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The Value of ENSO Information to Agriculture: Consideration of Event Strength and Trade

Chi-Chung Chen and Bruce A. McCarl

The agricultural value of El Niño-Southern Oscillation (ENSO) phase knowledge is measured in a value-of-information framework using economic models. We examine the value of considering the full distribution of ENSO phase strength effects as opposed to average ENSO phase strength effects, as well as the implications of considering ENSO impacts on the rest of the world (ROW). A stochastic U.S. agricultural sector model linked with a global trade model is used to assess the value of ENSO phase information. When the full distribution of ENSO phase strength is considered, the value of phase information increases twofold with respect to the average ENSO effects.

Key words: agricultural sector model (ASM), El Niño-Southern Oscillation (ENSO), spatial equilibrium model, stochastic programming, value of information

Introduction

Today, researchers are involved in an effort to determine whether systematic disturbances in climate can be detected and exploited in terms of improved decision making which is conditional on climate information. The El Niño-Southern Oscillation (ENSO) effect is such a climate disturbance, and refers to changes in the ocean-atmosphere system in the eastern Pacific which contribute to significant climate shifts around the world (National Oceanic and Atmospheric Administration). Currently, there is a debate about whether and how much to improve the Global Ocean Observing Program in an effort to provide additional information for climate forecasting. In the U.S. the proposed system is to be the Integrated, Sustained Ocean Observing System (ISOOS), which will integrate "disparate observational systems and data sets to maximize their utility for many users and purposes" (National Oceanographic Partnership Program). Its implementation will require investments in infrastructure (networks and data management systems) and ongoing support for new and existing observation systems in the open and coastal ocean.

Economic analyses are playing a role in this process by deriving benefits measures for possible ways society can exploit the improved information that might arise from such a system (Teisberg et al.). The present study is a contribution to that effort, and

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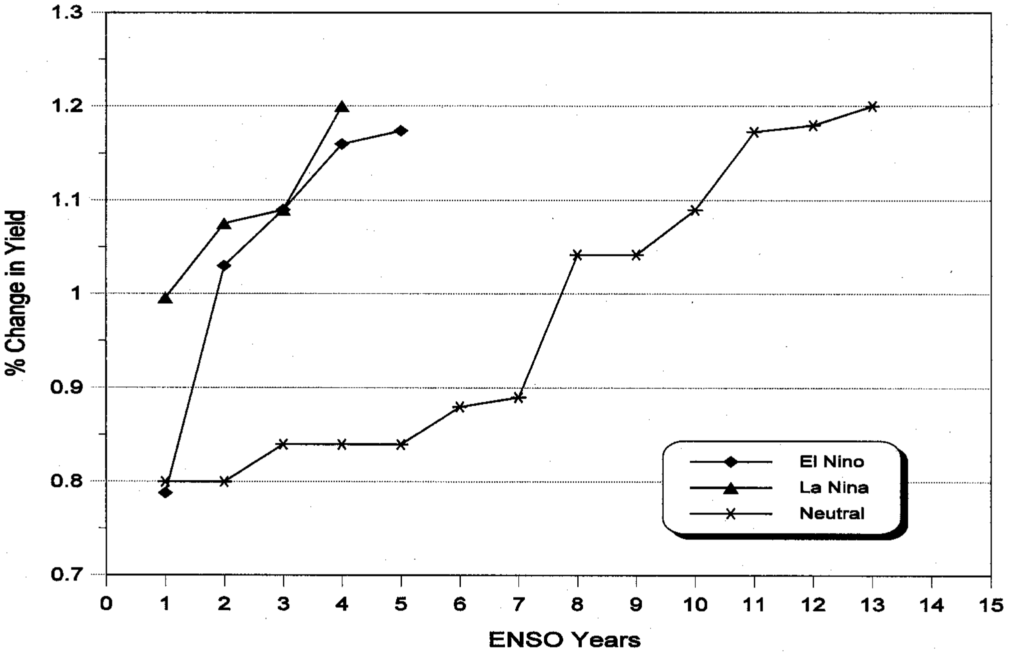

Figure 1. Georgia dryland corn yield distribution by ENSO phase (1972–93)

a reassessment of the value of ENSO phase information in factoring in global implications and event strength.

Although the ENSO phenomenon occurs in the Pacific, the associated ocean temperature changes also alter the atmosphere which, in turn, affects climate on a more global scale. In fact, the ENSO effect has been found to be associated with regional climate variations in many areas of the world (Cane, Eshel, and Buckland). Such variations directly impact crop yields (Legler, Bryant, and O'Brien; Mjelde, Hill, and Griffiths). ENSO is comprised of three phases: (*a*) the warm, called El Niño; (*b*) the cold, La Niña; and (*c*) the remaining phase, denoted "Neutral."

Prior studies on ENSO phase information have shown it to have economic value. Studies on the agricultural value have been conducted by Solow et al.; Mjelde, Penson, and Nixon; and Mjelde et al., among others. The approach in these studies is to first estimate the implications of the ENSO phase for crop production through econometric methods or crop simulation models. A value-of-information framework is then used to simulate how farmers or decision makers might adjust their behavior with and without ENSO phase information. This information gives estimates on how the aggregate market supply curve is shifted by the provision of phase information. Subsequently, welfare effects with and without the information are developed and, using event probabilities, are combined into an overall value-of-information estimate.

In the aforementioned studies, analysis was based on average ENSO phase strength, without taking into account that ENSO phases may be of varying strength; i.e., when considering the occurrence of an El Niño phase, the phase was calculated as the average strength for combined past El Niño years. However, historic records show El Niño phases have had a wide range of weather implications—some mild (like 1991), some severe (like 1982). Moreover, across the phase strengths in different geographic regions, there have been varying degrees of yield and economic implications.

For example, figure 1 illustrates the range of Georgia dryland corn yields from 1972–93 collected by ENSO phase (and whitened to remove systematic time and other effects, as discussed later in the article) relative to the 1972–93 average. These data show that Georgia corn yields under the El Niño phase range from just below the average yield to 120% of average yield due to varying event strength. Further, the relationship between the variation in regional yields may vary across different strengths of events in an ENSO phase.

Based on the preceding discussion, ENSO phase strength may be an important factor in estimation of the economic value of ENSO information. Thus, a primary objective of this study is to extend previous work by examining the implications of considering ENSO phase strength on the value of ENSO phase information.

As a second factor, earlier studies of the agricultural value of ENSO information have been limited to the farm level (e.g., Mjelde, Penson, and Nixon; Mjelde et al.), to the regional level (e.g., Adams et al.), or to a specific country open to trade without consideration of ENSO shifts occurring in the rest of the world (e.g., Solow et al.). However, because ENSO phases have broad global climate implications, it makes sense that effects across the world should be considered. Therefore, this study also seeks to extend previous work by more fully factoring in global ENSO phase production and trade effects.

A Conceptual Approach for Considering Uncertain Strength of ENSO Phases

A procedure to incorporate event strength can be developed using a value-of-information approach much like that used in Adams et al. We first present the approach using certain (average) phase strength, and then introduce uncertain phase strength.

Average Phase Strength

Suppose a decision maker is trying to decide what to do with and without ENSO phase information. In the absence of an ENSO phase declaration, the expected gain from choosing decision **Y** is specified as:

$$E(w(\mathbf{Y})) = \sum_{e} w(\mathbf{Y} \mid e)P(e),$$

where e is the set of possible ENSO phases; **Y** is the decision variable, which in our case is crop mix and grain storage levels; $w(\mathbf{Y} \mid e)$ is the welfare that results under decision **Y** when ENSO phase e occurs; $P(e)$ is the probability that ENSO phase e occurs; and E is the expectation operator. The optimal decision $\mathbf{Y}^*$ can be found by maximizing $E(w(\mathbf{Y}))$ over the set of possible Y decisions.

Now suppose the decision maker receives phase information and has the opportunity to make not just one simple decision, but rather a variable decision ($\mathbf{Y}_e$) which is conditional on ENSO phase e occurring. Thus, in practice, a different crop mix and carryover storage level might be chosen given a November announcement of ENSO phase for the crops sown or carried into the following spring. Consequently, with phase information, the value of the decisions becomes:

$$EPI\big(w(\mathbf{Y}^e)\big) = \sum_e w(\mathbf{Y}_e \,|\, e)P(e),$$

with the principal difference that the chosen decision $\mathbf{Y}_e$ now varies with ENSO phase e, and $\mathbf{Y}^e$ is the vector of $\mathbf{Y}_e$ decisions.

The value of the ENSO phase information is then the value gained by adjusting decisions from $\mathbf{Y}$ to $\mathbf{Y}_e$ ($EPI - E$). This assumes that the value of information can be measured only in terms of average phase strength, as in the previous sectoral-level studies.

Uncertain Phase Strength

We now introduce uncertain phase strength. In the absence of an ENSO phase declaration, the expected welfare gained from choosing decision $\mathbf{Y}$ is specified as:

$$ES\big(w(\mathbf{Y})\big) = \sum_e \sum_{s_e} ws(\mathbf{Y} \,|\, s_e)P(e)Ps(s_e \,|\, e),$$

where s_e is the set of possible ENSO phase strengths under phase e; $ws(\mathbf{Y}|s_e)$ is the welfare measure when ENSO phase event of strength s_e occurs and decision $\mathbf{Y}$ is chosen; and $Ps(s_e\,|\,e)$ is the probability that ENSO phase event of strength s_e occurs given ENSO phase e is occurring.

The introduction of phase information again creates the opportunity to make a decision $\mathbf{Y}_e$ conditional on ENSO phase e occurring. The with-phase information and uncertain strength value of the decisions becomes:

$$ESPI\big(w(\mathbf{Y}^e)\big) = \sum_e \sum_{s_e} ws(\mathbf{Y}_e \,|\, s_e)P(e)Ps(s_e \,|\, e),$$

where $\mathbf{Y}_e$ is conditional on phase, but not on strength, since the strength does not become known until after planting and carryover storage are set. Finally, the value of the phase information with strength considered is $ESPI - ES$. One other important characteristic of the framework is that without event strength considered, the returns to phase information are treated as certain outcomes, whereas with strength considered, the phase returns are distributions across s_e.[1]

A Sectoral/Global Model for Valuing Forecast Phase Information

The ultimate benefit estimate in this study measures the value of informing the agricultural sector about the effects of ENSO phase strength. Development of that measure requires construction of a model wherein the nature of sectoral adjustments given ENSO phase information and the value of those adjustments can be simulated. Such a framework is inherently probabilistic as the without-information distribution is the long-run probability of normal weather events, whereas the with-information distribution is characterized by conditional weather event probabilities dependent upon occurrence of a particular ENSO phase.

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[1] Adams et al. and Solow et al. partially deal with the uncertain phase strength issue when they introduce the concept of a phase forecast being wrong—i.e., that an El Niño phase is announced, but a La Niña event occurs. In the Northern Hemisphere, however, agriculture can generally fully adjust because the phase is known with certainty in November. Thus the authors' notion of improper phase information may be better interpreted in terms of *phase strength*, where the realized weather of the El Niño phase more closely resembles La Niña weather.

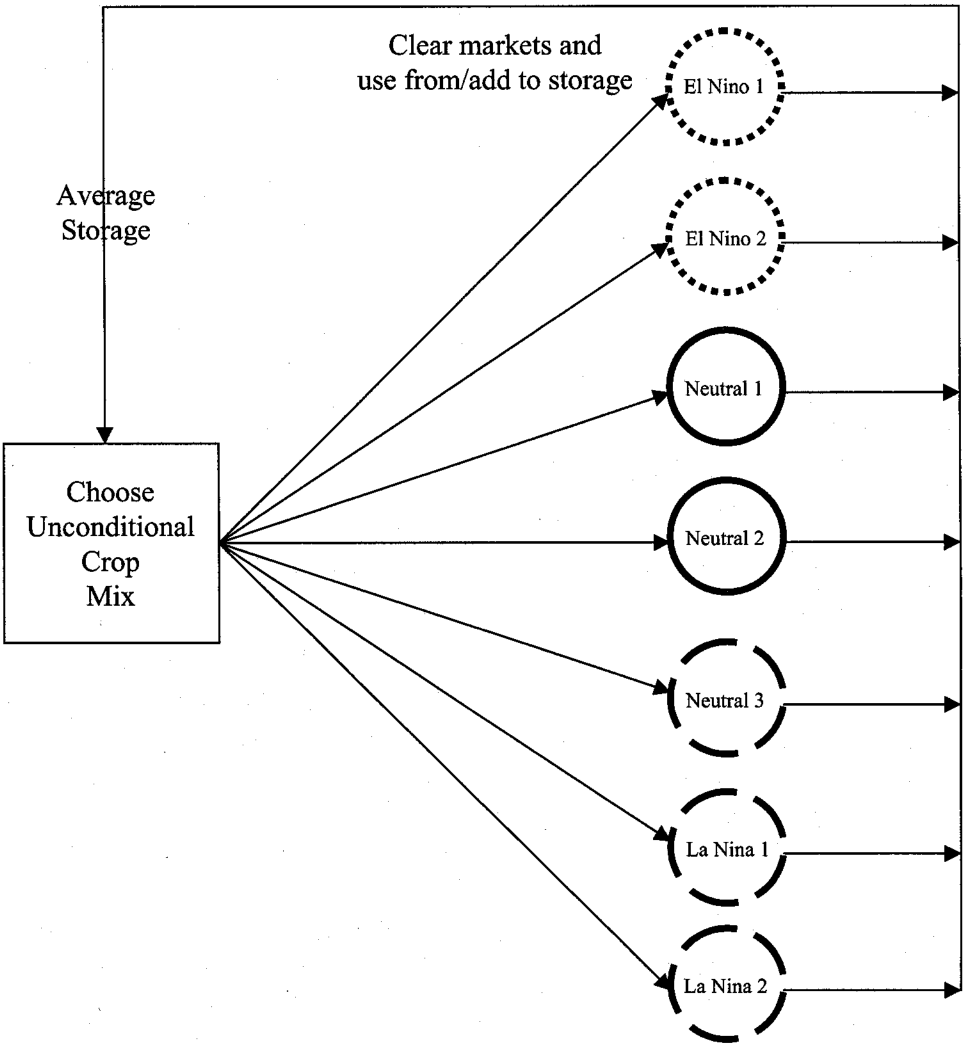

Figure 2. Situation without ENSO phase information

The basic modeling structure implements the above value-of-information framework using a decision-tree-based approach. We model crop mix, carryover storage, and livestock feeding choices with and without ENSO phase information as decisions which face different probability distributions of crop yields. In the case without ENSO phase information, the decisions are made with consideration of the full yield distribution without regard to the influence of ENSO phases (as illustrated in figure 2). But when ENSO phase information is available, then the decision is conditional considering only the events that occur under a particular phase (as shown by figure 3).

Figure 3 can also be used to clarify the way in which our analysis differs from previous aggregate ENSO analyses. In terms of incorporation of event strength uncertainty, the prior work of Solow et al. and Adams et al. also employed a decision-tree approach to forecast value. Their perfect information procedure was similar to that portrayed in figure 3, but incorporated only one event under each phase, with the yield effects being

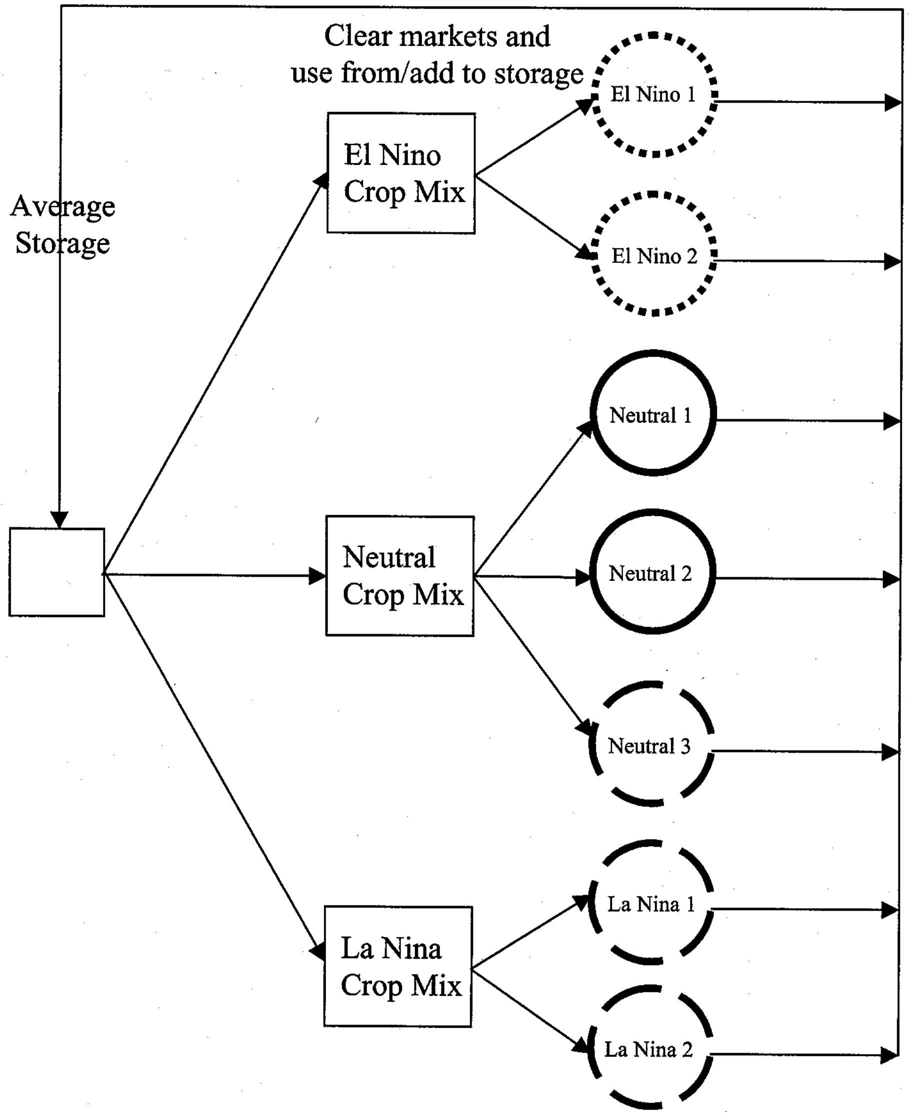

Figure 3. Situation with ENSO phase information

the average impacts of the ENSO phase. Thus their counterpart to our figure 3 has only three terminal nodes, whereas we show terminal nodes for each strength event.

Modeling Implementation of Conceptual Framework

The framework above was implemented in a stochastic programming with recourse, price endogenous sector model, as discussed in Lambert et al. In particular, a three-stage model is used. In the first phase, we include a balance constraint that ensures average storage additions equal average withdrawals. In the second phase, we assume knowledge of ENSO phase when the crop mix and livestock feeding numbers are chosen; but in the absence of ENSO phase information, the crop mix and livestock on feed remain the same for all phases. In the third phase, we have knowledge of event outcomes, and thus prices, consumption levels, and trade activities are set accordingly.

For this study we extend McCarl et al.'s U.S. agricultural sector model (ASM) (as applied by Chang et al. and Lambert et al.). The ASM is a price-endogenous mathematical program following the market equilibrium and optimization concept developed by Samuelson, and by Takayama and Judge.[2] Such a model simulates competitive equilibrium solutions under a set of demand and supply conditions in agricultural commodity and input markets. In this framework, social welfare is maximized to drive the model to an equilibrium condition.

Incorporating the Rest of the World

Normally sector models like the ASM treat the demand and supply from the rest of the world (ROW) through the use of excess supply and demand functions. However, the potential differential sensitivity of ROW regions to ENSO phases and events mandates a more complex approach. We addressed this problem by formally linking a detailed U.S. sector model to a worldwide multi-commodity spatial equilibrium model à la Takayama and Judge. This procedure required representation of regional markets in the U.S. in order to reflect the advantage held by west coast regions versus other parts of the country relative to shipping wheat to Asian countries. It also required modeling of transport from regional U.S. markets to ROW markets, and the specification of demand and supply relationships in ROW countries including the way they are influenced by ENSO phases and events. Such an integrated framework simultaneously depicts U.S. domestic agricultural production/consumption and world trade. This framework also yields welfare distribution information both across regions within the U.S. and in foreign countries.

Model Algebraic Representation

The model is a mathematical programming model and is summarized in the equations that follow. The objective function is written as:

$$
\begin{aligned}
(1)\qquad \text{Max} \sum_e pf_e \Big[& -\sum_j \sum_k g_{jk} X_{jke} - \sum_k \sum_r \int \alpha(R_{rke})\, dR_{rke} \\
& + \sum_s p_{s/e} * \Big[\sum_i \int \varphi(Q_{ise})\, dQ_{ise} \\
& + \sum_i \sum_c \Big(\int fd(FQD_{icse})\, dFQD_{icse} - \int fs(FQS_{icse})\, dFQS_{icse} \Big) \\
& - \sum_i \sum_k \sum_c USFTRD_{ickse} usfcst_{ikc} \\
& - \sum_i \sum_c \sum_{c1} FTRD_{i,c,c1,s,e} ffcst_{i,c,c1} \\
& - \sum_i \sum_k \sum_{k1} USTRAN_{i,k,k1,s,e} uscst_{i,k,k1} \\
& - \sum_i \sum_k pdif_{ik} * TN_{ikse} \\
& - \sum_i \sum_k \sum_s stor_i QSTORW_{ikse} \Big]\Big].
\end{aligned}
$$

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[2] For a review of the Samuelson/Takayama and Judge concept, interested readers should refer to McCarl and Spreen and/or Norton and Schiefer.

In equation (1), parameters appear as lowercase alphabetical or Greek characters, while variables appear as uppercase alphabetical letters. Definitions of these notations are as follows:

e	indexes the ENSO phase,
i	indexes commodities,
j	indexes production processes,
k, $k1$	indexes U.S regions,
c, $c1$	indexes ROW regions,
r	indexes resources,
s	indexes strength of ENSO phase,
pf_e	the probability that ENSO phase e occurs,
g_{jk}	cost of jth production process per unit in U.S. region k,
X_{jke}	usage of jth production process in U.S. region k when phase e occurs,
$p_{s/e}$	the probability that ENSO strength event s arises when it has been revealed that phase e is occurring,
Q_{ise}	consumption of ith product under ENSO event s and phase e,
FQD_{icse}	excess demand quantity in ROW region c for commodity i under ENSO strength s and phase e,
FQS_{icse}	excess supply quantity in ROW region c for commodity i under ENSO strength s and phase e,
R_{rke}	factor supply for U.S. region k of resource r when phase e is occurring,
$\varphi(Q_{ise})$	inverse U.S. demand function for commodity i consumed under ENSO strength s and phase e,
$\alpha(R_{rke})$	inverse U.S. factor supply function for factor r in region k,
$fd(FQD_{icse})$	inverse excess demand function for commodity i in importing ROW region c,
$fs(FQS_{icse})$	inverse excess supply function for commodity i in exporting ROW region c,
$FTRD_{i,c,c1,s,e}$	trade between ROW regions c and $c1$ of commodity i under ENSO strength s and phase e,
$USFTRD_{ickse}$	trade between ROW region c and U.S. region k of commodity i under ENSO strength s and phase e,
$USTRAN_{i,k,k1,s,e}$	shipment volume between U.S. regions k and $k1$ of commodity i under ENSO strength s and phase e,
$ffcst_{i,c,c1}$	transportation cost from ROW regions c and $c1$ for commodity i,
$usfcst_{ikc}$	transportation cost from U.S. region k to ROW region c for commodity i,
$uscst_{i,k,k1}$	transportation cost between U.S. regions k and $k1$ for commodity i,
$pdif_{ik}$	price difference between U.S. region k and U.S. national market for commodity i,
TN_{ikse}	U.S. national consumption of commodity i from U.S. region k under ENSO strength s and phase e,
$stor_i$	storage cost in the U.S. for commodity i, and
$QSTORW_{ikse}$	quantity withdrawn from storage of commodity i in U.S. region k under ENSO strength s and phase e.

This framework blends the spatial equilibrium and price endogenous sector models. In particular (for now ignoring the stochastic, ENSO phase dimension), the first two lines of (1) include terms typically in the conventional sector model containing perfectly elastic production costs associated with inputs used in the production process j ($g_{jk}X_{jke}$) and the quantity-dependent supply curve integrals for factor r ($\int \alpha(R_{rke})\,dR_{rke}$), with line 2 giving the area under the U.S. national demand equations ($\int \varphi(Q_{ise})\,dQ_{ise}$). Line 3 gives the area under the excess demand less that under the excess supply curves for commodity i in ROW region c. Line 4 sums the transportation costs times the volume traded between the U.S. regions and ROW regions for U.S. imports and exports (*USFTRD*). Line 5 sums the transportation costs times the volume traded among the foreign regions (*FTRD*). Line 6 sums the transportation costs between regions in the U.S. (*USTRAN*). Line 7 is the difference between U.S. regional and U.S. national market prices times the regional quantity. This variable (*TN*) is incorporated in order to balance the national market while maintaining regional price differences at levels observed historically. Finally, line 8 gives the cost of storage.

The model is stochastic in that both the ENSO phase and the event strength occur with varying frequency and consequences. It also is a multiple-stage model in that all terms and variables, except those not in the first line of (1), are ENSO event strength and phase dependent, while the first line is only ENSO phase dependent. Thus it is assumed that crop acreage and animals on feed, as well as much of the factor use, are chosen dependent on ENSO phase but before ENSO event strength is known. However, demand and trade are set given knowledge of what event strength occurred depending on realized prices. (For more on the multiple-stage process, refer to Lambert et al.) The first and second lines of (1) incorporate the relevant probabilities. This renders the objective function a maximization of expected welfare, and also yields production choices where expected marginal revenue is equated with marginal cost.

The model contains commodity balances in the U.S. as follows:

$$\begin{aligned}(2)\qquad & -\sum_{j}\left((y_{ijk} + yr_{ijkse}) * X_{jke}\right) - \sum_{c} USFTRD_{ickse} - \sum_{k1} USTRAN_{i,k1,k,s,e} \\ & - QSTORW_{ikse} + TN_{ikse} + \sum_{c} USFTRD_{ikcse} + \sum_{k1} USTRAN_{i,k,k1,s,e} \\ & + QSTORA_{ikse} \le 0, \qquad \forall\, i,k,s,e,\end{aligned}$$

which balances yield from production on average (y) plus the difference due to ENSO phase and event (yr) times acreage (X) plus that imported from other U.S. (*USTRAN*) and world (*USFTRD*) regions plus withdrawals from storage (*QSTORW*) against exports to other U.S (*USTRAN*) and world regions (*USFTRD*), as well as movements into domestic demand (*TN*) plus additions to storage (*QSTORA*) for commodity (i) in region (k) under ENSO strength event (s) and phase (e).

There is also a U.S. national commodity balance constraint:

$$(3)\qquad Q_{ise} - \sum_{k} TN_{ikse} \le 0, \qquad \forall\, i,s,e,$$

where aggregate demand (Q) is balanced with the quantities (*TN*) from the regions (k) by commodity (i), strength event (s), and phase (e).

The factor constraint for region k in the U.S. is given by:

(4) $$\sum_j f_{rjk} X_{jke} - R_{rke} \leq 0, \quad \forall k, r, e,$$

where f_{rjk} is the resource usage per acre for the jth production process in region k for resource r. This equation balances factor supply (R) against usage by production (fX) in region k for factor r.

The commodity balance constraint for good i in ROW region c is specified as:

(5) $$\begin{aligned} &+FQD_{icse} + \sum_k USFTRD_{ickse} + \sum_{c1} FTRD_{i,c,c1,s,e} \\ &- FQS_{icse} - \sum_k USFTRD_{ikcse} - \sum_{c1} FTRD_{i,c1,c,s,e} \leq 0, \quad \forall i, c, s, e, \end{aligned}$$

where ROW region demand (*FQD*), exports to the U.S. (*USFTRD*), and exports to other ROW regions (*FTRD*) are balanced against ROW region supply (*FQS*), imports from the U.S. (*USFTRD*), and imports from the other ROW regions (*FTRD*).

The storage balance is written as:

(6) $$\sum_e \sum_s pf_e p_{s/e} \left[QSTORW_{ise} - QSTORA_{ise} \right] = 0 \quad \forall i,$$

where probability weighted net additions and withdrawals are equal.

Base Model Specification

As stated above, we began the model specification with the U.S. agricultural sector model (ASM) which is discussed extensively elsewhere (refer to the bibliography and discussion in Chang et al.). To portray trade, the model was extended by the introduction of 27 world regions (identified in appendix table A1). We included a multi-commodity spatial equilibrium model involving hard red spring wheat (HRSW), hard red winter wheat (HRWW), soft white winter wheat (SOFT), durum wheat (DURW), corn, soybeans, and sorghum. Further, we divided the U.S. market into 10 regional models based on regions defined by the U.S. Department of Agriculture (USDA): Northeast, Lake States, Corn Belt, Northern Plains, Appalachia, Southeast, Delta States, Southern Plains, Mountain, and Pacific. Data for transportation cost, trade quantity, price, and elasticity were obtained from Fellin and Fuller, USDA statistical sources, and the USDA SWOPSIM model (Roningen).

Specifying ENSO Effects

To examine the agricultural and economic consequences of ENSO phase strength, we extracted a distribution of the effects of ENSO events from historic yield data. These data were assumed to be free of bias due to ENSO forecasts, since they were drawn from a period where ENSO information was not provided. We also assume independence across years between ENSO events based on evidence in Quinn and Neal. In particular, following the efforts in Thaysen, we whitened the data using regressions of yields on acreage, time (in years), and yield lagged one period for 63 U.S. regions and 13 crops. In turn, we computed the residuals, grouped them by ENSO phase, and then added them to the1994 forecasted yield to develop stationary yield distributions by ENSO phase for each crop and location.

Table 1. Effects of ENSO Phases on Rest of the World (ROW) Production

	Proportion of Total Production by ENSO Phase		
Region/Country	El Niño	Neutral	La Niña
WHEAT PRODUCTION:			
Australia	0.896	1.029	0.985
Argentina	1.042	0.992	0.987
Canada	1.034	0.985	0.989
Western Europe	0.974	1.012	1.000
China	0.982	1.003	0.996
USSR	1.100	0.976	1.154
East Block Europe	0.985	1.017	1.041
East America	1.044	0.935	1.059
West America	0.935	1.004	1.004
North Africa	0.948	0.992	1.084
CORN PRODUCTION:			
USSR	1.128	0.928	1.363
East Africa	1.032	1.055	0.960
China	0.983	1.005	0.972
Western Europe	1.076	0.997	0.922
SOYBEAN PRODUCTION:			
Brazil	1.020	0.968	1.008
Argentina	0.992	1.009	0.961
SORGHUM PRODUCTION:			
Argentina	1.016	1.034	0.919
Australia	0.766	1.067	1.127

Note: The numeric data give the proportion that total production in the country/region is under an ENSO phase in comparison to average long-run production when a statistically significant effect was found in our analysis. If the value is greater than 1.0, it means the ENSO phase has higher production than on average; a value of less than 1.0 denotes decreased production.

The resulting distributions show the ENSO phases have overlapping distributions. For example, figure 1 illustrates the distribution of Georgia dryland corn yield for the El Niño years of 1973, 1977, 1983, 1987, and 1992; the La Niña results from the years 1972, 1974, 1976, and 1989; and the remaining "Neutral" ENSO phase results. The El Niño, La Niña, and Neutral means are 105%, 109%, and 100%, respectively. These results illustrate that the full distributions of ENSO phases differ from the average (or point estimates) of ENSO phases and that they overlap. Such results were found in most of the cases examined.

ENSO events also affect weather and possibly yields around the world. Yield effects were examined here using historical data. In particular, we examined production, yield, and acreage for wheat, corn, soybeans, and sorghum for 28 world regions (appendix table A1) over the period 1972–93 using data from the USDA's annual *Agricultural Statistics*. Again, regression was employed to develop ENSO phase distributions. These regressions predicted total regional production by crop as a function of acreage, time (in

Table 2. Aggregated ENSO Effects on Rest of the World (ROW) Production

	Shift in ROW Production by ENSO Phase (000s bushels)		
Commodity	El Niño	Neutral	La Niña
Corn	-7,025	13,275	-86,683
	(-0.49)	(0.79)	(-5.17)
Soybeans	13,249	-23,366	-7,761
	(1.72)	(-3.03)	(-1.01)
Hard Red Spring Wheat (HRSW)	74,889	-28,854	151,753
	(17.09)	(-6.58)	(34.64)
Hard Red Winter Wheat (HRWW)	-3,445	6,629	40,816
	(-0.52)	(1.01)	(6.19)
Soft White Wheat (SOFT)	-57,795	31,775	113,611
	(-27.52)	(15.13)	(54.10)
Durum Wheat (DURW)	3,551	-852	11,276
	(7.55)	(-1.81)	(23.99)
Sorghum	-8	6	-3
	(-0.003)	(0.002)	(-0.001)

Note: Numbers in parentheses represent the percentage change resulting from the ROW ENSO effects on total U.S. exports for a commodity.

Table 3. Information Value Under Different ENSO Strength Evaluations

	Value Estimate ($ mil.)	
Description	Average ENSO Event Strength Distribution	Full ENSO Event Strength Distribution
With ENSO Effect on ROW Production:		
U.S. Consumer	400	1,262
U.S. Producer	-267	-967
Foreign Surplus	34	104
Total	167	399
Without ENSO Effect on ROW Production:		
U.S. Consumer	660	944
U.S. Producer	-537	-659
Foreign Surplus	40	102
Total	163	387

years), and production lagged one period. In turn, the residuals were added to the 1994 forecasted production to develop production distributions by ENSO phase. Summaries of the results appear in table 1. Entries of greater than 1.0 in the ENSO phase columns indicate that the ENSO phase on average is associated with increased production, while results of less than 1.0 imply decreased production.

Table 2 reports the total ENSO phase effects aggregated across all ROW regions using production weights. Results show, for example, that the El Niño phase causes a 57.8

Table 4. Average Crop Acreage Changes (%) Between Solutions With/Without ENSO Information for the 10 USDA Regions

	Average Crop Acreage Changes (%)					
USDA's 10 Regions	Corn	HRWW	SOFT	Sorghum	Soybeans	Cotton
Northeast	1.9	—	22.0	-2.0	16.3	—
Lake States	1.3	-7.8	-5.2	—	13.7	—
Corn Belt	1.0	—	1.9	3.2	-1.2	-1.0
Northern Plains	-5.2	5.3	—	0.2	-1.7	—
Appalachia	7.5	—	-5.3	16.1	-2.4	-22.8
Southeast	2.7	—	-7.8	-9.5	3.2	1.7
Delta States	11.5	—	-2.4	3.9	-0.7	2.3
Southern Plains	10.0	-3.6	—	-6.8	-7.4	3.6
Mountain	2.5	1.6	—	-1.3	—	-0.1
Pacific	1.2	1.5	—	-22.7	—	6.5

Table 5. Percentage Change in Sector Performance Measures with ENSO Information

	Commodities					
Description	Corn	HRSW	HRWW	SOFT	Sorghum	Soybeans
Change in Total U.S. Production (%):						
El Niño	7.6	-10.9	12.9	6.9	0.3	1.8
La Niña	6.6	-16.1	-0.3	-7.7	-7.9	-4.8
Neutral	-3.8	0.4	-2.2	-0.3	0.6	1.4
Average	0.7	-5.2	1.6	-0.03	-1.0	0.4
Change in World Trade Volume (%):						
El Niño	3.7	-0.1	2.4	-1.8	0.7	0.4
La Niña	-2.1	-5.3	-2.8	-6.4	-5.2	-0.4
Neutral	-0.01	1.5	0.8	2.6	-1.3	0.3
Average	0.5	-0.1	0.5	-0.02	-1.6	0.2

million bushel decline in total ROW soft wheat production, while La Niña increases production by 113.6 million bushels, with these effects ranging from -27.52% to +54.10%, respectively, of total U.S. soft wheat exports. Such findings lead us to conclude that ROW ENSO-induced shifts may be important factors in ENSO information valuation.

Experimentation and Results

We now turn attention to the empirical value of information. The model was used to examine the effect of no ENSO phase information verus knowledge of the ENSO phase information. In performing this evaluation, we varied the degree to which ROW ENSO effects and uncertain strength of ENSO phase was considered.

Value of ENSO Information as Influenced by Event Strength

A fundamental question here involves to what extent consideration of the full distribution of ENSO phase strength alters the estimated value of ENSO phase information. To address this question, the model was first run with 22 historically based states of nature across the three ENSO phases, and then was repeated with just average ENSO event strength under each of the three phases. Table 3 presents the results, and shows that the phase information value estimate increases by almost twofold when considering event strength (comparing numeric columns 1 and 2). We initially found this result surprising, as we felt the ability to tailor the crop mix and livestock numbers to the average yield outcomes might create greater value than occurs when the same crop mix/herd was used across the various phase event strengths. However, this was not the case, and is anticipated by the classical arguments of both Oi and Waugh, who found that welfare increases under supply uncertainty as opposed to average supply. Our results also demonstrate that the model can find true value in the release of the phase information by making welfare-increasing adjustments in crop mix and livestock feeding.

Value of ENSO Information as Influenced by Including ROW Production Effects

A second fundamental question involves the consequences of incorporating ROW ENSO effects versus ignoring them. This was investigated by running the model with and without ENSO-induced shifts in the ROW supply and demand curves as implied by the data in table 1.

Comparing the totals in the upper and lower sections of table 3 shows the value of ENSO phase information increases by only a small amount ($4–$12 million) when ROW ENSO effects are considered. These gains are small because the ENSO information is considered on a broader basis; thus the potential gains in one country are balanced by losses in others and vice versa. As seen by table 3, there are also significant shifts in the distribution of welfare, with more moderate effects in the distribution between U.S. consumers and producers, but not much effect on total foreign surplus.

Production Shifts with ENSO Information

Yet a third issue to be addressed with these results is how production patterns shift with the presence of ENSO information. Discussion here is limited only to model results from the run with the full distribution of ENSO phase strength and the included ROW effects. Table 4 displays crop acreage data for selected major crops by the 10 USDA regions. Results show the shifts due to the provision of ENSO phase information occur in greatest magnitude generally in the Southeast, Southern Plains, Delta, and Appalachia regions where the ENSO signal is strongest,[3] but there are also significant adjustments elsewhere due to marketplace signals.

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[3] For information on regional sensitivity, see Legler, Bryant, and O'Brien; or Chen.

Table 6. Percentage Change in Total U.S. Storage Due to ENSO Information

	Commodities					
Description	Corn	HRSW	HRWW	SOFT	Sorghum	Cotton
Change in Total U.S. Storage Incoming (%):						
El Niño	143.1	-100.0	250.9	-77.5	-83.4	31.7
La Niña	170.3	-100.0	-81.3	-17.6	22.4	-10.9
Neutral	-100.0	48.8	-62.1	52.1	7.4	5.7
Average	4.4	-12.1	5.6	9.9	-10.5	8.6
Change in Total U.S. Storage Outgoing (%):						
El Niño	-35.5	-53.1	-86.1	38.2	-95.3	-13.7
La Niña	-86.4	-100.0	-88.9	-13.6	21.2	-82.4
Neutral	47.6	30.8	-69.8	6.3	12.3	45.2
Average	4.4	-12.1	5.6	9.9	-10.5	8.6

Table 7. Alterations in Selected Items With/Without ENSO Phase Information

Description	Without Phase Information	With Phase Information	Change
World Prices ($/bushel):			**(%)**
Corn	3.31	3.30	-0.30
	(4.85)	(4.49)	(-7.42)
Hard Red Spring Wheat (HRSW)	5.53	5.53	0.00
	(13.62)	(12.25)	(-10.05)
Hard Red Winter Wheat (HRWW)	4.62	4.52	-2.16
	(6.43)	(4.94)	(-23.17)
Soft White Wheat (SOFT)	4.24	4.23	-0.23
	(19.70)	(18.42)	(-6.49)
Durum Wheat (DURW)	4.52	4.51	-0.22
	(5.31)	(5.03)	(-5.27)
Soybeans	6.09	6.06	-0.49
	(2.34)	(2.60)	(11.11)
Sorghum	11.59	11.68	0.77
	(2.42)	(2.75)	(13.64)
Welfare (mean, $mil.):			**($ mil.)**
U.S. Consumers	1,174,277	1,175,539	1,262
	(1.300)	(0.890)	(-31.54)
U.S. Producers	36,971	36,004	-967
	(43.625)	(29.402)	(-32.59)
Foreign Surplus	248,293	248,397	104
	(3.892)	(3.895)	(0.07)
Total	1,459,541	1,459,940	399
	(0.705)	(0.710)	(0.71)

Note: Numbers in parentheses are coefficients of variation.

Use of the ENSO phase information also alters U.S. and ROW production and trade (table 5). Large shifts occur in total U.S. production due to ENSO phase, with 6–15% shifts occurring under some phases for all commodities except sorghum. The total volume of world trade is also affected, although to a lesser degree.

Table 6 shows changes in U.S. storage as influenced by the availability of ENSO phase information. The average amount in storage for corn, hard red winter wheat, soft white wheat, and cotton increases with ENSO phase information, while it decreases for hard red spring wheat and sorghum. However, the percentage of storage additions and withdrawals varies by ENSO phase and strength, and is related to crop production.

The level and variability of world prices and welfare are listed in table 7. Use of ENSO phase information decreases world price for all trade products except hard red spring wheat and sorghum, and decreases the variability of world prices except for soybeans and sorghum. The distribution of welfare is also altered by ENSO phase information. U.S. consumers and foreign countries gain due to the ENSO phase information, while U.S. producers lose. However, welfare variability for both U.S. consumers and producers decreases when employing ENSO phase information.

Concluding Comments

This study has examined the forecast value implications of considering ENSO phase event strength and the rest of the world (ROW) ENSO sensitivity. To do so, the ENSO impacts on crop yield and production in the U.S. and ROW were estimated using econometric methods, and a linked stochastic, U.S. agricultural sector/global trade model was developed.

Three interesting points arise from the empirical results. First, the value of ENSO phase information increases by almost a factor of two when event strength is considered. This implies future studies should incorporate such information, and that public awareness efforts should attempt to include event strength discussion/information. Second, consideration of the rest of the world did not greatly increase the estimates of information value; our results suggest the correlation of the event effects across the world tends to redistribute the gains, but does not greatly add to them. Third, widespread use of ENSO phase information does influence crop acreage, production, storage, and prices. If ENSO information is widely adopted, perhaps conditional marketing strategies will need to be considered.

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Appendix

Table A1. Identification of the 27 World Regions Defined in the Model

No.	Region Name	Countries Included
1	WEST AFRICA	Dahomey, Angola, Benin, Cameroon, Canary Islands, Ghana, Guinea, Ivory Coast, Liberia, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo, Burkina Faso, South W. Africa, Zaire
2	NORTH AFRICA	Algeria, Libya, Morocco, Tunisia
3	EAST AFRICA	Botswana, Malawi, Kenya, Mozambique, South Africa, Tanzania, Uganda, Zambia, Zimbabwe, Rwanda, Madagascar, Swaziland, Lesotho, Burundi
4	EAST MED	Egypt, Israel, Lebanon, Syria
5	RED SEA	Ethiopia, Somalia, Sudan, Yemen
6	WEST ASIA	Afghanistan, Bangladesh, Nepal, Pakistan, Sri Lanka, India
7	PERSIAN GULF	Iran, Iraq, Kuwait, Saudi Arabia, Bahrain, Oman, United Arab Emirates
8	ADRIATIC	Cyprus, Greece, Turkey
9	CHINA	China
10	SOUTHEAST ASIA	Hong Kong, Indonesia, Malaysia, New Zealand, Okinawa, Philippines, Singapore, Thailand, Vietnam, French Pacific Islands, South Pacific Islands, Other Pacific Islands
11	JAPAN	Japan
12	SOUTH KOREA	South Korea
13	TAIWAN	Taiwan
14	EAST AMERICA	Belize, Brazil, Costa Rica, El Salvador, Curacao, Guatemala, Honduras, Nicaragua, Panama, Paraguay, Suriname, Uruguay, Venezuela, French Guiana
15	CARIBBEAN	Leeward Islands, Bahamas, Barbados, Dominican Republic, French West Indies, Haiti, Trinidad, Jamaica
16	AUSTRALIA	Australia
17	N. CENTRAL EUROPE	Austria, Belgium, Germany, Netherlands, Switzerland
18	EAST BLOCK EUROPE	Bulgaria, Czechoslovakia, Hungary, Poland, Romania, Yugoslavia
19	WESTERN EUROPE	France, Italy, Malta, Portugal, Spain, Others
20	ISLANDS	Iceland, Ireland, U.K.
21	SCANDINAVIA	Denmark, Finland, Norway, Sweden
22	CANADA	Canada
23	EAST MEXICO	Mexico
24	USSR	Former United Soviet Socialist Republic
25	WEST AMERICA	Bolivia, Chile, Colombia, Ecuador, Peru
26	BRAZIL	Brazil
27	ARGENTINA	Argentina