AGRICULTURAL VALUE OF ENSO INFORMATION UNDER ALTERNATIVE PHASE DEFINITION

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Abstract. The El Niño-Southern Oscillation (ENSO) effect has been found to be associated with regional climate variations in many regions of the world, and, in turn, with variation in crop yields. Previous studies have found that early releases of ENSO phase information could permit agricultural producers to make adjustments in their decisions and in turn generate an increase in agricultural sector welfare. This study examines whether the value of the agricultural responses can be enhanced by releasing more detailed ENSO information. Namely we evaluate the implications for projected agricultural welfare under release and adaptation to the Stone and Auliciems five phase definition of ENSO states as opposed to the more standard three phase definition. This value is estimated using a stochastic, U.S./global agricultural model representing 22 climate years. The results indicate that the release and exploitation of the more detailed ENSO phase definition almost doubles the welfare impact. The results also indicate that there is room for up to another doubling of information value through further refinements.

1. Value of ENSO Information to Agriculture under Alternative ENSO Phase Definitions

The El Niño/Southern Oscillation (ENSO) process arises due to an interaction of the equatorial sea temperature with the atmosphere and influences climate variation across much of the world (Bjerknes, 1966, 1969; Ropelewski and Halpert, 1987, 1989; Stone et al., 1996; Walker, 1924). Changes in the equatorial Pacific sea temperatures and atmospheric pressures precede seasonal climate variation in other regions by one to 12 months (Montroy et al., 1998; Ropelewski and Halpert, 1989; Climate Prediction Center). This lag is the basis for seasonal forecasting based on ENSO phases which portend later systematic climatic shifts. Several efforts have been made to estimate the agricultural welfare implications of such ENSO based information (Adams et al., 1995; Hill et al., 1998, 2000; Mjelde et al., 1998; Solow et al., 1998; Chen and McCarl, 2000).

Multiple definitions of ENSO phases exist. The two we consider are one based on Southern Oscillation data which categorizes ENSO events into three phases

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Climatic Change **54:** 305–325, 2002.

(Climate Prediction Center), warm (El Niño), cold (La Niña) and neutral, and the other which defines five phases (Stone and Auliciems; Queensland Center for Climate Applications):

Phase 1	Persistently negative
Phase 2	Persistently positive
Phase 3	Rapidly falling
Phase 4	Rapidly rising
Phase 5	Neutral

The five phase definition may give greater insight into resultant weather shifts by permitting more finely tuned adaptive responses and thereby increasing the value of the forecast. Hill et al. (2000) provide information that this is the case in a wheat only U.S. Canada setting. Here we investigate whether there are differences in the forecast value between the two ENSO phase definitions in a global, multi-commodity, agricultural setting. Specifically we examine the effects of the announcement, dissemination and agricultural reaction to three versus five state ENSO definitions in terms of forecast value.

2. ENSO Effects on Crop Yields in the U.S. and Crop Production in the Rest of World

ENSO events have been associated with crop yield variation in a number of regions (Legler et al., 1999; Hill et al., 1998; Mjelde and Keplinger, 1999; Nicholls and Hammer, 1998). Such information has been generated using crop simulation or historically based statistical investigations. Here we use a historical based methodology as in Chen and McCarl (2000) to develop yield and production implications of the alternative phases using data from USDA Agricultural Statistics. In particular, we

1. Gather data from 1972 to 1993 on crop yields in 63 U.S. regions for 13 crops and total crop production for 7 crops in 28 world regions (as defined in Appendix B).
2. Use a regression based approach for each crop in each region to remove systematic trends from the data using acreage, lagged yield and time as independent variables.
3. Form a multi-variate unconditional probability distribution of yields across all crops and regions regardless of ENSO state by constructing a 1994 forecast then adding the residuals from step 2. In this distribution the residuals for each of the 22 years are associated across all the locations and crops. This allows us to adequately represent spatial and inter-crop correlation.

4. Construct a multi-variate probability distribution across all crops and regions conditional on ENSO phase by grouping the data from the unconditional distribution by each of either the three phase or five phase definitions. For example, there were five El Niño events during 1972 to 1993. Thus, in the three phase case, to represent the effects of knowing an El Niño event was coming we used the data from those five events to develop a five point El Niño distribution. We thereby identify the effects of El Niño under that coming from the distribution of five events classified as an El Niño event which were of varying strength. Again associating the events by year allow us to represent the spatial and inter-crop correlation that, in this case, characterizes El Niño events. More generally we constructed grouping of the years under each of the three or five phase systems.

Such a procedure relies heavily on the historical data to adequately depict the yield consequences of the various ENSO phases and leads to small sample sizes depicting either 3 or 5 phases with 22 years of data. On the other hand, we felt the historic approach was the best we could use given that we did not have the resources to employ crop simulation in all the 63 U.S. and 28 world regions for the 7 principal crops. Furthermore, even if we did try to employ simulation then it would be a daunting task to adequately represent spatial and inter-crop correlation across the 63 regions. Also, while from a strict ENSO viewpoint longer time periods would be desirable, it is not as clearly desirable from an agricultural yield standpoint as substantial technical progress is and has occurred. The longer the series the more difficult the assumption that the yields are all from the same probability distribution. Thus we use the 22-year period.

Table I displays the resulting estimated mean percentage changes in U.S. Cornbelt region crop yields under the alternative ENSO phase definitions while Table II shows effects on the aggregate of non U.S. production. In the next section we will place these data into in a global agricultural model to see if crop mix, commodity consumption and storage strategies can be found which better adapt to the different ENSO phases in turn generating information value.

3. A Framework for Valuing ENSO Phase Information

The value of improved ENSO information to agriculture has been estimated by, among others, Adams et al. (1995), Solow et al. (1998) and Chen and McCarl (2000) using multi-commodity sector modeling, Mjelde et al. (1997a,b) using firm level modeling and Hill et al. (2000) using single commodity aggregate modeling. We choose to derive our valuation results at the broadest scale possible and thus will use a multi-commodity, multi-country approach following Chen and McCarl (2000).

Valuing ENSO forecasts requires simulation of adjustments given ENSO phase information. The framework we use will be probabilistic operating across the dis-

Table I

Mean percentage change in U.S. cornbelt region crop yields under alternative ENSO phase definitions

	Crop			
	Corn	Soybeans	SOFT	Sorghum
3 Phase				
El Niño	5.52	2.64	2.66	3.97
La Niña	–0.14	–1.71	–0.04	1.17
Neutral	–1.32	0.01	–1.96	–0.30
5 Phase				
Phase 1	–0.15	–3.37	1.30	4.95
Phase 2	–1.23	–1.52	–1.20	–1.83
Phase 3	0.09	1.41	–8.18	0.08
Phase 4	6.22	7.62	8.31	5.49
Phase 5	1.09	2.65	–1.78	–0.41

SOFT labels soft white wheat.

Table II

Mean percentage change in ROW crop production for alternative ENSO definitions

	Crop						
	Corn	Soybeans	HRSW	HRWW	SOFT	DURW	Sorghum
3 Phase							
El Niño	–0.15	1.05	1.73	–0.21	–1.25	2.04	–3.24
La Niña	–1.93	–0.62	3.50	2.45	2.45	6.47	–1.44
Neutral	0.30	–1.86	–0.67	0.39	0.69	–0.49	2.64
5 Phase							
Phase 1	1.34	0.60	3.95	1.17	1.29	4.92	–0.84
Phase 2	–0.80	–1.20	1.09	1.72	2.18	2.64	0.29
Phase 3	0.70	2.17	–0.34	–2.74	–2.35	–5.42	3.04
Phase 4	–2.24	0.47	–2.25	–0.86	–2.80	–2.01	–2.54
Phase 5	–0.47	–3.54	–1.37	0.54	0.18	0.25	2.24

HRSW labels data for hard red spring wheat; HRWW labels hard red winter wheat; SOFT labels soft white wheat and DURW labels durum wheat.

tribution of weather states which includes all events without ENSO information and the various strength events under a given ENSO phase. Details on the exact model form are presented in Chen and McCarl (2000) and in Appendix C. Here we cover some of its major features.

3.1. BROAD CHARACTERISTICS OF MODEL STRUCTURE

The model hereafter called GlobalASM is a stochastic model with 22 weather states based on a representation of production under yields from 1972–1993. It depicts production in 63 U.S. regions and 28 world regions. It covers production of 52 crop and livestock primary commodities as well as 36 secondary commodities (McCarl et al. (2001) presents a list). GlobalASM simulates regional production of the 52 primary commodities considering prices, production possibilities, processing alternatives, water, labor and land supply and national production, consumption etc. for the 36 secondary commodities. GlobalASM clears product markets for each state of nature considering price responsive demand with demand curves for each commodity in the U.S and demand curves in the world trade regions for the major grain commodities (corn, sorghum, rice, soybeans and four types of wheat) as well as excess import supply and export demand curves for the rest of the 88 commodities. Trade between U.S. and foreign regions is simulated. On solution, GlobalASM yields a measure of total world economic welfare arising from the production and consumption of the goods modeled by state of nature. Changes in this measure provide the value of information measure. The base year for this study is 1996. Details on this overall class of models can be found in McCarl and Spreen with details on the stochastic version in Lambert et al. (1995) and the ENSO application in Adams et al. (1995), Solow et al. (1998) and most recently in Chen and McCarl (2000).

3.2. REPRESENTATION OF FORECAST DEPENDENT ADJUSTMENTS

GlobalASM employs a decision tree based approach to represent alternative climate events and phase strengths. U.S. crop mix, and storage choices plus U.S. and 28 world region consumption quantities can be adjusted based on ENSO phase information. Namely these decisions are made in the face of forecast dependent probability distributions of crop yields and international production. In the without ENSO phase information case, the decisions are made facing the full yield distribution without regard to the influence of ENSO phases as in Figure 1. In other words, crop mix, storage and consumption are the same regardless of ENSO phase. But when ENSO phase information is available then the decision is conditional considering only the events that occur under a particular phase as in Figure 2 plus overall carry over storage value. The difference between the three phase and five phase definitions is manifest in the refinement of crop mix, storage and consumption (CMSC) levels with a three phase forecast operating in the long run under three different CMSC sets of decisions, each tailored to be the best possible reaction to

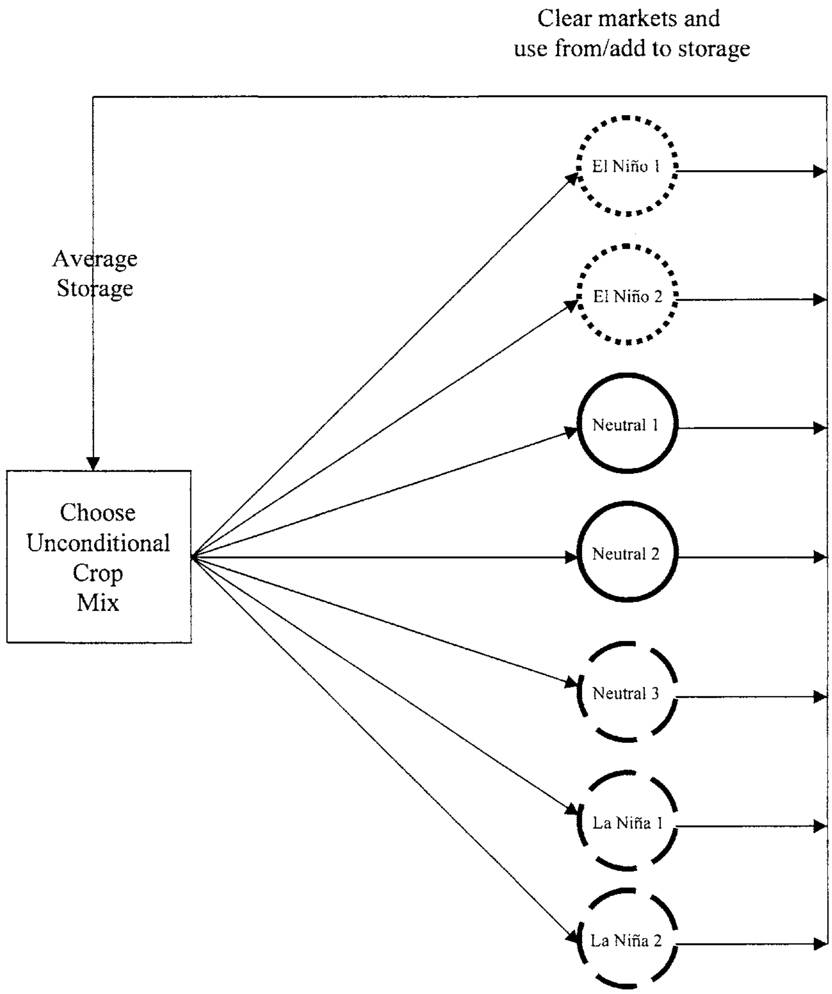

Figure 1. Situation without ENSO phase information.

an ENSO phase forecast. On the other hand, five CMSC patterns occur under the five phase forecast. The essential question then is: Does the information in the more detailed phase description permit even more refined, valuable alterations in CMSC decisions?

4. Experimentation and Results

To examine the value of possible CMSC decision refinements as estimated by the phase information release three scenarios were simulated.

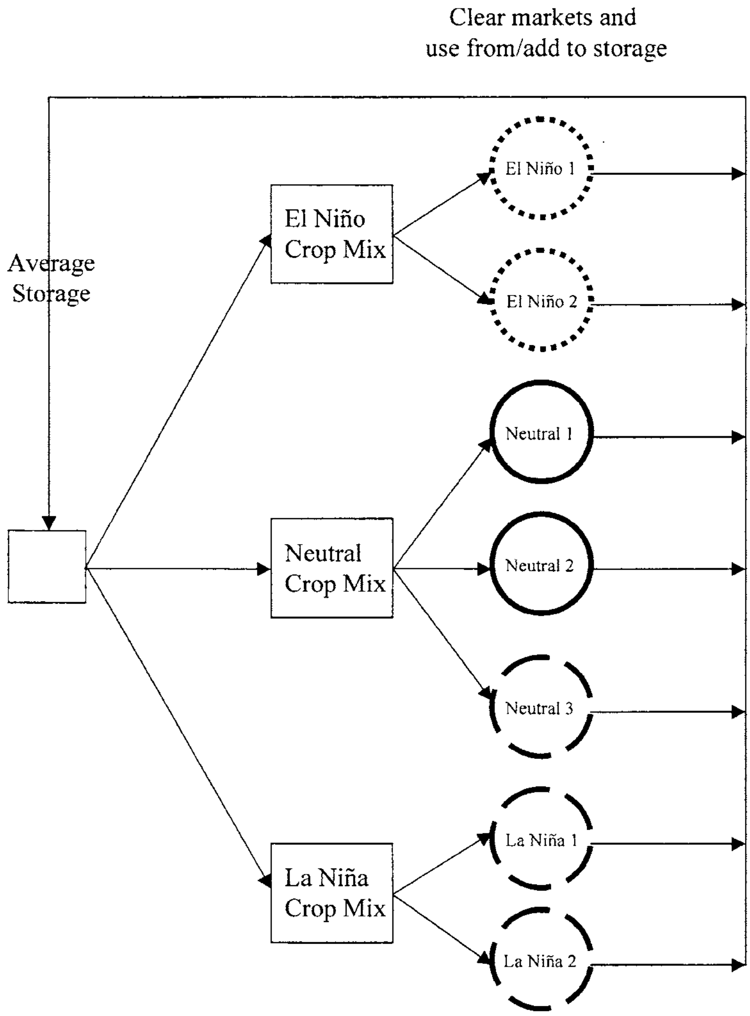

Figure 2. Situation with ENSO phase information.

1. The first involves a no ENSO phase forecasting situation where each of 22 different historical weather states and associated yields are portrayed as equally likely.
2. The second involves a model setup where CMSC decisions could be made with full knowledge of which of the three ENSO states was happening thus permitting the CMSC decisions to be fully tailored to the subset of the 22 states of nature corresponding to emerging ENSO phase. This means the CMSC decisions are tailored to the phase but are still subject to the uncertainty of event strength (i.e., five El Niño events ranging from weak to strong are represented under the El Niño phase). Here the probability of a phase forecast involves the relative frequency of the phases occurring in the 22-year history and under

Table III
Value of ENSO information under alternative ENSO definitions in 1996 $

Welfare measure	Unit	No forecast	3 Phase	5 Phase	22 Phase
U.S. consumers' surplus	Million 1996 $	1174277	1262 [b]	2095	3292
	Coef. of variation	(1.30) [a]	(0.86)	(0.57)	(0.18)
U.S. producers' surplus	Million 1996 $	36971	–967	–1395	–2124
	Coeff. of variation	(43.52)	(28.24)	(19.99)	(4.97)
Foreign surplus	Million 1996 $	248293	104	54	221
	Coef. of variation	(3.89)	(3.49)	(3.41)	(3.89)
Total welfare	Million 1996 $	1459541	399	754	1390
	Coef. of variation	(0.70)	(0.63)	(0.62)	(0.71)

[a] The numbers in parentheses are the coefficients of variation for the welfare measures.
[b] The $ figures for the last three columns are the changes from the no forecast case.

each phase the various strength events are treated as equally likely. Storage decisions link the phases together as one can set ending storage in accordance with production under the ENSO phase and strength events but each event begins with average ending storage which is set optimally considering all the phases, event strengths and

3. The third involves the five phase definition and is implemented just the same as in the three phase case but the data are separated into the five phases as defined in the data in Appendix A.

In addition we wished to examine the potential returns to further forecasting refinements and did this by examining the 'perfect foresight' case as follows:

4. The fourth uses a structure where 22 CMSC reactions are allowed to be formed one for each year in the data set to simulate ultimate customization of phase forecast and reaction.

4.1. EFFECTS OF THREE VERSUS FIVE PHASE INFORMATION

GlobalASM generated estimates of welfare gains from the scenarios are listed in Table III. Three phase ENSO information increases total welfare by $399 million dollars. Use of the five phase ENSO information raises the total value of information to $754 million dollars but also reduces the variability of welfare. Thus, the results show there are significant potential gains from release of five as opposed to three ENSO phase information.

Table IV reports information on the crop mix shifts in adjustment to production patterns for selected major crops in 10 USDA defined major U.S. production regions. These results show that the provision of ENSO phase information gen-

Table IV
Average percentage changes in cropped acreage from the no forecast solution

USDA	3 Phase				5 Phase			
10 regions	Corn	HRWW	Sorghum	Soybeans	Corn	HRWW	Sorghum	Soybeans
Northeast	1.9		–2.0		3.3		–12.7	
Lakestates	1.3	–7.8			–8.1		–0.8	
Cornbelt	1.0		3.2	–12	5.3		1.8	–5.3
Northplain	–5.2	5.3	0.2		–5.2	5.8	–6.7	
Appalachia	7.5		16.1	–2.4	–0.8		–26.0	–11.4
Southeast	2.7		–9.5	3.2	3.0		–13.2	10.0
Deltastates	11.5		3.9	–0.7	6.6		–17.9	5.5
Southplain	10.0	–3.6	–6.8	–7.4	27.9	–7.5	–5.1	–23.4
Mountain	2.5	1.6	–1.3		13.0	1.9	–14.2	
Pacific	1.2	1.5	–22.7	6.5	1.0	4.5	–8.9	6.3

HRWW labels hard red winter wheat.

erally redistributes crop acreage across the country and shows the magnitude of the acreage shifts are larger under the five ENSO phase information forecasts than under the three phase forecasts. Table V shows that shifts occur in total U.S. production under the provision of any ENSO phase information with 0.3–16% shifts occurring the three phase information. Generally even larger shifts occur under the five phase information. World trade quantity is also affected although to a lesser degree due to the much more limited modeling of adjustment. Table VI shows changes in U.S. storage as influenced by forecast form. Average amount in storage increases for all crops but corn under five as opposed to three phase information. The forecast form also affects level and variability of world prices as shown in Table VII. The use of the ENSO phase information decreases world price for all trade products except for sorghum and decreases the variability of world prices except for soybeans and sorghum.

4.2. VALUE OF PERFECT FORECASTING

When the CMSC decisions are allowed to fully adjust to each and every one of the 22 years in the distribution, the information value rises further to $1390 million showing that there are substantial further gains to be acquired if meteorologists are able to even further refine their information differentiating more precisely the exact nature of the event strengths.

Table V

Percent change in U.S. production and world trade quantity measures with ENSO information

		Corn	Hrsw	Hrww	Soft	Sorghum	Soybeans
3 Phase							
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
World trade quantity	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
5 Phase							
Total U.S. production	Phase 1	1.1	11.8	–2.6	6.0	–2.6	–2.9
	Phase 2	–0.2	–1.9	2.4	–6.4	–15.7	–4.4
	Phase 3	–4.5	–10.7	18.8	–5.3	5.2	–1.0
	Phase 4	11.4	–19.8	0.1	9.9	–1.9	7.1
	Phase 5	1.7	–12.5	1.8	–3.5	0.3	3.7
	Average	1.3	–4.1	2.4	–1.2	–5.2	–0.5
World trade quantity	Phase 1	1.8	–3.2	–0.7	–3.3	1.6	–0.2
	Phase 2	–1.8	–0.3	–0.3	–0.6	–3.9	–0.5
	Phase 3	2.0	–0.5	7.0	1.7	–0.6	–0.2
	Phase 4	–0.4	1.3	2.0	–1.3	–4.5	1.1
	Phase 5	2.3	2.3	1.2	2.4	–1.0	0.3
	Average	0.6	–0.2	0.9	–0.2	–1.6	–0.03

HRSW labels data for hard red spring wheat; HRWW labels hard red winter wheat; and SOFT labels soft white wheat.

4.3. WELFARE DISTRIBUTION IMPLICATIONS OF INCREASED PRECISION

A pattern emerges in the welfare distribution results with respect to precision of information. Namely, increased phase refinement and resultant crop mix/storage strategy refinements redistribute gains from producers to consumers. This is not unexpected as overall aggregate production is increasing and, given inelastic commodity demand, this results in lower prices leading to consumer gains at the expense of producer losses (this is a widely found result in aggregate economic appraisals).

Table VI
Percentage chnge in U.S. storage additions and withdrawals

		Corn	HRSW	HRWW	SOFT	Sorghum	Cotton
3 Phase							
Additions	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
Withdrawals	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
5 Phase							
Additions	Phase 1	–3.2	189.4	29.9	31.8	!18.3	–68.4
	Phase 2	9.8	–1.9	–8.5	–5.8	–43.8	131.4
	Phase 3	–100.0	–100.0	213.5	–41.4	–100.0	–100.0
	Phase 4	297.5	–100.0	–100.1	–100.0	–100.0	457.6
	Phase 5	–61.9	–24.8	20.2	63.9	63.9	–100.0
	Average	–1.1	17.5	8.9	10.0	12.2	31.5
Withdrawals	Phase 1	9.2	–19.7	129.2	–30.9	–100.0	109.9
	Phase 2	18.6	–17.8	–32.2	–1.2	150.3	–59.4
	Phase 3	65.3	–100.0	–100.0	72.8	–100.0	90.8
	Phase 4	–14.8	69.5	67.7	72.8	–64.9	–100.0
	Phase 5	–50.1	111.4	–26.7	15.2	7.6	96.2
	Average	–1.1	17.5	8.9	10.0	12.2	31.5

On the other hand, the variability of U.S. consumers and producers' welfare is reduced as the ENSO definition is refined from a three to a five then on to 22 phase system. The welfare variations for foreign surplus and total welfare do not exhibit significant change as the ENSO definition is refined.

5. Concluding Comments

This study once more affirms the findings of others that ENSO forecasts do have value but goes further to show that the value of the forecast can roughly be doubled by releasing more refined forecasts and educating agricultural producers to use them. Namely, in the context of the 22 years of climate data we employ, the use

Table VII
World prices by forecast type

		No forecast	3 Phase	5 Phase
Corn	Price $/bushel	3.31	3.30 (–0.3)	3.29 (–0.6)
	C.V.	4.85	4.49 (–7.42)	4.58 (–5.56)
HRSW	Price $/bushel	5.53	5.53 (0)	5.54 (0.18)
	C.V.	13.62	12.25 (–10.05)	9.90 (–27.31)
HRWW	Price $/bushel	4.62	4.52 (–2.16)	4.45 (–3.68)
	C.V.	6.43	4.94 (–23.17)	5.64 (–12.28)
SOFT	Price $/bushel	4.24	4.23 (–0.23)	4.29 (1.18)
	C.V.	19.70	18.42 (–6.49)	19.88 (0.91)
Soybeans	Price $/bushel	6.09	6.06 (–0.49)	6.10 (0.16)
	C.V.	2.34	2.60 (11.11)	2.61 (11.54)
Sorghum	Price $/bushel	11.59	11.68 (0.77)	11.69 (0.86)

The numbers in parentheses are percentage changes.

of the five phase forecast definition roughly doubles the total value of the potential agricultural adjustment relative to the more widely distributed three phase information. The results also show that there is room for yet another doubling if further refinements beyond five states can be made. The results are potentially limited by the short 22-year series but expansion beyond that series raises serious question about the stationarity of the underlying crop yield distributions.

Acknowledgements

This research was partially supported by the Texas Agricultural Experiment Station, USDA- Natural Resources Conservation Service and USAID through the SANREM CRSP. Thanks to Jim Mjelde, Steve Fuller and Luis Fellin for help during project execution.

Appendix A. ENSO Phases of Historic Years Via Different Phase Definitions

Year	3 Phase	5 Phase
1970	La Niña	Phase 2
1971	La Niña	Phase 2
1972	El Niño	Phase 1
1973	La Niña	Phase 2
1974	Neutral	Phase 2
1975	La Niña	Phase 2
1976	El Niño	Phase 4
1977	Neutral	Phase 1
1978	Neutral	Phase 5
1979	Neutral	Phase 5
1980	Neutral	Phase 5
1981	Neutral	Phase 3
1982	El Niño	Phase 1
1983	Neutral	Phase 2
1984	Neutral	Phase 5
1985	Neutral	Phase 5
1986	El Niño	Phase 4
1987	El Niño	Phase 1
1988	La Niña	Phase 2
1989	Neutral	Phase 2
1990	Neutral	Phase 5
1991	El Niño	Phase 1
1992	Neutral	Phase 3
1993	Neutral	Phase 1
1994	Neutral	Phase 1
1995	El Niño	Phase 5

Sources: www.dnr.qld.gov.au/longpdk.

Appendix B. Non U.S. Regions Defined in Model

Number	Region name	Countries included
1	WEST AFRICA	Dahomey, Angola, Benin, Cameroon, Canary Island, Ghana, Guinea, Ivory Coast, Liberia, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo, Burkina, 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, Un Arab Em
8	ADRIATIC	Cyprus, Greece, Turkey
9	CHINA	China
10	SOUTHEAST ASIA	Hong Kong, Indonesia, Malaysia, New Zealand, Okinawa, Philippines, Singapore, Thailand, Vietnam, Fr. Pac. Is., So. Pac. Is., Other Pac. Is.
11	JAPAN	Japan
12	SOUTH KOREA	South Korea
13	TAIWAN	Taiwan
14	EAST AMERICA	Belize, Costa Rica, El Salvador, Curacao, Guatemala, Honduras, Nicaragua, Panama, Paraguay, Suriname, Uruguay, Venezuela, Fr. Guiana

Appendix B (*Continued*)

Number	Region name	Countries included
15	CARRIBEAN	Lee Wind Is., Bahamas, Barbado, Dominican Rep., Fr. Wst. Ind., Haiti, Trinidad, Jamaica
16	AUSTRALIA	Australia
17	N. CENTRAL EUROPE	Austria, Belgium, Germany, Netherlands, Switzerland
18	EAST BLOCK EUROPE	Bulgaria, Czechoslovak, Hungary, Poland Romania, Yugoslavia
19	WESTERN EUROPE	Italy, Malta, Portugal, Spain, Others
20	ISLANDS	Iceland, Ireland, U.K.
21	SCANDINAVIA	Denmark, Finland, Norway, Sweden
22	CANADA	Canada
23	MEXICO	Mexico
24	UNITED STATES	United States
25	U.S.S.R.	Former U.S.S.R.
26	WEST AMERICA	Bolivia, Chile, Colombia, Ecuador, Peru
27	BRAZIL	Brazil
28	ARGENTINA	Argentina

Appendix C. Model Used to Implement Conceptual Framework

The modeling framework above is cast in a stochastic programming with recourse, price endogenous sector model as discussed in Lambert et al. (1995). A 3 stage model is used. In the first phase, we have a balance constraint that insures average storage additions equals average withdrawals. In the second phase, we assume ENSO phase information dependent crop mix but event strength is unknown. In the third phase, we determine consumption levels and trade activities with perfect knowledge of yield outcomes.

This study employs Chen and McCarl's extension of McCarl et al.'s (2001) U.S. sector model (ASM) as used in Chang et al. (1992) and Lambert et al. (1995)

which is a price-endogenous mathematical program following the market equilibrium and optimization concept developed in Samuelson (1952), and Takayama and Judge (1971) as reviewed by McCarl and Spreen (1980) and Norton and Schiefer (1980). 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.

That model links a detailed U.S. sector model to a worldwide multi commodity spatial equilibrium model ala Takayama and Judge (1971).

C.1. MODEL ALGEBRAIC REPRESENTATION

The model is a mathematical programming model and is summarized in the following equations. The objective function is:

$$\begin{aligned}\max \sum_e pf_e \Bigg[& -\sum_j \sum_k g_{jk} X_{jke} - \sum_k \sum_r \int \alpha(R_{rke}) dR_{rke} \\ & + \sum_s p_{s/e} * \Bigg[\sum_i \int \varphi(Q_{ise}) dQ_{ise} \\ & + \sum_i \sum_c \left(\int (fd(FQD_{icse}) dFQD_{icse} - \int fs(FQS_{icse}) dFQS_{icse} \right) \\ & - \sum_i \sum_k \sum_c USFTRD_{i,c,k,s,e} usfcst_{i,k,c,e} \\ & - \sum_i \sum_c \sum_{cl} FTRD_{i,c,cl,s,e} ffcstsub_{i,c,cl} \\ & - \sum_i \sum_k \sum_{kl} USTRAN_{i,k,kl,s,e} uscst_{i,k,kl} \\ & - \sum_i \sum_k pdif_{ik} * TN_{ikse} \\ & - \sum_i \sum_k \sum_s stor_i QSTORW_{ikse} \Bigg] \Bigg], \end{aligned} \tag{1}$$

here parameters are typed in lower case or greek while variables are typed in upper case. The symbols are as follows:

e	indexes the ENSO phase,
i	indexes commodities,
j	indexes production processes,
k, k_1	indexes U.S. regions,
c, c_1	indexes ROW regions,
r	indexes resources,
s	indexes strength of ENSO phase,
pf_e	is 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,
$p_{s/e}$	is 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,
$FTRD_{iccl se}$	trade between ROW regions c and cl 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,
$USTRAN_{ikklse}$	shipment volume between U.S. regions kl and k of commodity i under ENSO strength s and phase e,
$ffcst_{iccl}$	transportation cost from ROW regions c and cl for commodity i,
$usfcst_{ikc}$	transportation cost from U.S. region k to ROW region c for commodity i,

$uscst_{ikkl}$	transportation cost between U.S. regions kl and k 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 blends the spatial equilibrium and price endogenous sector models. In particular (just for now ignoring the stochastic, ENSO phase dimension) the first two lines 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 ($\int \alpha(R_{rke})\, d\, R_{rke}$) with line two giving the area under the U.S. national demand equations ($\int \psi(Q_{ise})\, d\, Q_{ise}$). Line three gives the area under the excess demand less that under the excess supply curves for commodity i in ROW region c. Line four sums the transportation costs times the volume traded between the U.S. regions and ROW regions for U.S. imports and exports (USFTRD). Line five sums the transportation costs times the volume traded among the foreign regions (FTRD). Line six sums the transportation costs between regions in the U.S. (USTRAN). Line seven 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 but those not in the first line are ENSO event strength and phase dependent while the first line is only ENSO phase dependent. This assumes 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 see Lambert et al. (1995)). The first and second line incorporates 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:

$$\begin{aligned}
&-\sum_j((y_{ijk} + yr_{ijkse}) * X_{jke}) - \sum_c USFTRD_{i,c,k,s,e} - \sum_{kl} USTRAN_{i,kl,k,s,e} \\
&\quad -QSTORW_{i,k,s,e} + TN_{ikse} + \sum_c USFTRD_{i,k,c,s,e} + \sum_{kl} USTRAN_{i,k,kl,s,e} \\
&\quad +QSTORA_{i,k,s,e} \leq 0 \text{ for all } i, k, s, e\,.
\end{aligned} \tag{2}$$

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) off 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 a commodity (i) in a region (k) under ENSO strength event (s) and a phase (e).

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

$$Q_{ise} - \sum_k TN_{ikse} \leq 0, \quad \text{for all } i, s, e\,, \tag{3}$$

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

$$\sum_j f_{rjk} X_{jke} - R_{rke} \leq 0, \quad \text{for all } k, r, e\,, \tag{4}$$

where f_{rjk} is the resource usage per acre for jth production processing 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

$$\begin{aligned}
&+FQD_{icse} + \sum_k USFTRD_{i,c,k,s,e} + \sum_{cl} FTRD_{i,c,cl,s,e} \\
&\quad - FQS_{icse} - \sum_k USFTRD_{i,k,c,s,e} - \sum_{cl} FTRD_{i,cl,c,s,e} \\
&\quad \leq FYR_{icse}, \quad \text{for all } i, c, s, e\,,
\end{aligned} \tag{5}$$

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

The storage balance is

$$\sum_e \sum_s pf_e p_{s/e}[QSTORW_{ise} - QSTORA_{ise}] = 0 \quad \text{for all } i \, , \tag{6}$$

where probability weighted net additions and withdrawals are equal.

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(Received 31 August 2000; in revised form 16 January 2002)