# The Economic Impact of Crop Losses: A Computable General Equilibrium Approach

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The impact of crop losses on the U.S. economy are analyzed using a Computable General Equilibrium (CGE) Model. In doing so, concerns about widespread crop losses due to a global climate change or environmental event are addressed. The CGE approach allows for analysis of the interactions between supply and demand within agricultural markets as well as between these markets and the rest of the economy. The results suggest that policy responses which allow free market pricing signals to determine production mitigate the effects of an event that approximates the drought of 1988.

*Key words:* general equilibrium, agriculture, climate change.

During the past decade, concerns have been raised about the effects on the U.S. economy of sustained and widespread crop losses resulting from environmental changes. One issue gaining increased attention is the possible impact on agricultural production of a global climate change arising from an increase in atmospheric temperature caused by a build-up of gases, especially carbon dioxide (Adams; Rosenzweig). Some climatologists argue that the earth is in a warming trend, noting that the four warmest years of the past 150 occurred in the 1980s (*Economist*). Although the exact cause of this trend is unknown, droughts in North America in 1980, 1983, and 1988 and the prolonged and widespread drought in Sub-Saharan Africa which began in 1983 have been attributed to this global climate change.

Sustained and widespread crop losses reverberate throughout the economy, affecting price and production in both agricultural and nonagricultural sectors as well as income and international trade. Policy makers will be expected to provide appropriate initiatives designed to mitigate these effects. The policies should extend beyond traditional agricultural issues of price instability, food shortages, and low farm income, without exacerbating problems by distorting price signals necessary for efficient resource reallocation throughout the economy.

The purpose of this article is to analyze the impacts on the U.S. economy of permanent crop losses. Economy-wide changes in production, prices, and resource allocations are analyzed using a Computable General Equilibrium (CGE) model. The CGE approach allows for analysis of the interactions between supply and demand within agricultural markets as well as between these markets and the rest of the economy. CGE results can then be used to develop policies which address both sectoral and economy-wide effects. Thus, CGE simulation represents a methodological improvement over analysis confined solely to agricultural sectors.

CGE models are used often for public policy evaluation. However, traditional CGE analyses in public finance and international trade have focused on the role of labor and capital as inputs to the production process (Shoven and Whalley 1984) and have largely ignored the role of land. While models that focus on

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agriculture have explicitly accounted for land, they have been designed to analyze specific agricultural policies such as food subsidies and agricultural price supports (de Janvry and Sadoulet) or preferential tax policies for agriculture (Hertel and Tsigas 1988). By contrast, this study is designed to quantify the economy-wide impact of permanent crop losses. The agromanagement model EPIC is used to simulate the effects of the 1988 drought on crop yields and management practices. The resulting crop losses and increased management costs are incorporated into the CGE model to examine the impact on individual agricultural sectors, agriculture-related industries, and the economy in general.

## A General Equilibrium Model

The model presented below follows the tradition of the Shoven and Whalley (1972) taxation analysis and incorporates some methodological enhancements by Hudson and Jorgenson. It specifies a distinct demand system for each group of households by recognizing differences in the preferences of consumers as a function of their incomes. The specification of producer behavior couples neoclassical microeconomic assumptions with price-responsive input-output relationships. The model of consumer behavior is integrated with the model of producer behavior to provide a comprehensive framework for general equilibrium simulations. The equilibrium is determined by a vector of market-clearing prices for all goods and services, given the endowments of labor, capital, and natural resources.

On the supply side, production is represented by nested constant-elasticity-of-substitution (CES) functions that exhibit constant returns to scale.[1] The technology embedded in the production functions is prespecified and remains unchanged. This is reasonable, especially over the initial period of adjustment because of the extended time it takes to develop, test, and disseminate most new agricultural technologies on a large scale. More importantly, the immediate choices for policy makers will be restricted to those afforded by current agricultural technologies.

On the demand side, the model captures the behavior of consumers, the government, and the foreign trade sector. Consumers are grouped according to income, and a demand system is specified for each of six income groups. Each income group has an endowment of labor and capital and, given prices, decides the amount to save and the amount of each good and service to purchase. The government levies taxes on both production and consumption. There are taxes on factors of production, on output, on income, and on consumption. Government revenues then are distributed as income to consumers and are used to purchase goods, services, capital, and labor.

The foreign sector produces imports and consumes exports. A trade balance is assumed to hold at all times, but the exchange rate is not explicitly incorporated into the model specification. Following Ballard et al., exports are scaled upward to match imports in the 1984 benchmark year.[2] Specifically, the 1984 trade deficit is allocated proportionately among exporting sectors according to the original value of exports in each sector. Foreigners are regarded as consumers who purchase United States' exports with income from the sale of imports to the U.S.

Table 1 presents a key defining the symbols that appear in the analysis and delineates the specific producing sectors, types of consumer goods and services, and household income categories. The level of disaggregation depends upon data availability and upon judgments regarding which economic variables are of most interest for the problem at hand.

### *Production and Factor Inputs*

The production sector of the CGE model incorporates input-output relationships that allow substitution of the primary factor inputs (capital, labor, and land). The degree of flexibility depends on the choice of functional form

[1] This nested CES format with its global concavity features is appropriate for evaluating a supply shock. It is, however, not the only functional form used in CGE models. In their linearized model of U.S. agricultural tax policy, Hertel and Tsigas (1987a, b; 1988) make use of a (translog) flexible functional form, while in his model of U.S. manufacturing quotas, Tarr uses a linear expenditure system.

[2] This is done for both technical and economic reasons. Technically, such an assumption makes it relatively easy to balance all markets in the benchmark case. In economic terms, this makes it possible to strictly compare relative import and export price changes from the benchmark case.

**Table 1. Key to Symbols**

| | |
|---|---|
| | Industries |
| *AGONE* | Program Crops |
| *AGTWO* | Livestock |
| *AGTHR* | Nonprogram Crops |
| *CHEM* | Chemicals and Plastics |
| *CRUDE* | Crude Oil and Natural Gas |
| *FINAN* | Financial |
| *FOREST* | Forestry |
| *FOTB* | Food and Tobacco Products |
| *MAN* | Manufacturing |
| *MIN* | Mining |
| *REF* | Petroleum Refining |
| *SER* | Service |
| | Consumer Goods |
| *ALTB* | Alcohol and Tobacco |
| *CLJEL* | Clothing and Jewelry |
| *FINSR* | Financial and Other Services |
| *FOOD* | Food |
| *FRAPP* | Furnishings and Other Appliances |
| *GAS* | Gasoline and Other Fuels |
| *HOUSE* | Housing |
| *MOTOR* | Motor Vehicles |
| *NONDR* | Nondurable Household Items |
| *RANDR* | Reading and Recreation |
| *SAVEN* | Savings |
| *TRANS* | Transportation |
| *UTIL* | Utilities |

Household Categories

| Income Category | Income Range |
|---|---|
| 1 | \$0–9,999 |
| 2 | \$10,000–14,999 |
| 3 | \$15,000–19,999 |
| 4 | \$20,000–29,999 |
| 5 | \$30,000–39,999 |
| 6 | \$40,000 and above |

for the production functions. Each production sector is assumed to have a CES production function where sectoral value added is a function of labor and capital. For the three agricultural sectors and the forestry sector, land is included as a third factor of production because of the special importance of this input to these sectors. Land is incorporated by nesting the CES production function.[3] In addition, the government demands primary inputs. Labor and capital are used to provide government services and produce public goods for general consumer use.

The sale of output of the 12 producing sectors generates income that is distributed to the owners of the factors of production. The factor payments are used to purchase goods, pay taxes, or save.

## *Demand*

Table 1 shows that the composition of the consumer goods and services sectors does not match that of the producing sectors because the output of the producing sectors must go through various channels (i.e., transportation and distribution) before it can be consumed. A transformation matrix is introduced which specifies the contribution of each producing sector to the composition of each of the final goods and services. The demand for final goods and services comes from four primary sources: direct consumption by individuals, investment purchases, government purchases, and foreign purchases.

For households, utility is assumed to be a weighted function of the 13 consumer goods and services. The weights, which are household-category specific, are computed as the share of total purchases attributed to a specific consumer good or service. The nature of the CES utility function implies that the elasticity of substitution is the same between any pair of goods and/or services. Because reliable estimates of the respective substitution elasticities across pairs of goods and/or services are difficult to obtain, initially all are assumed to equal one.[4] Finally, the assumption is made that consumers derive utility from the consumption of leisure.[5]

The budget constraint is defined such that a household's expenditures on goods and services must be less than or equal to the total factor payments it receives. Maximizing utility subject to this expenditure constraint results in demand for goods and services by house-

[3] In particular, an input is defined which is solely a function of land and capital (in CES form). This takes the place of capital in the original production function specification. While it would be possible to simply add land as an explicit input in the production function, this would implicitly assume that the elasticity of substitution between all pairs of inputs are the same. Nesting permits the substitution elasticities to differ among inputs.

[4] Since there is no a priori reason why this elasticity should be one, it was varied from .8 to 1.2 for all consumer income classes. As expected, agricultural demand (and revenue) declines as substitutability rises. Changes in all revenues vary less than .0001% indicating that the magnitude of our results is quite robust with respect to this parameter.

[5] In the utility function leisure is assigned a weight of .5 times labor income. See Boyd for a discussion of the choice of this value. Drawing from studies reviewed by Killingsworth, an aggregate leisure demand elasticity of −.3 is used.

hold categories. Saving is an argument in the consumer's utility function. Thus, intertemporal tradeoffs in consumption are an integral part of the model.

The second component of the demand for goods and services is investment. Total investment in the CGE model is a flow of funds that is translated into sectoral investment demands for goods and services through a transformation matrix. Investment data, taken directly from the national income and product accounts as compiled by the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce (USDOC), are used to construct and calibrate the model. Since saving is assumed to exactly equal investment, personal saving is scaled to equal the gross investment observed for each of the 12 producing sectors.[6]

The government also demands goods and services, purchasing them as intermediate outputs. This is realistic for most sectors and particularly true for agriculture, where raw products are purchased for government storage.

The final component of demand for goods and services is exports. Since exports are delineated by the production sector, a matrix is used to transform each sector's output into final goods and services. A similar matrix is used to transform imports (foreign supply).[7] Exports and imports are scaled so that the balance of payments is in equilibrium. Demand and supply estimates found in the literature are used to construct import supply and demand relationships for each producing sector. The import demand elasticities are $-.8$ for the agricultural industries (Tarr). Crude and Refining import demand elasticities are $-1.1$ and $-1.4$, respectively (Uri and Boyd). Elasticities for all other industries range from $-1.0$ to $-1.4$ (Stern, Francis, and Schumacher). Following Ballard et al., an aggregate import supply elasticity of .4 for all trading sectors is used.

[6] Following the calculations of Ballard et al., a total as well as a sector-by-sector breakdown of investment is obtained. Since saving equals investment in equilibrium, consumer saving is scaled upward so that it equals total investment and is apportioned to each sector to match 1984 sectoral investment. Using Boskin's work, a saving/consumption tradeoff is derived for each income class. Hence when the model is perturbed, consumers are allowed to allocate their funds between consumption and saving according to Boskin's savings elasticities. This, in turn, affects the new level of investment in each output sector.

[7] In modeling imports, Armington's assumption that imported goods are imperfect substitutes for their domestic counterparts is employed. This same assumption is made by Robinson, Kilkenny, and Adelman and by Hertel, Tsigas, and Thompson in their CGE models of agricultural trade.

### *Government and Taxes*

The government is treated as a separate sector with a Cobb-Douglas utility function. Tax receipts affect factor usage and prices as well as output and prices of final goods and services. The government collects tax revenue in several forms. Taxes include personal income tax, labor tax, capital tax, sales and excise tax, and property tax. All taxes are ad valorem taxes, and marginal rates are used for each income group. The model represents a distinct improvement over earlier general equilibrium models which simply employed lump sum transfer schemes or used average tax rates (see Shoven and Whalley 1984).

The government produces public goods and redistributes income with the tax revenue collected. Redistribution in the model is handled by means of transfer payments. In addition to land, labor, and capital, each of the six consumer groups is endowed with a given amount of transfer income from the government. This income is used to purchase goods and services and hence enters directly into each group's utility function. The level of government expenditures of public goods is held constant during all runs of the model.[8]

### *A Mathematical Statement of the Model*

On the basis of the preceding discussion, the precise conditions that must be satisfied for a general equilibrium to exist are:

(i) No positive excess quantities demanded:

$$(1) \quad \sum_{j=1}^{m} a_{ij}M_j - E_i(p, Y) \geq 0 \qquad \text{for } c.s.\ p_i \geq 0,$$

where $i$ ($i = 1, 2, \ldots, n$) denotes the consumer goods and services; $a_{ij}$ denotes the $ij$th element in the activity analysis matrix; $M_j$ ($j = 1, 2, \ldots, m$) denotes the activity levels; $E_i$ denotes the demand for good or service $i$; $p$ denotes a vector of prices for the $n$ consumer goods and services; and $Y$ denotes a vector of incomes for the $k$ consumers.[9]

[8] Public goods are created by land, labor, capital, and materials purchased by the government. These goods are not paid for by consumers and are consumed collectively. Keeping expenditures on such goods constant permits utility comparisons.

[9] The notation *c.s.* implies that complementary slackness holds for each consumer good and service. If the expression for a specific good or service is multiplied by $p$, the relationship will hold with equality. For a more detailed discussion, see Takayama and Uri.

(ii) No positive economic profits associated with a given activity:

$$(2) \qquad -\sum_{j=1}^{m} a_{ij}p_i \geq 0 \qquad \text{for } c.s.\ M_j \geq 0.$$

(iii) Nonnegative prices and activity levels:

$$(3a) \qquad p_i \geq 0, \qquad i = 1, 2, \ldots, n$$

and

$$(3b) \qquad M_j \geq 0, \qquad j = 1, 2, \ldots, m.$$

The model is solved for a general equilibrium using the interactive algorithm Sequence of Linear Complementary Problems (SLCP) developed by Mathiesen (1985a, b).

*Data for the 1984 Base Year*

The general equilibrium model is calibrated for 1984. For the producing sectors, capital receipts and taxes were computed from data obtained directly from USDOC, the U.S. Department of Agriculture [USDA (1987a)], the U.S. Department of Energy (USDOE), and from Hertel and Tsigas (1987b). Capital income (earnings) and labor income were obtained from the USDOC. Land income was estimated using factor shares obtained from USDA (1987a) and applied to the capital income component. Data for expenditures by each of the six household categories on each of the 13 goods and services were obtained from the Bureau of Labor Statistics. Data for the number of households in each income category were from the BEA. This information was used to compute aggregate expenditures by each household for each category of consumer goods and services. Marginal tax rates were obtained from the U.S. Department of the Treasury, the USDA (1987a), Hertel and Tsigas (1987b), and Ballard et al. Agricultural subsidy and loan data were based on Hertel, Chattin, and Tsigas and are the same as those used in Hertel, Tsigas, and Thompson. Finally, the values for exports and imports in 1984 were taken from USDOC with the exception of energy data obtained from the Energy Information Administration of the USDOE and agriculture data obtained from the USDA (1987b).

Benchmark prices for all activities were normalized to one. Changes from the benchmark calibration, hereafter referred to as the benchmark (BM) case, are not exhausted immediately after the perturbations occur because of the intertemporal optimization in consumption. Therefore, the impact of exogenous changes on equilibrium prices and quantities represents the difference between long-run equilibrium positions.[10]

Following any perturbation of the model, the prices and wages facing consumers will change, and each individual will want to change his/her consumption of leisure accordingly. In order to make predictions as accurate as possible, the most current marginal tax rates available were employed. Thus, although the model is calibrated to 1984 data, individuals change their consumption of leisure in accordance with the marginal tax rates implied by the Tax Reform Act of 1986.

## A Methodological Caveat

The primary advantage of general equilibrium analysis is that all interrelationships among sectors, both consuming and producing, are specified explicitly. Since all economic agents are maximizers, no transactions are conducted at prices other than equilibrium. Thus for every factor of production and every good and service consumed, the quantity supplied must exactly match the quantity demanded, i.e., all markets are required to clear.

Another advantage of the CGE model approach is that it is disaggregated and hence can identify sector-specific impacts. CGE analysis explicitly accounts for the fact inputs and outputs of sectors are interconnected. In addition, such analysis allows for the allocation of finite raw inputs to the sector with the highest return.

The general equilibrium modeling approach has some limitations. The values of the various parameters and elasticities usually are specified from the results of outside research. Estimates for many of the parameters are sparse and the literature is sometimes contradictory. This does not mean that a complete set of econometric results cannot be generated at some future date. The complexities of such an

[10] Like all other goods, the price of imports takes on the value of one in the BM case. When the model is perturbed and demand for a tradeable good rises (falls), imports of that good will rise (fall) according to its import demand elasticity. Because of the assumption that imports and domestically produced goods are imperfect substitutes, an import price can diverge from its domestic counterpart. A new equilibrium occurs when the value of all imports equals the value of all exports.

undertaking, however, are enormous (Jorgenson; MacKinnon), and so it is not attempted here.

Another assumption that does not completely emulate reality is that consumer and producer behaviors are modeled with full and complete adjustment between perturbations. Lags associated with the adjustments of each producing and consuming sector's various factors are not modeled, although the magnitude of the full adjustment is captured. This, in turn, implies that inventories adjust to perturbations of the model in an optimal manner.[11] Additionally, there is the implicit assumption that all economic agents know the vector of final equilibrium prices, thus allowing for full adjustment on their parts.

These limitations imply that the results of the modeling should not be accepted unequivocally. Rather, the interpretation of the results provides insights into the distributional effects of a crop loss that would not be forthcoming in models that use conventional econometric techniques.

## General Equilibrium Results

To simulate a crop loss, it could be assumed that losses vary uniformly across the U.S., and an event like the drought of 1988 could be entered into the CGE model as a simple parametric shift. However, many types of crops are confined to particular regions. To address the problem of nonuniform crop losses, the EPIC (Erosion-Productivity Impact Calculator) model developed by the USDA was utilized (Williams, Jones, and Dyke; Williams, Dyke, and Fuchs; Putnam and Dyke). The EPIC model is a Biological-Management simulator and divides the United States into physiographic regions. Data on crops in these regions are entered and the submodels calculate plant stress under various temperature and precipitation levels.[12]

The EPIC model can be used to analyze various disaster scenarios. While technology remains at a specified level, the model allows fertilizer and irrigation water applications to vary as necessary at predetermined trigger levels. Once a specific disaster scenario is entered, the model calculates the resulting output levels and management costs for each crop type. The CGE model is perturbed from the BM case by entering the EPIC results calculated for the 1988 drought. All markets in the economy then are allowed to adjust.[13]

Table 2 presents percentage changes in quantities and prices for each sector using three different specifications of the model. The first specification, hereafter referred to as the Regular Demand Elasticity (RDE) case, provides results generated by the CGE model utilizing elasticities of substitution for the agricultural sectors derived from information contained in Caddy and in Hertel and Tsigas (1987a). The elasticity of substitution between labor and the other primary inputs is .8 while the elasticity of substitution between land and capital is .3.[14] The second and third specifications, the Low Demand Elasticity (LDE) case and the Cobb-Douglas (CD) case, respectively, consider alternative elasticities of substitution in production and are used in the sensitivity analysis section below to examine the robustness of the results.

### *Production Sector*

In the RDE case, the crop loss has its most pronounced quantity impact on program crops (*AGONE*), which decline by 15.4% (table 2). Though the crop losses simulated by EPIC are 24.3%, the final decline from the CGE model is less since producers respond to output prices which rise over the adjustment period and allow for factor substitution. Livestock production (*AGTWO*) falls by .90%, a decline which exceeds the .58% decrease predicted by EPIC. This relatively larger decrease is attributed to

[11] In the case of public inventories, the assumption that the government behaves like any other expenditure-minimizing agent is made. This assumption is identical to that made in Ballard et al.

[12] As Howe points out, streamflows in the West are highly variable due to rain and the depth of snowpack. Studies by Adams, Glyer, and McCarl; Dudek; and Adams et al. indicate that California and the Pacific Northwest gain at the expense of more southerly climates. These conclusions are similar to EPIC predictions that crops in California suffer little in comparison to program crops.

[13] When the cost and output changes derived from EPIC are entered into the CGE model, further (long-run) adjustments of inputs are made. These adjustments include changes in all chemical inputs to agriculture, changes in energy inputs to agriculture, and changes in the level of labor and capital intensity of agricultural production. The causal chain is quite clear. A climate change affects the production functions of the agricultural sectors themselves. This in turn affects the prices and quantities of commodities and inputs throughout the economy.

[14] See Boyd for sources of the values of all other elasticities of substitution.

**Table 2. CGE Percentage Quantity and Price Changes from Benchmark**

| | % Quantity Changes | | | % Price Changes | | |
|---|---|---|---|---|---|---|
| | RDE | LDE | CD | RDE | LDE | CD |
| | | | Industries | | | |
| *AGONE* | −15.359 | −15.286 | −15.746 | 25.528 | 25.618 | 26.070 |
| *AGTWO* | −0.898 | −0.710 | −1.056 | 0.605 | 0.701 | 1.186 |
| *AGTHR* | −0.776 | −0.629 | −1.066 | 0.396 | 0.480 | 0.905 |
| *CHEM* | −0.168 | −0.180 | −0.170 | −0.049 | −0.049 | −0.050 |
| *CRUDE* | 0.402 | 0.382 | 0.441 | −0.308 | −0.309 | −0.325 |
| *FINAN* | −0.142 | −0.233 | −0.130 | −0.118 | −0.119 | −0.128 |
| *FOREST* | 0.278 | 0.306 | 0.200 | 0.408 | 0.427 | 0.519 |
| *FOTB* | −0.810 | −0.590 | −0.932 | 1.058 | 1.096 | 1.282 |
| *MAN* | 0.398 | 0.386 | 0.422 | 0.000 | 0.000 | 0.000 |
| *MIN* | 0.352 | 0.350 | 0.380 | −0.133 | −0.134 | −0.141 |
| *REF* | 0.325 | 0.298 | 0.359 | −0.250 | −0.251 | −0.264 |
| *SER* | −0.124 | −0.119 | −0.131 | −0.033 | −0.032 | −0.031 |
| | | | Consumer Goods | | | |
| *ALTB* | −0.586 | −0.408 | −0.682 | 0.511 | 0.530 | 0.624 |
| *CLJEL* | −0.049 | −0.114 | −0.034 | −0.023 | −0.023 | −0.023 |
| *FINSR* | −0.039 | −0.107 | −0.024 | −0.032 | −0.032 | −0.031 |
| *FOOD* | −0.845 | −0.561 | −0.949 | 0.770 | 0.791 | 0.891 |
| *FRAPP* | −0.055 | −0.117 | −0.040 | −0.016 | −0.016 | −0.016 |
| *GAS* | 0.068 | −0.057 | 0.092 | −0.143 | −0.143 | −0.149 |
| *HOUSE* | 0.037 | −0.080 | 0.062 | −0.111 | −0.112 | −0.120 |
| *MOTOR* | −0.048 | −0.114 | −0.031 | −0.024 | −0.024 | −0.025 |
| *NONDR* | −0.029 | −0.108 | −0.011 | −0.047 | −0.047 | −0.049 |
| *RANDR* | −0.093 | −0.137 | −0.091 | 0.018 | 0.021 | 0.033 |
| *SAVEN* | −0.029 | −0.026 | −0.010 | 0.019 | 0.020 | 0.021 |
| *TRANS* | −0.040 | −0.109 | −0.026 | −0.033 | −0.032 | −0.031 |
| *UTIL* | −0.043 | −0.113 | −0.027 | −0.033 | −0.032 | −0.031 |
| % Change in Aggregate Consumer Prices | | | | 0.113 | 0.117 | 0.137 |
| | | | Imports | | | |
| *AGONE* | −25.047 | 25.129 | 25.547 | 49.780 | 49.943 | 50.771 |
| *AGTWO* | 0.116 | 0.204 | 0.654 | 0.720 | 0.904 | 1.840 |
| *AGTHR* | −0.093 | −0.016 | 0.373 | 0.305 | 0.465 | 1.279 |
| *CHEM* | −0.538 | −0.545 | −0.581 | −0.587 | −0.594 | −0.631 |
| *CRUDE* | −0.957 | −0.968 | −1.030 | −1.264 | −1.276 | −1.354 |
| *FOREST* | −0.081 | −0.069 | −0.013 | 0.327 | 0.358 | 0.506 |
| *FOTB* | 0.569 | 0.599 | 0.750 | 1.627 | 1.694 | 2.032 |
| *MAN* | −0.489 | −0.496 | −0.532 | −0.489 | −0.496 | −0.532 |
| *MIN* | −0.622 | −0.630 | −0.673 | −0.755 | −0.764 | −0.814 |
| *REF* | −1.705 | −1.725 | −1.837 | −1.948 | −1.969 | −2.093 |
| *SER* | −0.522 | −0.529 | −0.563 | −0.554 | −0.561 | −0.594 |
| Foreign Exchange | | | | 0.489 | 0.497 | 0.533 |
| | | | Factors of Production | | | |
| Capital | | | | −0.583 | −0.586 | −0.616 |
| Labor | | | | 0.100 | 0.100 | 0.103 |
| Land | | | | −14.537 | −14.108 | −11.877 |

Note: RDE = Regular Demand Elasticitiy case; LDE = Low Demand Elasticity case; and CD = Cobb-Douglas case. See table 1 for definitions of variables.

the rise in input prices. In particular, *AGONE* prices, which include the prices of many feed grains, rise by 25.5%. On the other hand, a relatively small overall decline in *AGTWO* production occurs despite the rise in feed grain prices because low-cost resources, especially land for forage and grazing, flow to this sector and temper strict input-output induced declines. The decline in nonprogram crops (*AGTHR*) production is .78%, and is less than the 2.2% decline predicted by EPIC. This relatively smaller decrease also results from substitution effects. Finally, while program crop prices rise 25.5%, prices in the livestock and nonprogram crop sectors rise to a much smaller extent. These price changes are congruent with the output changes.

The effect of the crop loss in other sectors of the economy also can be observed within the CGE framework. Production and prices in agricultural output industries adjust as the prices of agricultural commodities, which are inputs to these industries, rise. For example, the food and tobacco industry (*FOTB*) realizes production declines of .81% with prices rising by 1.06%. The production of final consumer goods categorized under food (*FOOD*) and alcohol and tobacco (*ALTB*) decline by .845% and .586% as prices rise by .77% and .51%, respectively. Price increases in primary agricultural commodities (*AGONE, AGTWO, AGTHR*) are passed along the food marketing chain first to the intermediate industry (*FOTB*) and finally to the consumer goods sectors (*FOOD, ALTB*). However, the surge in primary commodity prices is mitigated as it is passed along because primary commodities represent a smaller share of total inputs used in the intermediate and final goods industries.

The 14.5% decline in the price of land is notable. This price decline reflects its lower productivity, especially in the *AGONE* sector. This lower price helps moderate the production declines in the livestock and nonprogram crop sectors and helps explain the .278% rise in forestry production (table 2, *FOREST*) that takes place as land is shifted into production activities less susceptible to losses. The price of land falls despite the increase in agricultural output prices. This scenario is different from the factors affecting the land market in the 1970s and 1980s when land values rose and fell with the expectations of future earnings that varied with commodity prices (Melichar). Rather, in this case, earnings fall with the decline in productivity.

Finally, most nonagricultural imports decline and agricultural imports rise, especially *AGONE* imports. Fewer imports are drawn into the nonagricultural sectors as the relative domestic price of nonagricultural products declines.

### *Consumption Sector*

The inclusion of utility functions for six different income categories of consumers permits use of CGE results to explore the impact on consumer welfare. A widely employed measure of the welfare gain or loss is the Hicksian equivalent variation.[15] When the utility function is linear homogeneous as in this case, equivalent variation is the percentage change in utility level multiplied by the original level of income. Multiplication by income, however, tends to obscure regressivity that may exist. An alternative method for measuring the distribution of the welfare loss is to determine the percentage change in utility level. The results presented in table 3 are percentage changes in utility levels and indicate a relatively larger utility loss for the lower income groups. Except for the highest income group, the fall in utility diminishes as income rises and is attributable to the smaller fraction of income higher income groups spend on food. The higher utility loss for income group six (−.175%) versus income group five (−.165%) is due to the fact that those with incomes of $40,000 and above are more likely to be land and capital owners who experience losses when the relative values of land and capital decline.

It is also important to know the equity effects of crop losses on landowners themselves. Indeed, a major concern is how small farmers will be hurt relative to their larger counterparts. Table 4 presents losses to landowners by income category. It is apparent that the largest absolute dollar losses are incurred by the higher income classes. However, when looking at the losses to landowners as a percent of income, we find that the highest relative losses are suffered by those with incomes less than $20,000. This is due primarily to the high proportion of assets held in land by lower income groups.

**Table 3. Equivalent Welfare Variations by Income Class—Percentage Change from Benchmark**

| Income Category | RDE | LDE | CD |
|---|---|---|---|
| 1 | −.26226 | −.26269 | −.26099 |
| 2 | −.25154 | −.25245 | −.25429 |
| 3 | −.23260 | −.23338 | −.23377 |
| 4 | −.18824 | −.18903 | −.18950 |
| 5 | −.16462 | −.16562 | −.16645 |
| 6 | −.17511 | −.17725 | −.18580 |

Note: See note to table 2 for definitions of RDE, LDE, and CD.

[15] For further discussion on welfare comparisons of this type, see Shoven and Whalley (1984).

**Table 4. Loss to Landowners by Income Category ($ million)**

| Income Category | RDE-BM | LDE-BM | CD-BM |
|---|---|---|---|
| 1 | 377 | 399 | 277 |
| 2 | 361 | 381 | 217 |
| 3 | 436 | 461 | 262 |
| 4 | 983 | 1,038 | 591 |
| 5 | 865 | 914 | 520 |
| 6 | 1,456 | 1,537 | 875 |

**Loss to Landholders as a Percentage of Income (by Income Category)**

| Income Category | RDE-BM | LDE-BM | CD-BM |
|---|---|---|---|
| 1 | .242 | .256 | .145 |
| 2 | .255 | .269 | .153 |
| 3 | .265 | .280 | .159 |
| 4 | .242 | .256 | .146 |
| 5 | .230 | .243 | .138 |
| 6 | .155 | .164 | .093 |

Note: BM = benchmark. See note to table 2 for definitions of RDE, LDE, and CD.

The final evaluation of the effect on consumers considers the change in consumer prices. Table 2 presents Laspeyres price indices for the percentage change in aggregate consumer prices from the BM case calculated from the 13 consumption goods sectors. The model predicts prices will rise .11%. This indicates that changes in agricultural prices have a small impact on the overall level of prices for the economy.

*Sensitivity Analysis*

Sensitivity analysis is used to evaluate the appropriateness of some of the key assumptions of the model. This is accomplished by generating CGE results using models that employ alternative parameter values. If an appropriate model is specified initially, the impact of using alternative parameter values will affect the results only marginally. Due to uncertainty about the precise values of the factor demand elasticities used, two sets of sensitivity results are considered. The first is for the Low Demand Elasticity (LDE) case, in which the elasticities of substitution between the factors of production are lower values than those for the RDE case reported above. The second is for the Cobb-Douglas (CD) case, with the elasticity of substitution between land, labor, and capital in the agricultural and forestry sectors restricted to unity.

The LDE and CD case results are included in tables 2, 3, and 4 with RDE case results. Table 2 shows that the percentage change in quantity from the benchmark for program crops, livestock, and nonprogram crops under both the LDE and CD case specifications is similar to the RDE case, with the greatest difference occurring in the CD case where the elasticities of input substitutes are greatest. The price results indicate minimal sensitivity to elasticity changes. The effects on other sectors of the economy also are minor, including small differences in quantity and price changes in those industries and consumer goods sectors related to food and agriculture.

The effects on the consumption sector also are minor. Table 3 shows that the percentage changes in utility are minimally affected by altering the model's specification. In table 4 landholders' losses vary little under different parametric changes with the smallest losses coming when land use is relatively easy to alter. Finally, table 2 shows that the change in aggregate consumer prices also is quite insensitive to the various parametric assumptions.

This sensitivity analysis indicates that the results presented for the RDE case represent the general economic impact of a loss in agricultural production. The results are robust and are not merely the consequence of the elasticity assumptions that have been made.

## Conclusions and Policy Implications

This CGE analysis of crop losses due to global climate or environmental change suggests that increases in retail food prices and the overall price level will be minimal. There are several reasons for this. First, farm gate prices are only a small component of retail food prices. Second, food prices account for less than 20% of the Consumer Price Index (CPI). Third, international trade balances adjust to mitigate the price impact of domestic crop losses.[16] Finally,

[16] Because of the importance of the international sector in offsetting such crop losses, a sensitivity check with respect to changes in the model's import elasticities was conducted. Specifically, the import elasticities for all agricultural production sectors were raised and lowered by .5. Hence, simulations were conducted with import elasticities of −.3 and −1.3 in addition to the original estimate of −.8. Lowering these import elasticities causes program crop im-

and most importantly, the price flexibility embodied in CGE analysis permits production and consumption substitutions that play a vital role in the economy's ability to respond to climatic-environmental events.

The moderate effect on prices identified in this study is consistent with recent analyses that have examined the short-term impacts of droughts. Both Smith and Benjamin found that carryover stocks of grain serve to buffer the inflationary shocks of previous droughts and demonstrated that one year after each drought the percentage increases in farm prices and in the food component of the CPI were less than the percentage increase in the CPI for all items. In addition, surplus stocks were rebuilt quickly as acreage restrictions were lifted, encouraging farmers to expand acreage.

Although the CGE analysis suggests a moderate overall impact, the process of adjusting to a climatic environmental change would bring hardships to the farm sector. The pressure on agricultural policy makers to provide income support may be considerable, especially if small landholders suffer high relative losses. Agricultural policy, which historically has been based on price supports, may require new directions since a global climate change causing crop losses affects agricultural regions disproportionately (Adams, Glyer, and McCarl). Individual farmers whose yields are reduced severely will not benefit from price supports because such programs do not address the asymmetrical effects of crop losses across producers. In addition, if price supports are maintained and price signals distorted, the market forces needed for timely adjustment will be delayed, exacerbating the effects of the climatic environmental change. Furthermore, a reliance on disaster relief programs that are implemented after crop losses occur is not a desirable policy option. Disaster relief programs delay timely adjustments by producers because some of the production risks are shifted to the taxpayer.

The challenge for policy makers, therefore, is to design a policy that encourages price flexibility yet confronts the prospect that individual farmers suffer losses asymmetrically. Farm policy should rely on programs that insure individual farmers against crop losses rather than those that alter prices. One potential strategy is for the government to modify the all-risk crop insurance program to increase participation and provide incentives for farmers to adjust their production practices to the changing environment by adopting a risk-based premium schedule. Such a policy protects individual farmers who sustain substantial crop losses, allows prices and premiums to signal necessary resource adjustments, and avoids moral hazard problems of disaster relief programs.

A compromise policy which allows market prices to influence production decisions while continuing certain price supports is the Production Entitlement Guarantee (PEG) proposed by Blandford et al. This program limits the quantity of production eligible for support payments at the individual farm level. Production above the guaranteed PEG limit must be sold at free market prices, enabling resource employment to respond to appropriate price signals. Crop losses which bring the production level below the PEG limit can be insured.

Upon reflection, some might find it unusual that the policy recommendations do not include measures to bring all available acreage into tillage in response to sustained crop losses of the magnitude that occurred in 1988. However, the CGE results presented above suggest such action is not necessary. Furthermore, increasing tillable acres may bring into production highly erosive soils aggravating pollution of water resources. Agricultural policies which promote price flexibility while protecting individual farmers as the industry adapts to the changing environment will minimize the effect of the crop loss on the overall economy.

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ports to drop by 7.8% while raising these elasticities causes program crops to increase by 12.6%. Imports of all other commodities (including other agricultural products), however, remain virtually unchanged. Thus, although program crop imports are moderately sensitive to the level of the import demand elasticities used, the overall results are fairly robust with respect to changes in these parameters.

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