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The benefits to Mexican agriculture of an El Niño-southern oscillation (ENSO) early warning system☆

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Abstract

Weather agencies worldwide are attempting to determine if systematic disturbances in climate, such as the El Niño-southern oscillation (ENSO), can be detected far enough in advance so that decisions can be altered to better accommodate these disturbances. Mexico is one country where ENSO-related climatic disturbances have been observed. If climate forecasters were able to disseminate information on upcoming ENSO-induced weather patterns with sufficient lead time, Mexican farmers could adjust by altering a variety of crop decisions, such as growing less (or more) water consumptive crops, planting drought resistant varieties, or altering planting times. This could have a positive impact on crop production, enhancing food security, farmers' incomes, and social welfare. The purpose of this paper is to value such forecasts in a Mexican agricultural setting.

To assess the economic consequences of climate arising from various ENSO phases, estimates of regional crop yield sensitivity for key crops were modeled using a crop biophysical simulator. The value of a forecast is then measured by the expected increase in economic benefits due to changes in cropping patterns, production and consumption arising from the yield changes under each ENSO phase forecast. These economic estimates are derived from an economic model of Mexican agriculture. The value of the ENSO information will depend on its accuracy in terms of predictions of the weather consequences of each phase.

The economic model is a stochastic, price endogenous, mathematical programming model that represents agronomic and economic conditions in a five-state Mexican region. This model depicts agricultural behavior across the three ENSO phases and provides the basis for calculating the value of information. The benefits of an ENSO early warning system for Mexico is approximately US$ 10 million annually, based on a 51-year time period of ENSO frequencies and when a forecast skill of 70% is assumed. This value translates into an internal rate of return for such an early warning system of approximately 30%. The values for higher skill levels are correspondingly higher. The values estimated here should be viewed as lower bound estimates of the value of an ENSO early warning system because benefits are not estimated for other parts of Mexican agriculture, such as non-commercial (subsistence) agricultural areas, areas where there is only a weak ENSO signal that is not very predictable, and the livestock sector. Also, benefits here do not include benefits that could occur with adjustments in

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energy generation, water management, or any other economic sectors that may be positively affected by the existence of an ENSO early warning system.

Keywords: Climate forecast; ENSO; Economic value; Agriculture; Mexico

1. Introduction

Weather agencies worldwide are attempting to determine if systematic disturbances in climate can be detected far enough in advance so that decisions can be altered to better accommodate these disturbances. The climate effects of the El Niño-southern oscillation (ENSO) are one such item of concern. ENSO refers to semi-periodic changes in the tropical Pacific ocean-atmosphere system (National Oceanic and Atmospheric Administration, 2000). Although the ENSO phenomenon occurs in the tropical Pacific, the associated climate effects occur on a more global scale (Glantz, 2001), and, in turn, have broad regional implications for crop yields (Legler et al., 1999; Mjelde et al., 1998; Izaurralde et al., 1999).

Mexico is one country where ENSO-related climatic disturbances have been observed. Variations in climate characteristics and reservoir inflows for some regions of Mexico have been reported (Magana et al., 1999 and Acosta, 1988) for the three ENSO phases (El Niño, La Niña and Neutral). In addition, there are variations in weather patterns across Mexico during a given ENSO phase. These changes in seasonal weather patterns and streamflows have been associated with alterations in agricultural yields in important agricultural regions of Mexico (Magana et al., 1999).

If climate forecasters were able to disseminate information on upcoming ENSO-induced weather patterns with sufficient lead time, Mexican farmers could adjust by altering a variety of crop decisions, such as growing less (or more) water consumptive crops, planting drought resistant varieties, or altering planting times. This could have a positive impact on crop production, enhancing food security, profits, and social welfare. Such benefits have been found in studies in other regions. For example, the value of ENSO forecasts to US agriculture has been found to be positive in a series of studies (Adams et al., 1995; Solow et al., 1998; Mjelde et al., 1998; Chen et al., 2001). The purpose of this paper is to value such forecasts in a Mexican agricultural setting.

2. Background—Mexican agriculture and climatic sensitivity

Magana et al.'s (1999) study of the impacts of the El Niño phase on Mexican climate indicates that most El Niño years exhibit reduced summer months precipitation, and reduced winter season inflows to reservoirs (by about 40%). Acosta (1988) observed that inflows to reservoirs tend to increase when the El Niño phase ends. An examination of historical agricultural statistics show El Niño phases have been associated with crop failures, increased idling of land and reductions in agricultural yields. For example, during the 1982, 1986 and 1987 El Niño years, 97, 86 and 73% of land under rainfed crops in the semiarid north central region of Mexico was idled, compared to 13% on average over the past three decades for dryland crops in Mexico (SARH, 1986). The impacts of ENSO events on rainfed agriculture in Mexico are important, given that approximately 80% of land in Mexico is non-irrigated.

The strongest ENSO signal in Mexico is found across the important agricultural states of Jalisco, Guanajuato, Mexico, Michoacan, and Tamaulipas. These states are located in the temperate to subtropical central portion of Mexico and produce a wide range of crops. In aggregate they produce over 30% (by value) of national agricultural production in Mexico. In view of their agricultural importance and the presence of a strong ENSO signal, these five states were chosen as the empirical focus of this empirical analyses.

The five states selected here are characterized by predominately rainfed agriculture. Thus, changes in precipitation and temperature under various ENSO phases have the potential to alter yields. The effects of ENSO phases in terms of temperature and precipitation are presented in Table 1 for the five states. As is evident from the table, El Niño's and La Niña's have

Table 1
Annual average temperature[a] (Max and Min) and precipitation[b] by region and ENSO phase climate anomalies (1960–1989)

Region	Neutral			El Niño (diff.)			La Niña (diff.)		
	T_{max}	T_{min}	Precipitation	T_{max}	T_{min}	Precipitation	T_{max}	T_{min}	Precipitation
Mexico	24.62	7.52	603.20	0.25	−0.12	−2.39	−1.09	−1.12	−2.83
Guanajuato	26.19	9.83	641.40	−0.50	1.10	24.70	−0.53	−1.20	1.26
Jalisco	30.61	12.34	875.10	−3.66	0.86	−7.16	−0.77	−0.20	−2.29
Michoacan	26.45	11.33	786.90	0.50	−0.15	3.30	−0.15	−1.38	−1.04
Tamaulipas	29.00	16.64	544.50	−0.92	0.97	30.25	0.15	−0.18	9.51

[a] Temperature is in degrees Celsius, averaged across the calendar year and the 20-year period.
[b] Precipitation is in millimeters for the calendar year, averaged across the 20-year period.

generally consistent affects as temperatures across the five regions (El Niño's tend to be warmer and La Niña's cooler). However, the effects in terms of precipitation are mixed; in some regions, both phases show increased precipitation relative to the neutral or normal case (although the increases are greater under El Niño's). These climate anomalies are likely to lead to changes in yields, both across regions and ENSO phases.

3. Procedures

To examine the consequences of ENSO phases in this region of Mexico, we chose a set of 24 of the most economically important crops, ranging from high value (per acre) vegetable crops to lower value field crops. Production data for these crops were obtained from the Secretaria de Agricultura, Anuario Estadistico de la Production Agricola de los Estados Unidos Mexicanos. All crop budget and price data were converted to current values (year 2000 pesos) using an index of prices received by producers obtained from the Banco de Mexico.

Region-specific farm level crop production practices and costs of production for irrigated and rainfed crop production by season were obtained for each of the crops in the five states. Crop budgets were obtained from the College de Post Graduados Instituto de Ensenanza e Investigacion en Ciencias Agricolas. These budgets include detailed information regarding production technical coefficients, unit prices of products, inputs, such as fertilizer, seed and labor costs and land rental rates, which were provided by each State Department of Agriculture representative (Delegado Estatal de la Secretaria de Agricultura y Recursos Hidráulicos). Local machinery suppliers in each state provided machinery and equipment information. Water prices for irrigated crops were obtained from the water tariff of the National Water Commission (Comisión Nacional del Agua, 2001), and electricity prices were obtained from the tariff rates of the Federal Electricity Commission (Comisión Federal de Electricidad, 2001). Since these budgets were based on monetary values from 1990 to 1992, they were updated when possible with more current crop budget data obtained from Fideicimisos Instituidos en Relacion con la Agricultura (FIRA). When this was not possible, the values were updated to year 2000 pesos using the index of prices paid by producers obtained from the Banco de Mexico.

To assess the economic consequences of climate arising from various ENSO phases, estimates of regional crop yield sensitivity for the selected crops, under the three ENSO phases were needed. Because the intention was to identify ENSO impacts on Mexico's agriculture, a modeling effort able to predict crop yield under ENSO conditions was applied using weather generation in the process-based erosion-productivity impact calculator (EPIC) model developed by Williams (1995). EPIC has been a major tool for land use planning and soil management practices evaluation in the US since the 1985 Resource Conservation Act, when the model was expanded and refined to allow simulations of many processes important for agricultural management (Sharpley and Williams, 1990).

EPIC is a continuous simulation model that can be used to determine the effects of management practices on agricultural production and soil and water resources. Its major components are stochastic weather simulation, hydrology, erosion–sedimentation, nutrient cycling, pesticide fate, plant growth, soil temperature, tillage, economics, and plant environment control (Williams, 1995). In southern Mexico, EPIC was applied to explore the sustainability of corn production systems using conventional and no-tillage systems on steep lands (Villar, 1996).

Crop productivity in regional representative farms of five states in Mexico was simulated under the presence of ENSO events: El Niño (EN), La Niña (LN) and Neutral (N) conditions. This was possible by constructing a data base containing climate, soils and crop management information of production systems allocated in economically important agroecological regions. Crop management and soils information from the state representative agricultural systems (representative farms) were provided by scientists of the Instituto Nacional de Investigaciones Forestales, Agricolas y Percuarias (INIFAP) allocated at the State Experimental Stations. EPICs process-based crop and biophysical simulation model was then applied to identify crop responses under climate stresses associated with the ENSO phenomena.

EPIC offers a suite of methods to estimate internal parameters and variables according to available data and local biophysical conditions of farms. Specifically, the effects of ENSO scenarios on agriculture were simulated by running the model under climate generation mode. To perform this operation, monthly weather statistics of minimum and maximum temperatures and precipitation totals were calculated using daily data recorded at climatic stations corresponding to the representative farms in each state: means, standard deviations, skewness, number of rainy days, and transition rainfall probabilities (wet day after wet day, and wet day after dry day). These statistics were input into the model for climate generation to perform the 30 year ENSO scenario simulation (1960–1989) (EN, LN and Neutral). Major EPIC output variables of interest in this project were: actual and potential evapotranspiration, irrigation demand, biomass and grain production (yields). The resulting yield changes (from Neutral) for the ENSO climate anomalies represent the affects of "average" EN and LN events observed during the historical period. Thus, the analysis does not address specifically the issue of varying strengths within an ENSO phase.

Table 2
Yield responses to ENSO phases for selected crops, by region and season

Region	Crop	% Change	
		El Niño	La Niña
Fall–winter irrigated crops			
Guanajuato	Barley grain	03.0	10.4
Guanajuato	Beans	00.3	−12.6
Jalisco	Corn grain	00.3	−12.6
Tamaulipas	Corn grain	15.2	06.5
Tamaulipas	Cotton	−02.4	00.0
Jalisco	Melon	−18.2	−34.6
Jalisco	Melon	03.4	−13.8
Michoacan	Melon	12.0	−28.0
Mexico	Potato	00.0	03.5
Michoacan	Potato	−13.0	09.3
Tamaulipas	Sorghum grain	03.9	02.6
Jalisco	Tomato	−23.7	−13.2
Mexico	Tomato	−09.1	−54.5
Michoacan	Tomato	17.4	−43.5
Guanajuato	Wheat grain	−00.6	02.1
Jalisco	Wheat grain	27.8	08.3
Michoacan	Wheat grain	−04.2	−07.8
Fall–winter rainfed crops			
Tamaulipas	Cotton	−42.6	11.3
Tamaulipas	Sorghum grain	−76.9	19.2
Spring-summer irrigated crops			
Guanajuato	Beans	01.2	02.0
Jalisco	Beans	03.4	−03.4
Jalisco	Corn grain	−15.0	−05.6
Mexico	Corn grain	01.1	01.3
Michoacan	Corn grain	00.2	09.9
Tamaulipas	Corn grain	00.9	04.0
Guanajuato	Potato	00.5	−02.0
Michoacan	Potato	−04.0	06.1
Guanajuato	Sorghum grain	−02.2	−01.1
Jalisco	Sorghum grain	−12.5	−06.3
Tamaulipas	Sorghum grain	−05.7	00.9
Jalisco	Tomato	−12.5	−03.1
Mexico	Tomato	09.1	04.5
Michoacan	Tomato	00.9	04.3
Guanajuato	Beans	−05.6	−02.8
Jalisco	Beans	08.3	02.5
Michoacan	Beans	10.0	−20.0
Spring–summer rainfed crops			
Tamaulipas	Beans	04.2	−06.8
Guanajuato	Corn grain	08.0	06.0
Jalisco	Corn grain	07.5	−01.8
Mexico	Corn grain	19.7	−14.4
Michoacan	Corn grain	−01.5	03.2
Tamaulipas	Corn grain	−22.0	−12.3
Tamaulipas	Cotton	−01.8	−02.8
Jalisco	Potato	−01.8	−02.8
Guanajuato	Sorghum grain	−12.2	02.4

Table 2 (*Continued*)

Region	Crop	% Change	
		El Niño	La Niña
Jalisco	Sorghum grain	−00.5	04.9
Michoacan	Sorghum grain	−77.8	−20.0
Tamaulipas	Sorghum grain	05.1	09.0
Tamaulipas	Soybean	−01.8	−02.8
Mexico	Tomato	−01.8	−02.8

The EPIC model computational methods applied were: potential evapotranspiration using the Penman–Monteith (Monteith, 1965) equation, automatic heat unit scheduling was set for plant growth based on a predefined crop management calendar, and water demand by crop was set at automatic irrigation to induce plant growth at maximum evapotranspiration. Crop management practices defined in the EPIC model input file corresponded to applied practices, dates, machinery and products required for soil preparation, planting, fertilization and control of weeds and pests by the farmers. The percent changes in crop yields for each state for selected crops, by ENSO phase, are presented in Table 2. The resultant crop yield responses vary by season, type of production (rainfed versus irrigated production) and location. In general, rainfed crop yields decline under EN events and increase under LN events. Irrigated crop yields display greater variability (no consistent pattern) due to the complex interaction between rain and irrigation water and temperature for crops grown under irrigation. For example, rainfall during the growing season may actually be harmful to irrigated crops, depending on their phonological stage. Rainfall at critical crop stages may actually reduce seed set as well as the quality of the crop. A more detailed discussion of the procedures used to calculate yield changes across ENSO events and a listing of responses for all crops included in the analysis may be found in Adams et al. (2001).

4. The decision framework for valuing information

The framework for valuing ENSO information is based on Bayesian decision theory and has been used to assess the value of weather forecasts in other contexts (see for example, Katz et al., 1982; Sonka et al., 1987). This framework has been used in a number of previous ENSO valuation efforts (Adams et al., 1995; Solow et al., 1999; Chen et al., 2001). In this study, the value of a forecast will be measured by the expected increase in economic benefits, arising from changes in cropping patterns, production and consumption motivated by the forecast information concerning each ENSO phase. In the case of Mexican agriculture, it is assumed that without an ENSO early warning system—the no-forecast case—farmers make planting decisions that have performed well under the full distribution of climatic conditions observed in the past across all ENSO phases. It is assumed that with an ENSO early warning system in place, Mexican farmers will be given information identifying that a particular ENSO phase will occur and that in turn they would change cropping decisions to adapt to the altered weather characteristics observed historically under that particular ENSO phase.

The value of information is measured as the difference in social welfare under the "no forecast" scenario and the "new information" scenario. The value of this information will depend on its accuracy in terms of predictions of the weather consequences of each phase. This value will be positive as long as there are significant, valuable, production and consumption adaptations that can accommodate altered yields associated with each ENSO phase.

This approach may be formalized in terms of Bayesian decision theory. Let S denote the ENSO phase, and X a cropping pattern chosen by the farmer. The possible values of S are El Niño, La Niña, or Neutral ENSO phases. Let ES denote a realization of S and let $p(X/\mathrm{ES})$ be the welfare for cropping pattern X if the realized ENSO phase is ES. The expected welfare for $X(W(X))$, given that there is no ENSO prediction is:

$$\mathrm{expected}(W(X)) = \sum_{S}\sum_{\mathrm{ES}} p\left(\frac{X_S}{\mathrm{ES}}\right) \mathrm{Prob}\left(\frac{\mathrm{ES}}{S}\right) \mathrm{Prob}(F = S)$$

where $\mathrm{Prob}(F = S)$ is the probability that the forecast for phase S arises and $\mathrm{Prob}(\mathrm{ES}/S)$ is the probability that state ES arises given the forecast is for state S. Finally X_S is the cropping decision given the forecast of S.

For a given ENSO phase ES, the welfare is found from a model which determines the optimal cropping and consumption patterns given a forecast, using an economic model of the agricultural sector discussed in the next section.

In the absence of an ENSO phase prediction, the expected economic surplus is assumed to be given by

$$\text{expected}\left(W\left(\frac{X}{\text{NF}}\right)\right) = \sum_{\text{ES}} p\left(\frac{X}{\text{ES}}\right)\text{Prob(ES)}$$

where $p(X/\text{ES})$ is the economic surplus arising from a regional sector model when X is not adapted and the Prob(ES) probabilities are the likelihood that each state will occur.

In turn, the value of the forecast is the difference between the two above welfare measures. This value of the ENSO forecast (or the ENSO early warning system giving rise to the forecast) is a long-term concept. In any given year, an incorrect prediction may result in a loss. However, on average the use of the prediction will lead to an increase in profits, consumer surplus, or both.

5. The economic valuation framework—an economic model of regional agriculture

The economic model used to translate yield changes into economic values is a stochastic, price endogenous, mathematical programming model that represents agronomic and economic conditions in the five-state Mexican region. Such a model simulates perfectly competitive farm behavior where farmers equate average revenue with the cost of production (as explained in McCarl and Spreen, 1980; Lambert et al., 1995). The model is conceptually similar to the models employed in the assessment of ENSO phases in US agriculture (e.g. Adams et al., 1995; Solow et al., 1998; Chen et al., 2001).

The economic model simulates acreage allocation, crop prices, total production and input usage under the expected or forecast climate conditions. Production, consumption and crop prices vary by ENSO phase (El Niño, La Niña and Neutral). The objective function provides an estimate of social welfare under each forecast assumption that equals the sum of consumers' and producers' surplus. In turn, welfare can be decomposed into measure of welfare for agricultural producers and consumers. In addition, the model also reports changes in cropped acreages, prices, production and input use, as well as other measures of agricultural economic activity.

5.1. Components of the model

The economic model depicts crop-based agricultural activity within the five states of Guanajuato, Jalisco, Mexico, Michoacan and Tamaulipas. Specifically, the model depicts acreage allocation among 25 crops disaggregated by state and season of production (fall/winter, or spring/summer) under a mix of irrigated and rainfed production patterns.

The model contains a set of market level demand functions that allow estimation of the changes in price resulting from supply shifts associated with the three ENSO phases. The price and quantity changes lead to changes in the welfare measures. The demand functions were estimated based on 10 years of price and consumption data for each of the 24 crops. The demand estimation results indicate that eight crops faced downward sloping demand relationships, i.e. the region is a major producer of each of these eight crops. These demand curves are estimated in price-dependent form as constant elasticity demand functions. This means that the percentage change in price for a given change in quantity is constant across the demand curve. However, the elasticities do vary by crop. The remaining 16 crops from the region were determined to be price takers (no statistically significant effect of production from the region on national-level prices).

Agricultural decision-making is typically limited by resource availability, access to capital and other factors. The model included these constraints in two ways. First, land constraints were entered, with the cultivable acreage by season set to the maximum observed agricultural land use between 1995 and 1998 across the 24 crops in each of the five states. Land use was distinguished by type of production (irrigated or rainfed).

Second, crop mix constraints are included that implicitly represent other resource constraints reflecting agronomic restrictions, capital, resource availability and other factors (as discussed in Onal and McCarl, 1991, and McCarl, 1982). These constraints are included for irrigated and rainfed crop mix conditions. In particular, these historical farm crop mix choices implicitly have embedded within them farmers choices across all production possibilities of the limitations imposed by rotation, resources, and other technical factors. The crop mix constraints were drawn from 19 years of historical records (from 1980 to 1998). The use of historical crop mixes explicitly recognizes that farmers do respond to ENSO events. That is, since these 19 years contain all three ENSO phases, they reflect farmers planting decisions under ENSO events, in the absence of forecasts.

A key assumption in the model involves ENSO phase frequency probabilities. Three assumptions were developed, two depending on historical observations and the third on a recent projection of ENSO frequencies under climate change. For the historical series, the frequency of each ENSO phase over two recent time periods are used; a recent 19-year period from 1980 to 1998, and a 51-year period from 1951 to 2001, where each ENSO phase is defined by the Japanese Meteorological Agency (JMA) index. The JMA index is a 5 months running mean of spatially averaged sea surface temperature abnormalities over the tropical Pacific. The frequency of ENSO phases for the most recent period (1980–1998) features a higher percentage of Neutral phase years. As such, it is expected that the value of information will be less for this scenario than it would for a scenario with more extreme phases. For the 51-year time span, there is a higher frequency of La Niña phases and a lower frequency of Neutral phases than the 19-year time span. The third set of frequencies analyzed were frequencies simulated by Timmermann et al. (1999), which were calculated assuming increasing levels of greenhouse gases, as assumed under Intergovernmental Panel on Climate Change projections (IPCC, 1992). These frequencies assume that the occurrence of El Niño and La Niña years will increase, such that each ENSO phase occurs with almost the same frequency. The frequencies for each time period are reported in Table 3.

Table 3
ENSO phase frequencies under three time period assumptions

ENSO frequency	ENSO frequency or probability		
	El Niño	La Niña	Neutral
19-year period (using JMA index)	0.260	0.110	0.630
51-year period (using JMA index)	0.255	0.235	0.510
IPCC projections under climate change[a]	0.339	0.310	0.351

[a] Source: Timmermann et al. (1999).

5.2. Model use

The derivation of forecast value for the ENSO phenomenon depends on comparing the Base case (“no-forecast” case) with a model solution generated under assumptions representing ENSO forecasts. The Base case represents the solution of the economic model under current (1995–1998) weather, agronomic and economic conditions. Note that welfare results from the Base or no-forecast case are then compared with welfare results from a model run with ENSO forecasts. Distributional aspects of these results are also explored. The annual stream of benefits is then compared to the annual stream of costs to obtain a net present value and an internal rate of return for investment in an ENSO information system. Finally, a sensitivity analysis is performed to determine the tradeoffs in net present value associated with alternative levels of forecast skills versus the adoption rate by farmers of the ENSO early warning system.

5.3. “No forecast” model comparison (Base model validation)

Forecast values derived from this or any model are of little use if the model does not reasonably replicate current conditions (with no forecast). To examine the performance of the model solution in replicating current conditions, the Base case solution is compared with historical (1995 to 1981) land use, production and prices reported by the various state and federal agencies in Mexico for the five states evaluated here.

The total hectares in production estimated by the model in the Base case are similar to historical acreages. The total hectares of production for the crops modeled in the five states falls within 3% of the historical average—4,600,000 ha but below the maximum historical hectares in production, which is approximately 5,800,000 ha. The number of hectares in production in each of the five states is similar to historical averages. Specifically, in the Base model solution, the states of Mexico and Jalisco are almost equal to the historical average hectares of production, and the other three states range between 75 and 125% of historical average acreage in production.

The final component of the comparison involves the reasonableness of the estimated production and price levels. Given that this is a price endogenous model, it is important that it generate prices that are consistent with actual (historical) prices. The predicted and historical prices (average of 1980–1998 period and for El Niño or La Niña years) are reported in Table 4. All predicted prices are within 5% of the historical range (between mean and ENSO phases). The performance of the model in replicating acreages and prices is taken as an indication that the model is performing in an acceptable fashion for the valuation analysis to be performed here.

Table 4
Historical prices (1981–1998) and modeled prices, in year 2000 pesos

Variable	Actual			Modeled (Base case) prices[a]
	Mean price[b]	El Niño price[c]	La Niña price[d]	
Barley grain	2188	2302	1865	2113
Beans	6864	6909	5831	6232
Broccoli	2736	4106	3399	2442
Carrot	1205	765	2269	1033
Corn grain	2949	2525	2020	2536
Corn silage	496	394	538	478
Cotton	4426	7673	5651	4959
Chick peas	2092	2616	2067	1916
Garlic	7668	8919	6673	6743
Green pepper	5553	6065	5100	4929
Green tomato	4117	3880	3167	3428
Melon	2732	2730	2650	2225
Oat silage	728	552	599	561
Onion	2232	2704	2651	1894
Peas	4786	4765	4742	4725
Pepino	2051	1124	2187	1442
Potato	3834	3537	3508	3725
Sorghum grain	2011	1876	1427	1506
Sorghum silage	505	468	485	475
Soybean	3627	4990	3994	3288
Strawberry	5710	6360	5827	5453
Tomato	4042	3876	3597	4078
Watermelon	2084	2178	2043	1947
Wheat grain	2150	2087	1772	2111

Source: SAGAR.

[a] Modeled prices are for the entire 19-year period.

[b] Mean price is averaged over all ENSO phases for the entire 19-year period.

[c] El Niño prices are for El Niño years (1982, 1986, 1987, 1991 and 1997.

[d] La Niña prices are for La Niña years (1988 and 1998).

Finally, it is useful to examine the plausibility of the objective function value. In general, when elasticities for linear supply and demand curves are equal to 1 (unitary elasticity), economic surplus and gross value of production should be very similar, because both measure similar geometric areas under the demand curve. In this analysis, the elasticities vary (some higher, some lower than 1), but over the range of crop they are approximately unitary. In this Base case, the objective function value (value of consumers' plus producers' surplus) is approximately $ 16.8 billion pesos. Total value of production, (total revenue from crop production) for the 24 selected crops grown in the five-state region (during the 1995–1998 period), is $ 17.7 billion pesos, which is of the same relative size. The similarity between the objective function value and the total value of production corroborates the validity of the acreage and price estimates from the model presented in Table 4.

5.4. *Benefits of an ENSO early warning system*

Evidence suggests that ENSO events range in strength and that early warning systems improve the accuracy of forecasts of seasonal weather actually experienced by agriculture (Izaurralde et al., 1999). The value of ENSO forecasts was developed under two assumptions concerning the accuracy of such seasonal weather forecasts. These accuracy assumptions relate to the character of the resultant climate event experienced by agriculture under an ENSO phase forecast. Specifically, we developed actual climate data for the average phase event in each Mexican state and then ran the model where the phase event realized under the forecast was identical to an average event under that phase. This essentially is a perfect forecast. We also developed estimates on a "mixed strength" ENSO event. Mixed strength refers to situations where the actual climatic conditions experienced under a given phase differ from what is expected. In this case, it is assumed that when a given ENSO phase was forecasted, 70% of the time the weather would be like the average for that phase and the remaining 30% of the time it would actually resemble the other two phases

Table 5
Agricultural benefits of an ENSO early warning system in million US dollars (Year 2000)

	19-year ENSO historical probability	51-year ENSO historical probability	Climate change induced ENSO probability
Value of perfect skill forecast	46.7	47.4	62.1
Value of 70% skill forecast	8.5	10.3	24.8

(a 15% probability of each phase). This mixed ENSO outcome is an imperfect forecast. The resulting economic values of the perfect and imperfect forecasts for the three ENSO frequency assumptions are given in Table 5. The discussion below focuses primarily on the imperfect seasonal climate forecasts (accurate 70% of the time), given that it is unlikely that true or perfect forecasts could be ever achieved.

The difference between the objective function value for the Base case, or no forecast scenario and the 70% skill forecast for the 51-year time period reported in Table 5 is approximately 10.3 million US dollars annually. Thus, if farmers adopted crop mix strategies each year in response to ENSO forecast information, the overall gain in welfare would average approximately 10 million dollars, although in some years they would be expected to do better or worse. Under the assumption of a perfect forecast, where producers plant the optimal crop mix for each ENSO phase, the gain in annual economic welfare would be approximately 47 million US dollars. These results, coupled with the other forecast accuracy and frequency probability assumptions, lead to a range of annual benefits estimates from US$ 8.3 (19-year time period) to US$ 19 million (assumed changes in ENSO phase frequency due to global warming) for the 70% skill forecast. That perfect forecasts are better than imperfect forecasts is as expected. Also the forecast value rises the more frequent the incidence of extreme phases (non-Neutral ENSO phases), at least across the three ENSO frequency scenarios run here.

The benefit estimates for an ENSO early warning system represent the benefits obtained from the five Mexican states of Guanajuato, Jalisco, Mexico, Michoacan, and Tamaulipas, which account for approximately 32%, by value, of Mexico's agricultural production. It is expected that an early warning system will have little effect on the 30% of Mexican national production represented by the states of Sinaloa, Sonora, Chihuahua, and Baja California, because the ENSO signal for this area of Mexico is weak (Magana). In these states, no statistical relationships between ENSO states and climate can be found and thus the level of forecast skill would be very low. However, it is expected that improvements in production in the five states where ENSO forecasts are employed will reduce profits elsewhere, due to an increase in production of some crops and a subsequent national reduction in prices for the subject crops for which this region has a significant market share. As a result, the use of ENSO forecasts in one region of Mexico may reduce welfare elsewhere. These effects are not directly included here, although the price forecasting equations reflect interdependencies across regions in Mexico. Conversely, the value of the ENSO early warning system may be somewhat higher when other states, which account for the remaining 40% of value and represent more subsistence-oriented agriculture, are considered. However, it is uncertain whether subsistence farmers will be able to respond to information regarding climatic conditions as readily as commercial farmers.

An important factor to consider when evaluating the benefits of an ENSO early warning system, or any other public investment decision, is the distributional impacts of such an investment (i.e. who gains and who loses). In this analysis, the distributional issues primarily center on the differences between producers and consumers and between regions. As reported above, net social welfare increases by about US$ 10 million per year. This US$ 10 million is the total of producer and consumer surplus. Overall, the consumer surplus (welfare) decreases slightly from the Base case (by 3%) while the producer surplus (benefits) increase by about 6%. This is because producers use climatic information regarding ENSO phases to minimize the effects on profits. Specifically, they adjust crop mixes to those crops which perform best under each ENSO phase. In doing so, production of some crops, particularly staple crops, increases relative to the Base case while other crops experience a

Table 6
Percent change in hectares planted, by crop, under each ENSO phase

Selected crops	El Niño years	La Niña years	Neutral years
Beans	−1.6	0.0	0.0
Corn grain	−5.9	1.5	1.1
Oat silage	0.0	13.9	0.0
Onion	4.2	1.9	0.0
Sorghum grain	−31.0	−2.2	−1.4
Wheat grain	0.0	8.6	0.0
All crops	−23.0	0.3	0.1

reduction. This reduction translates into higher prices for these crops, which reduces consumer welfare.

Table 6 illustrates some of the underlying changes in cropping decisions that take place in the model solutions under the increased information regarding ENSO forecasts. Specifically, an early warning system results in a net 23% decrease in total hectares planted during El Niño years, compared to the Base case. The early warning system also results in a slight net increase in hectares planted during La Niña and Neutral years of 0.3 and 0.1%, respectively, compared to the Base case. While there is a net decrease in hectares during El Niño years (and a slight net increase during La Niña and Neutral years) the net change in individual crops does not always follow that pattern. For example, in El Niño years, the hectares of beans (a staple crop) planted decreases about 2% but the hectares in onions increases by over 4%. In La Niña years, there is a net increase in the hectares planted in corn grain, oat silage and wheat grain, but a decrease in hectares planted to sorghum grain. The hectares of corn, which, like beans, is a staple of the Mexican diet, increases by 1.5 and 1.1%, respectively in La Niña year and Neutral years, but decreases by 6% in El Niño years.

These changes in hectares planted also have an impact on total production of each crop. There is an increase in the quantity produced of most crops, with the largest increases being in broccoli, a minor crop, and soybeans, and a reduction in the production of some crops, such as barley grain, oat silage, and wheat.

The distribution of effects across regions may also require policy attention. For example, if a substantial amount of land is left uncultivated in a particular region, it could have a large impact on the income of the local labor force, as well as agricultural support sectors, such as fertilizer and seed suppliers. For example, results indicate no impact on total hectares planted in the regions of Michoacan and Mexico during El Niño years but a 48% decrease in hectares planted in Tamaulipas, as farmers reduce potential losses by idling land. Thus, policy makers may want to consider policies that would lessen the economic impact to those states that are impacted the most when El Niño or La Niña years are expected.

The value or benefit of the ENSO early warning system, can also be compared to the cost of establishing and implementing the early warning system; estimated by NOAA to be US$ 15 million for the initial investment and US$ 3 million for annual operational costs (Adams et al., 2000). Table 7 gives the results of net present value and internal rate of return calculations assuming no benefits in year 1 and a 5-year phase in (with 20% of the additional benefits accruing each year of the 5-five year phase in and full benefits from year 6 onward). Under these various assumptions, the benefits of the early warning system far outweigh the costs. This is reflected in the internal rate of return on

Table 7
Present value of benefits and costs and internal rate of return under three ENSO frequency scenarios in million US dollars

ENSO event probabilities	Accuracy of information	Present value of benefits ($)	Present value of costs ($)	Net present value of project ($)	Internal rate of return (%)
19-year period	Perfect	479.9	51.5	428.4	227.5
	70%	87.5	51.5	36.0	22.9
51-year period	Perfect	486.7	51.5	435.2	233.6
	70%	106.4	51.5	55.0	30.4
Climate change induced ENSO frequency	Perfect	637.2	51.5	587.5	441
	70%	255.8	51.5	204.3	90

The values reported here are converted from pesos to dollars using the 2001 conversion rate of approximately 9 Pesos to the US dollar.

such a system. For example, the internal rate of return for this system under these assumptions is over 30% for the 70% accuracy forecast using the 51-year time period. The rate of return rises to approximately 90% if extreme ENSO phases increase in the future.

6. Summary and conclusions

The benefits of an ENSO early warning system for Mexico, as represented by the states of Guanajuato, Jalisco, Mexico, Michoacan, and Tamaulipas, is approximately US$ 10 million annually, based on a 51-year time period of ENSO frequencies and when a forecast skill of 70% is assumed. This value translates into an internal rate of return for such an early warning system of approximately 30%. The values for higher skill levels are correspondingly higher.

The net present value of the ENSO early warning system of 70% accuracy ranges between US$ 36 and 55 million, depending on the frequency of ENSO events that is assumed for the system. The minimum forecast skill necessary for a positive net present value for the ENSO early warning system is 69% if a 10% per year adoption rate is assumed, 68% if the 20% adoption rate is assumed, and 67% if there is instant adoption (full adoption in year 1) of the ENSO early warning system. Conversely, the frequencies of ENSO phases have a significant effect on the value of information. Specifically, if a time period is selected with more El Niño and La Niña phases (the 51 years historical record and a hypothesized increase in such phases as may occur under global warming), the value of a forecast system increases over that of a shorter time period (19 years).

The values estimated in this exploratory study should be viewed as lower bound estimates of the value of an ENSO early warning system for Mexican agriculture for several reasons: (1) benefits are not estimated for other parts of Mexican agriculture, such as non-commercial (subsistence) agricultural areas, areas where there is only a weak ENSO signal that is not very predictable, and the livestock sector; (2) benefits are not measured in terms of their implications for international agricultural markets; (3) benefits do not include benefits that could occur with adjustments in energy generation, water management, nor any other economic sectors that may be positively affected by the existence of an ENSO early warning system; and (4) the only decisions farmers make in the present model solution is crop mix (adding decisions on livestock, crop planting and harvest timing and varieties planted would increase the benefits estimate).

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