regional Research Bulletin No. 356. Southern Cooperative Series. (1990):1-103.

Chang, C.C., B.A. McCarl, J.W. Mjelde, and J.W. Richardson. "Sectoral Implication of Farm Program Modifications." *Amer. J. Agr. Econ.* 74(1992):39-49.

Cocks, K. "Discrete Stochastic Programming." *Mgmt. Sci.* 15(1968):72-79.

Dantzig, G. "Linear Programming Under Uncertainty." *Mgmt. Sci.* 1(1955):197-206.

Hazell, P.B.R. and C. Pomareda. "Evaluating Price Stabilization Schemes with Mathematical Programming." *Amer. J. Agr. Econ.* 63(1981): 550-56.

Hazell, P.B.R. and P.L. Scandizzo. "Competitive Demand Structures under Risk in Agricultural Linear Programming Models." *Amer. J. Agr. Econ.* 56(1974):235-44.

Hazell, P.B.R. and P.L. Scandizzo. "Farmers' Expectations, Risk Aversion, and Market Equilibrium under Risk." *Amer. J. Agr. Econ.* 59(1977): 204-19

Hazell, P.B.R. and P.L. Scandizzo. "Market Intervention Policies when Production is Risky." *Amer. J. Agr. Econ.* 57(1975):641-49.

He, Quifen. "The Effect of Global Warming on U.S. Agriculture and its Variability." Masters Thesis, Texas A&M University, December 1992.

Kaiser, H.M. "Climate Change and Agriculture." *N. E. J. Agr. Res. Econ.*, 20(1991):151-63.

Kokoski, Mary F. And V. Kerry Smith. "A General Equilibrium Analysis of Partial Equilibrium Welfare Measures: The Case of Climate Change." *Amer. Econ. Rev.* 77(1987):331-341.

Lambert, D.K. and B.A. McCarl. "Risk Modeling Using Direct Solution of the Expected Utility Function." *Amer. J. Agr. Econ.* 67(1985):846-52.

Lambert, D.K. and B.A. McCarl. "Sequential Modeling of White Wheat Marketing Strategies." *N.C.J. Agr. Econ.* 11(1989):105-15.

Martin, L.J. "Quadratic Single and Multicommodity Models of Spatial Equilibrium: A Simplified Exposition." Cdn. J. Agr. Econ. 29(1981):21-48.

McCarl, B.A. and G.L. Parandvash. "Irrigation Development versus Hydroelectric Generation: Can Interruptible Irrigation Play a Role?" *W. J. Agr. Econ.* 13(1988):267-276.

McCarl, B.A. and T.H. Spreen. "Price Endogenous Mathematical Programming As a Tool for Sector Analysis." *Amer. J. Agr. Econ.* 62(1980):87-102.

Norton, R.D. and G.W. Schiefer. "Agricultural Sector Programming Models: A Review." *Eur. Rev. Agr. Econ.* 7(1980):229-64.

Onal, H. and Y. Fang. "The Effects of Future Climate Change upon the Agriculture of Illinois." *World Resource Review.* 3(1991):259-275.

Pomareda, C. and O. Samayoa. "Area and Yield Response to Price Policy: A Case Study in Guatemala, CA." *Amer. J. Agr. Econ.* 61(1979):683-686.

Rae, Allen N. "Stochastic Programming, Utility, and Sequential Decision Problems in Farm Management." *Amer. J. Agr. Econ.* 53(1971a):448-460.

__________. "An Empirical Application and Evaluation of Discrete Stochastic Programming in Farm Management." *Amer. J. Agr. Econ.* 53(1971b):625-638.

Reilly, John and Neil Hohman. "Climate Change and Agriculture: The role of International Trade." *Amer. Econ. Rev.* 83(1993):306-312.

Rosenberg, N.J., and P.R. Crosson. "Processes for Identifying Regional Influences of and Responses to Increasing Atmospheric CO_2 and Climate Change -- The MINK Project: An Overview." Prepared for the United States Department of Energy. Resource for the Future, Washington D.C., August 1991.

Rosenzweig, C., M. Parry, G. Fischer, and K. Frohberg. "Climate Change and World Food Supply: A Preliminary Report." Manuscript, Environmental Change Unit, University of Oxford, Oxford, UK. May 1992.

Samuelson, P.A. "Spatial Price Equilibrium and Linear Programming." *Amer. Econ. Rev.* 42(1952):283-303.

Sherony, K.R., G.J. Knowles, and R. Boyd. "The Economic Impact of Crop Losses: A Computable General Equilibrium Approach." *W. J. Agr. Econ.* 16(1991):144-155.

Simmons, R.L. and C. Pomareda. "Equilibrium Quantities and Timing of Mexican Vegetable Exports." *Amer. J. Agr. Econ.* 57(1975):472-79.

Takayama, T. and G.G. Judge. "Spatial Equilibrium and Quadratic Programming." *J.Farm Econ.* 46(1964):67-93.

Thaysen K. "An Analysis of Agricultural Risk Implications of United States Policy Changes." Ph.D dissertation in process, Department of Agricultural Economics Texas A&M University, personal communication, 1994.

Tobey, James, John Reilly, and Sally Kane. "Economic Implications of Global Climate Change for World Agriculture." *J. Agr. Res. Econ.* 17(1992):195-204.

U.S. Department of Agriculture. *Agricultural Statistics.* Washington D.C. 1987, 1990.

Weimar, M.R. and A. Hallam. "Risk, Diversification, and Vegetables as an Alternative Crop for Midwestern Agriculture." *N. C. J. Agr. Econ.* 10(1988):75-89.

Willett, K.D. "Single and Multi Commodity Models of Spatial Equilibrium in a Linear Programming Framework." *Cdn. J. Agr. Econ.* 31(1983):205-21.

Endnotes

1. See Boisvert and McCarl or Apland and Hauer for a more comprehensive review.

2. Sherony, Knowles and Boyd's computable general equilibrium (CGE) analysis of the 1988 drought, a proxy they chose for global warming, confirmed the small general equilibrium social welfare effects of changes in expected crop yields.

3. Adams et al. use the results of two GCC simulators because of differences in predicted temperature and precipitation levels resulting from those simulators.

4. The mixture of EPIC and actual data was used to both avoid calibration problems with the absolute yields in EPIC and to maintain the interregional and intercrop correlation in the original yield deviations while altering the mean and variance to reflect GCC. Revision of the correlations under global warming was not undertaken as a version of EPIC which preserved interregional and intercrop weather correlation data was not available.

5. SPRASM generates a market equilibrium under each state-of-nature. Consequently, price, production, and welfare projections are derived under each of the 13 states of nature. Only summary statistics are reported here.