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ECONOMY-WIDE EFFECTS OF EL NIÑO/SOUTHERN OSCILLATION (ENSO) IN MEXICO AND THE ROLE OF IMPROVED FORECASTING AND TECHNOLOGICAL CHANGE

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Abstract

Weather fluctuations, such as those caused by the El Niño Southern Oscillation (ENSO), add to the riskiness associated with agricultural production. Improved predictive capacity may help ameliorate negative impacts of climate and weather shocks on agriculture, but it is possible that the benefits of an improved forecast will be distributed unevenly. In particular, poor farmers may not have access to improved forecasts, or they may not have the means to adapt to new weather information.

This paper uses a stochastic computable general equilibrium (CGE) model to examine the distributive effects of improved forecasting of ENSO in Mexico. The particular focus is on agriculture, one of the most vulnerable sectors in the face of ENSO, as well as a sector which provides income to many of the country's poorest households. The model is used to investigate the responsiveness of various sectors of the economy under different degrees of improved predictive capacity and improvements in agricultural technology.

The CGE model used in this study is augmented with a stochastic component, which allows us to simulate a range of stochastic shocks using Monte Carlo methods. With this framework we can compute the mean values and variances of key variables, such as production levels and incomes under stochastic shocks. Given that the model is highly nonlinear, Monte Carlo methods provide information on the sources of volatility in the economy and the built-in shock absorbers that help dampen that volatility.

The results show that while agricultural losses are small as a share of the overall economy, improved forecasting techniques can eliminate these losses. ENSO events harm some regions – particularly the Central, Pacific South, and South East regions – more than others. Agricultural production in these regions benefits the most from improved forecasting. Since these regions also are the regions with higher poverty, they should be targeted by policy makers who are concerned with alleviating the effects of ENSO events on the poor. The simulations also show that poor households are the least able to take advantage of improvements in forecasting, since at higher levels of preparedness agricultural production shifts to sectors from which poor households receive less income. Finally, in Mexico, ENSO events contribute only a small share of overall variability in agriculture. It might be better to focus efforts on the latter problem, in terms of improved agricultural seeds, extension services, and schemes to protect already fragile lands.

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1. Introduction and Motivation

Even in the face of improved forecasting techniques, climate and weather remain the most variable inputs to agricultural production. The El Niño Southern Oscillation (ENSO) is but one piece of the forecasting puzzle that climatologists face. While climatologists have made great strides in predicting ENSO events, translating an ENSO forecast into concrete, local *weather* prediction is much more difficult.[1] The uncertainty involved in predicting ENSO-induced weather adds to the riskiness associated with agricultural production. The prediction problem is further complicated by the fact that not all agricultural sectors or agricultural producers are affected equally from ENSO-induced weather. For example, farmers with low levels of technology are even more vulnerable to climate shocks than those who have access to more modern means of production, such as drought-resistant seed varieties or irrigation systems.

Improved predictive capacity may help ameliorate negative impacts of climate and weather shocks on agriculture, but it is likely that the benefits of an improved forecast will be distributed unevenly.[2] It may be that only some farmers will have access to improved climate information, and that a large segment – most likely among the most vulnerable population – cannot obtain this information. Lack of communications technology, illiteracy, and even traditional practices which disregard modern forecasting methods may prevent some farmers from utilizing forecasts. Some poor households who *do* have access to improved forecasting may not be able to take advantage of the information. If they do not have the resources to change their production methods or crop mix, or abandon farming altogether, they gain very little from better forecasts. This suggests that improvements in forecasting must be accompanied by complementary investments in communications and outreach to poor rural households.

This paper uses a stochastic computable general equilibrium (CGE) model to examine the potential distributive effects of improved forecasting of ENSO in Mexico. This is an economy-wide model, but the particular focus is on agriculture, one of the most vulnerable sectors in the face of ENSO, as well as a sector which provides income to many of the country's poorest households. The model imposes the initial "shock" of an ENSO-induced weather event on the agricultural production functions and then solves for new equilibrium values of all of the endogenous variables, such as sectoral outputs and household incomes.

[1] It is important at the outset to distinguish between *weather* forecasts, which predict events up to about two weeks, and *climate* forecasts which are for longer periods. Predicting ENSO events falls into the latter category. Given that an ENSO event has been predicted for a season or year (or longer), the short-term and local prognostics of that event are considered weather forecasts. In this paper, we shall refer to weather caused by ENSO events as "ENSO-induced weather." See Mjelde *et al* (1998) and other papers associated with the American Agricultural Economics Association's 1998 panel on "ENSOnomics: The Agricultural Economics of Climate and Climate Forecasting."

[2] It is also possible that some segments of society *benefit* from unforeseen weather events. For example, if a drought causes a shortage of a product which leads to an increase in its price, those farmers who are less affected by the drought (i.e., because they utilize irrigation systems) may be better off.

The model is used to investigate the responsiveness of various sectors of the economy under different degrees of improved predictive capacity and improvements in agricultural technology. It is this area of improved predictive capacity and agricultural technology – referred to as "preparedness" in this paper – upon which policy makers may have some impact. The results of the model should shed light on what types of preparedness are most useful and how their benefits are distributed.

The study starts by examining how the economy absorbs general exogenous shocks to agricultural production when shocks from any source are unforeseen. These shocks could be caused by ENSO- or non-ENSO-induced weather, but also by bad seeds, pests, or any other unusual circumstances that affect farming. By examining how general shocks affect the system, we can get a benchmark for investigating how ENSO-specific shocks will affect the model. Particular attention is paid to how average production and incomes change, and the extent of their fluctuations.

These results are then compared to those emerging from model simulations that allow for increasing levels of preparedness, in terms of forewarning and technological improvements. Initially, farmers have no forewarning or assistance to deal with production shocks. In the first level of preparedness, improved technologies alone, without the aid of forecasts, help farmers cope with uncertainties, which has the effect of reducing the variance of the shocks. For example, farmers may receive drought resistant seeds. In the second level of preparedness, farmers have access to improved technologies *and* receive early warning of the random events which permits farmers to move their factors of production to ameliorate the negative impacts. The third and highest level of preparedness adds to the second level an increased productivity boost, indicative of even further improvements in crop technology.

Next, the study moves from general shocks to agricultural production to the problem of agricultural fluctuations specifically caused by ENSO-induced weather events. Again, the model is tested under the different levels of preparedness described in the preceding paragraph. Finally, the model tests the sources of variability, comparing the effects on the economy from general shocks to agriculture with those caused by imperfect forecasting of ENSO-induced weather.

A CGE model is the appropriate tool for analyzing a shock which has "spillover" effects. An ENSO-induced weather shock limited to one agricultural region, for example, will likely change production behavior in other agricultural regions through price effects. Furthermore, while climate variability has the greatest direct impact on agricultural production, it may affect non-agricultural sectors indirectly. For instance, downstream industries, such as food processing, may be impacted by the availability of raw agricultural goods. International trade may be affected if imports or exports respond to changing domestic supply and demand conditions. This study focuses on the agricultural sectors, but the CGE model also allows an examination of the spillover effects to the rest of the economy. The direct impacts of ENSO-induced weather events on non-agricultural sectors will not be addressed.

The CGE model used in this study is augmented with a stochastic component, which allows us to simulate a range of shocks using Monte Carlo methods. With this framework we can compute the mean values and variances of key variables, such as production levels and incomes. Given that the model is highly nonlinear, Monte Carlo methods provide information on the sources of volatility in the economy and the built-in shock absorbers that help dampen that volatility.

This paper is organized as follows: the next section describes the ENSO phenomenon as it affects Mexico. Section 3 reviews the literature relating to CGE models of weather and risk. Section 4 describes the data used for the model and Section 5 explains the modeling techniques used. Section 6 discusses the results of the experiments. Section 7 draws policy lessons from the experiments and concludes.

2. ENSO in Mexico[3]

El Niño Southern Oscillation (ENSO) describes the anomalies in sea surface temperatures in the Pacific Ocean which tend to be associated with oscillations in the barometric pressure of the South Pacific Ocean. Together these two conditions cause extreme weather events around the world, especially in Latin America and the Caribbean. During El Niño years, the air-pressure pattern that normally takes place between the eastern and western Pacific reverses itself, leading to raised sea levels and higher sea temperatures off the Pacific coast of South America. Very generally speaking, El Niño years are warmer and wetter in the Americas, and cooler and drier in the western Pacific (i.e., Australia and Indonesia). During La Niña years, the normal air-pressure pattern intensifies and the sea surface temperatures are cooler than usual. The weather patterns are generally the opposite of those which result from an El Niño year. Nonetheless, it is difficult to make too many generalizations about ENSO events, which occur irregularly at 2 to 7 year intervals. They vary in intensity, and the effects may even reverse themselves from one El Niño (or La Niña) event to another (Magaña, 1999).

The ENSO phenomenon has a wide range of effects on Mexico, depending on the season and region in which it is present. Generally, El Niño winters are more humid in the north part of country, and summers are drier. La Niña winters are drier and summers are wetter (especially in the center of the country). ENSO effects in Mexico, as everywhere in the region, tend to be stronger in the winter than in the summer. According to classifications by Tiscareño (2000), the arid and semiarid regions experience warmer temperatures during an El Niño event in all seasons. The arid and semiarid regions in north Mexico tend to have increases in precipitation during all phases of ENSO in all times of the year, except for La Niña winters. The temperate regions have lower temperatures in the spring and summer when there is an El Niño event, and less rain during El Niño winters. These areas have more rain during La Niña summers. The humid tropics are cooler during El Niño and La Niña events and are drier in spring and summer during both phases as well.

[3] See Magaña (1999) for an in-depth description of ENSO characteristics in Mexico.

During El Niño summers, hurricane activity increases on the Pacific side of the country, while it diminishes on the coasts of the Gulf of Mexico and the Caribbean. Since rainfall is often associated with hurricanes, this implies that the east coast states in particular receive lower rainfall during this period. A La Niña event has the reverse effect (Magaña, 1999).

One of the problems with analyzing ENSO impacts on weather is that they have been inconsistent over time. For example, the El Niño event of 1986-87 did not result in much more rain in the winter than usual, but winter rain during the El Niño event of 1982-83 was above normal, and rainfall in the winter of 1991-92 was even higher. In certain regions of the country, in particular, the north-west region, including the agriculturally important states of Sonora and Sinaloa, the ENSO impacts are quite erratic and considered very difficult to predict (Magaña, 1999).

Mexico is agro-ecologically diverse in terms of rainfall, soil conditions, and use of technology. Rosenberg, *et al* (1997) divide the country into three agro-ecological zones. The arid and semi-arid zones, covering about 49% of Mexico, are located in the north. This area receives very little rain, which falls solely in the summer months. Livestock and irrigated agriculture are the major sources of agricultural production, with some non-irrigated land activity by poor subsistence farmers on marginal lands. Around 24% of land falls under a temperate climate, located in the central part of the country. Here there is a wide range of temperature and rainfall, due to the diverse topography of the area. Agricultural activity includes perennial and annual crops, using both irrigated and rainfed land, as well as livestock. The third zone is the tropics, covering about 28% of land, including the Yucatán Peninsula, the Gulf of Mexico coast, and most of the Pacific coast. Rosenberg, *et al* (1997) divide this zone into humid and dry tropics, so even within this zone, rainfall conditions vary. The drier region, in the northwest tropical zone, employs more mechanized agriculture and irrigation, while the humid zone has more subsistence farming.

Indeed, irrigation and modern farming techniques are more prevalent in the north part of the country. Land ownership – with its implied differences in technology and input use – also varies: in 1991, about 60% of all farms were smaller than 5 hectares, covering about 15% of available land. Farm size tends to increase in the northern states, and is smaller in the central, south Pacific, and southeastern regions of the country (Casco and Romero, 1997).

All of these factors contribute to the different impacts that a single ENSO event can have on different regions and crops within Mexico. A summer-time El Niño event has a major impact on the agricultural sector, since the majority of crop production (about 70% in value terms[4]) occurs in the spring-summer cycle. According to the Ministry of Agriculture (SAGAR) figures cited in Magaña (1999), about 14% of crops was lost in the summer harvest of 1998 because of the lack of rain associated with that El Niño event.

[4] Calculated using data from SAGAR (1998).

About 85% of summer production is on non-irrigated land. According to the Erosion Productivity Impact Calculator (EPIC)[5] model of Mexico produced by Tiscareño, *et al* (2000), it is non-irrigated land cultivation that is particularly hurt from the temperature and rain anomalies associated with ENSO events. Nevertheless, their study of rainfed maize and beans shows large production swings by state of these crops during ENSO events. For example, during an El Niño event, the state of Mexico (in the center of the country) is expected to experience more than a 15% decrease in corn production, while Chiapas (in the southeastern region) gains about the same percentage. These effects are reversed (and with greater magnitude) during La Niña events. The results for bean production are similarly mixed. A very fine disaggregation of ENSO impacts is needed to get clear and robust results.

3. Literature on CGE models including weather and risk

While there is a large literature exploring uncertainty and agricultural markets in a partial equilibrium settings, including risk of any type in a general equilibrium model is still relatively uncommon.[6] Boussard and Christensen (1999), for example, add risk to a CGE model not as a *technical* risk (i.e., weather events), but as an *economic* risk associated with price variability. They use a dynamic recursive model to examine how agriculture in Poland and Hungary would be affected if those countries entered the European Union. Risk is included in the first order conditions for profit maximization, which now subsumes a risk aversion coefficient and price variances.

A CGE model by Arndt and Tarp (2000) includes risk reducing strategies in its analysis of gender roles. The authors consider the cassava crop in Mozambique, which is used in a risk reducing strategy since, among other qualities, it is relatively drought and disease resistant. A risk premium parameter is added to the factor demand equation and factor income equation, in a mixed complementarity framework in which the risk premium is tied to production of cassava. The value of the risk premium depends on the exogenous shock imposed on the model.

Burfisher, *et al* (2000) add risk into a CGE model of the NAFTA countries as a risk premium which is dependent on variance in historical returns, income, and farmers' subjective risk averse preferences. This premium is added to the production function.

Arndt *et al* (1999) use an archetypical CGE model to show how improved drought forecasting might affect an African economy. Drought is simulated in the model as a shock to the production functions of the agricultural sectors. An "unanticipated" drought, one in which there has been no forecast, is modeled such that farmers do not have time to

[5] For details of the model, refer to Rosenberg, *et al*.

[6] Examples of risk in partial equilbrium – as opposed to economy-wide – settings include Fafchamps (1992); Finkelshtain and Chalfant (1991); and, Moscardi and de Janvry (1977). Uncertainty is included in some CGE models, such as Harrison, *et al* (1993), with regard to sensitivity analysis applied to the exogenously specified parameters of the model. That is, a parameter (for example, a trade elasticity) will be allowed to vary within a range, to test the robustness of the model's conclusions to that parameter's (or more likely, a group of parameters) specification. This is relating to the uncertainty of the model, *per se*, and not the uncertainty that the economic agents face.

reallocate agricultural labor and capital. A forecasted drought is simulated by making agricultural labor and capital flexible among sectors.

In all of the preceding examples, there are no explicitly stochastic variables and the models incorporate risk aversion as leading to increased costs of production in a deterministic model. There are examples of CGE models explicitly including stochastic variables, using Monte Carlo methods. Models by Adelman and others incorporate stochastic shocks through specifying parameters which are subject to variability. For example, Adelman *et al* (1991) compare the different trade strategies conducted by Yugoslavia in the 1980s under the same random shocks to import and export prices, workers' remittances and the exchange rate. In another example, Adelman and Berck's (1990) CGE model of Korea specifies random shocks to both world prices and food productivity. These models use repeated sampling methods to measure the means and variances of crucial variables (such as household incomes, production, etc). The current model incorporates stochastic variables in a manner similar to the Adelman models. The stochastic component is generated as a random variable affecting agriculture, based on historical agricultural yield data.

4. Data

A. Social Accounting Matrix

The CGE model used in this analysis relies on a social accounting matrix (SAM) of Mexico, based in the year 1996.[7] The SAM accounts for all income and expenditure transactions of all sectors and institutions in the national economy, and thus serves as the underlying data framework for the CGE model.[8] The data were first collected as a national SAM. Then production and factor markets as well as households were disaggregated into 6 regions. Thus the model is able to capture differences among the regions in terms of production and consumption patterns.

Mexico's gross domestic product (GDP) is not very heavily reliant on agriculture, as shown in Table 1. Just 5 percent of national output comes from raw agriculture, including crops, livestock, forestry, and fishing. Another 8 percent of output is from processed foods, including wheat and maize flour, dairy products, processed fruits and vegetables, and sugar. The rest of production is focused on non-agricultural related output, with a large portion in services (at over 30% of output) and commerce,

[7] The data used in constructing the SAM include: "Sistema de Cuentas Nacionales de México," INEGI, 1996, for national accounts data and other macro data; Informe Anual, Banco de México, 1996 for macro data; SAGAR, 1998 for data on crop yields and land utilization; Encuesta Nacional de Ingresos y Gastos de Hogares, INEGI, 1996, for household income and expenditure data; and the GTAP database for import and export data. The initial estimates of the input-output coefficients come from a 1993 input-output table. Further details on the construction of the SAM, and the use of cross-entropy estimation techniques to balance it, may be found in Harris (Forthcoming).

[8] For a detailed discussion of SAMs, see Pyatt and Round (1985).

communications and trade (at about 20%). Importantly, as calculated by the Organisation for Economic Co-operation and Development (OECD, 2001), agriculture employs about 20% of the work force.

Table 1. Sectoral Composition of Mexican Economy, 1996

(percent)

Agriculture	5
Food	8
Manufacturing	18
Consumer	12
Construction	5
Services	31
Commerce	20

Source: Social Accounting Matrix constructed by author.

Five of the regions in the SAM are rural, roughly corresponding to climatic regions in accordance with Magaña (1999). The geographic diversity of the country – including mountain ranges, volcanoes, plateaus, deserts and coastal plains – suggests that five is the minimum number of regions for any investigation into weather and climate in Mexico. For example, the north part of the country contains most of the Sonoran and Chihuahuan deserts, yet the summer ENSO signal is very weak only in the North West region (making it difficult to predict the effects of an ENSO event on weather there). On the other hand, the North West region does have a strong ENSO signal in the winter. While both the Pacific South and the South East have humid climates, the negative correlation between El Niño events and summer rainfall (the most important rains for the larger summer harvest) is stronger in the Pacific South. Table 2 shows which states are in each rural region, as also seen in the map in Figure 1. Figures 2.1 – 2.5 show monthly rainfall for each region over the period 1980-1996. As the figures demonstrate, all regions follow a similar annual pattern, in which winters are drier and summers are rainier. Nevertheless, there is still much variation among the regions.

In the model, the rural regions only produce agricultural activities, which are divided into summer and winter crops. Each region produces up to 6 crops (*maize*, *wheat*, *beans*, *other grains*, *fruits and vegetables*, and *other crops*), though not all regions produce all crops in significant quantities. If the value of a seasonal *maize*, *wheat* or *beans* crop for a region was less than 1 percent of the total national annual crop value, it was combined with the *other crop* sector. Thus, in total, the model contains 41 different agricultural activities. Each crop "feeds into" a national, annual commodity, so that, for example, winter *maize* and summer *maize* from all five regions combine into one *maize* commodity which is marketed nationally (as well as exported).

Table 2. Rural Regions

North West	Pacific South
Baja California Norte	Jalisco
Baja California Sur	Nayarit
Sonora	Colima
Sinaloa	Oaxaca
	Michoacan
North Central	Guerrero
Coahuila	
Chihuahua	South East
Nuevo Leon	Veracruz
Tamaulipas	Tabasco
Durango	Campeche
Zacatecas	Chiapas
Aguascalientes	Yucatan
San Luis Potosi	Quintana Roo
Central	
Guanajuato	
Queretero	
Mexico	
Distrito Federal	
Puebla	
Morelos	
Tlaxcala	
Hidalgo	

Figure 1. Map of Rural Regions of Mexico.

Figure 2.1 Rainfall in North West Region

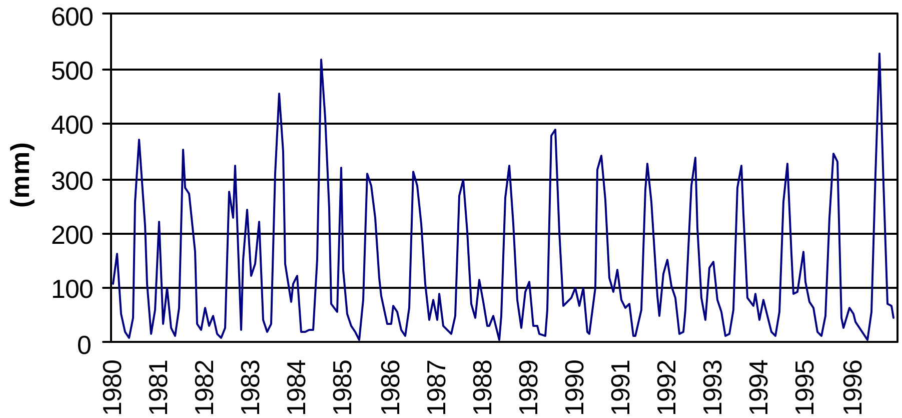


Figure 2.2 Rainfall in North Central Region

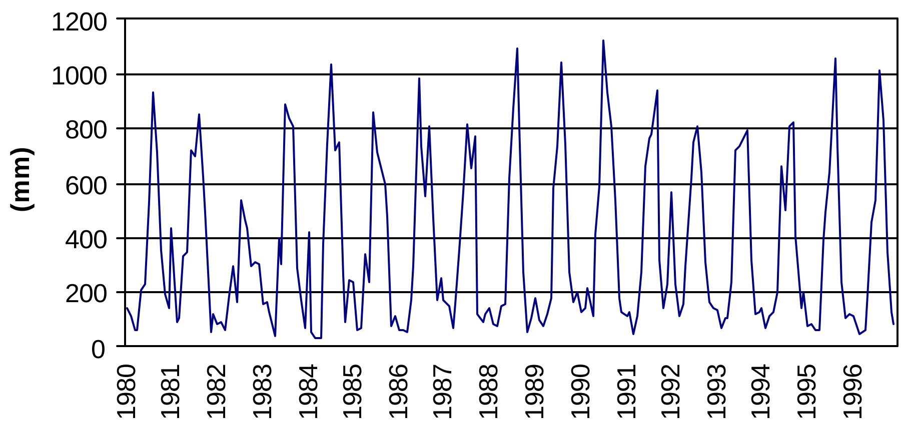


Figure 2.3 Rainfall in Central Region

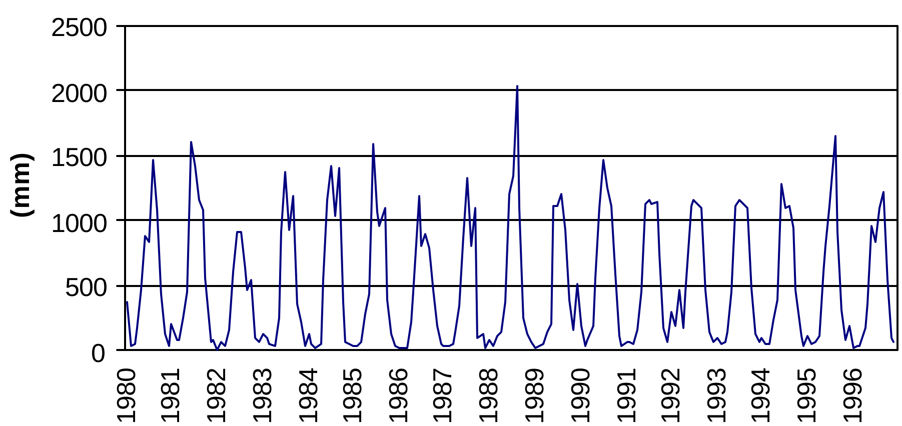


Figure 2.4 Rainfall in Pacific South Region

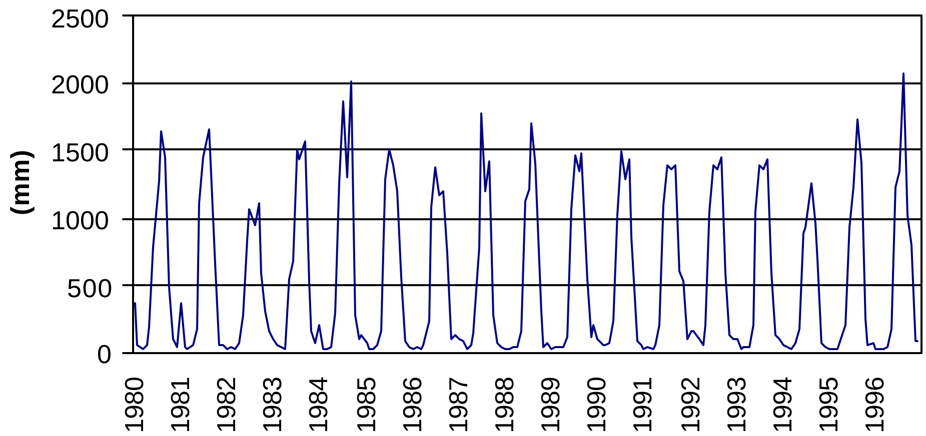
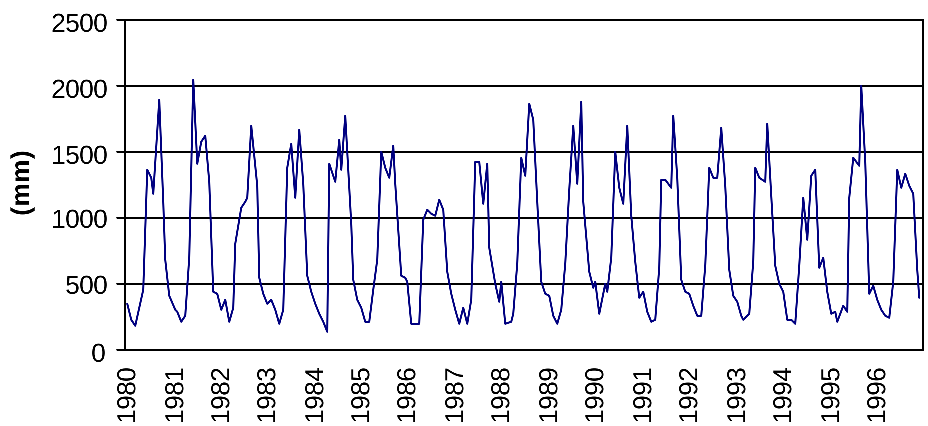


Figure 2.5 Rainfall in South East Region



source: IFPRI calculations based upon University of East Anglia Climate Research Unit 0.5 Degree 1901-1996 Monthly Climate Time Series.

Fruits and vegetables are produced mainly in the North West and Pacific South regions, basic grains are grown primarily in the Central and Pacific South regions, and non-food crops, such as coffee beans and raw sugar, come mostly from the Pacific South and South East regions. As can be seen from Table 3, the North West region derives most of its crop value from fruits and vegetables. Nevertheless, a significant portion of its crop value comes from grains, mainly comprised of winter wheat and some winter maize. The South East receives the most value from non-food crops such as coffee and cotton. The other regions receive most of their crop value from grains, particularly maize, though the Central region also has a large percentage of its crops devoted to bean production.

Table 3. Value of crop composition by region, 1997

(percent)

	Grains	Fruit &Veg	Non Food
North West	34	38	20
North Central	31	19	22
Central	42	24	21
Pacific South	33	16	14
South East	20	19	29

note: rows sum to 100%. Source: SAGAR (1998).

The bulk of Mexican crop production is produced in the summer season, accounting for about 70% of crop value. However, the seasonal importance in production varies across the regions, as seen in Table 4. In particular, the North West region produces 2/3 of its crops in the winter. Moreover, while only 30% of the country's basic grains are produced in the winter, about half of that production comes from the North West. In the summer, this region only accounts for 5% of grains production. Similarly, about 1/3 of fruit and vegetable output is produced in the winter, but again, it is clearly dominated by North West production, accounting for over half of winter production. The Pacific South region produces just 17% of the nation's non food crops in the summer, but 48% of the winter harvest (SAGAR, 1998).

Table 4. Value of Seasonal Crop Production by Region, 1997

(percent)

	Summer	Winter
North West	33	67
North Central	75	25
Central	88	12
Pacific South	68	32
South East	82	18

note: rows sum to 100%. Source: SAGAR (1998).

Table 5 shows the value of irrigated and non-irrigated land use in each region.[9] The North West region has the highest percent of irrigated land use, with 93% of land value under irrigation. Moving south and east across the country, non-irrigated land use becomes more common. In fact, the South East region reflects the mirror image of North West land use, with 93% of land value coming from non-irrigated land use. The impact of ENSO-induced weather on crops will depend to a large extent on the crops' dependence on rainfed land.

Table 5. Value of land type by region, 1997

(percent)

	Irrig.	Non Irrig.
North West	93	7
North Central	53	47
Central	49	51
Pacific South	33	67
South East	7	93

note: rows sum to 100%. Source: SAGAR (1998).

There is one "national" urban region, which comprises all of the urban areas of Mexico, regardless of geographical location. The urban area produces processed agricultural goods and other goods and services. In the CGE model, these sectors do not get directly shocked by ENSO-induced weather, but they may be indirectly affected by the impacts on raw agricultural products. See Table 6 for a list of all of the sectors in the model.

Agricultural activities are only produced in the rural regions, and use only agricultural factors of production. These factors of production (agricultural labor, irrigated land, non-irrigated land, and agricultural capital) are each specified by region and by season (for example, North West, winter, irrigated land). Intermediate inputs, such as fertilizers, seeds, and transportation, are also used in the production of activities.[10] Urban activities do not use any of the agricultural factors, instead relying on four labor types (professional, white collar, blue collar, and unskilled) and one non-agricultural capital factor.

Each region has three household types, characterized as poor, medium, and rich, for a total of 18 households. The income categories are defined at the national level, in which those households earning the top 20% of national income are considered "Rich", those earning the middle 40% are "Medium" and the bottom 40% of national income are "Poor."

[9] See Appendix Table 1 for the breakdown of all of the components of value-added for each crop.
[10] Note that water is not explicitly included as an input, but is implied through the use of irrigated or non-irrigated land.

Table 6. National Sectors in Model[a]

1. Maize
2. Wheat
3. Beans
4. Other Grains (Sorghum, Barley)
5. Fruits and Vegetables
6. Other Crops (Tobacco, Hemp, Cotton, Cocoa, Sugar, Coffee, Soy, Safflower, Sesame and Others)
7. Livestock/Forestry/Fisheries (Bovines, Goats, Sheep, Bees, Poultry and Others, Forestry and Fisheries)
8. Dairy
9. Prepared Fruits and Vegetables
10. Wheat Manufacturing
11. Corn Manufacturing
12. Sugar Manufacturing
13. Other Processed Foods (Coffee Manufacturing, Processed Meats, Oils and Fats, Feeds, Alcohol, Beverages and Others)
14. Light Manufacturing (Lumber, Wood, Paper, Print, and Cigar Manufacturing, Soft Fiber Textiles, Hard Fiber Textiles, Other Textiles, Leather, Apparel)
15. Intermediates (Chemicals, Synthetics, Rubber, Glass, Cement, Fertilizers, Other Chemicals, Oil Refining, Oil and Gasoline, Petrochemicals, Coal, Iron, Non-Ferrous Metal, Sand/Gravel, Minerals)
16. Consumer Items (Pharmaceuticals, Soaps, Plastic, Metal Furnishings, Household Appliances, Electronic Equipment, Automobiles and Parts)
17. Capital Goods (Metal Products, Metal Manufacturing, Non-Electronic Machines, Electronic Machines, Other Electric Goods, Transportation Materials, Mineral Manufacturing, Iron Manufacturing, Non-Ferrous Metal Manufacturing, Others)
18. Professional Services (Professional Services, Education, Medical, Finance/Real Estate, Public Administration and Defense, Electricity, Gas and Water)
19. Other Services (Other Services, Restaurants)
20. Construction
21. Commerce, Trade and Transportation

[a] The first 6 sectors, when specified as *activities*, are divided by region and season. These are the activities that are directly impacted by ENSO events in the model.

Changes in income distribution will be directly related to each household's allocation of factor incomes. As can be seen in Table 7, households derive income from a variety of sources. Urban households can only earn income from urban labor (i.e., from professional, white collar, blue collar, and unskilled jobs) and non-agricultural capital. Poorer urban households derive more of their wages from labor categories which require less education, especially unskilled labor (which includes informal labor) and blue collar jobs, while medium and rich households earn most of their incomes from white collar and professional labor, as well as non-agricultural capital.[11]

It is noteworthy that most rural households, particularly the non-rich, derive the bulk of their income from off-farm (i.e., non-agricultural) sources (see Table 7). Rich households tend to receive more income from on-farm activities, in part because they receive all of the returns to irrigated land. Nevertheless, all households tend to diversify their income sources, with earnings from urban-based jobs as well as capital.[12] This implies that these households have "built-in" cushions against agricultural downturns.

B. Agricultural and Climate Data Sources

The agricultural data used in this model come from SAGAR, which presents detailed data on output, yields, land (irrigated versus non-irrigated) planted and harvested, and prices by season (fall/winter and spring/summer) and by state for 406 crops, between 1980 and 1997. This data were aggregated to fit our 5 rural regions and 6 crop-types for the two seasons.

The rainfall data come from IFPRI calculations based upon the University of East Anglia Climate Research Unit 0.5 Degree 1901-1996 Monthly Climate Time Series. They provide monthly rainfall data in each state, which have been aggregated to fit our 5 rural regions and two seasons. Dummy variables were constructed in each region and season to represent "extreme" rainfall or lack thereof. That is, rainfall totaling more than one standard deviation from the mean rainfall of a region was considered "high" and rainfall totaling less than one standard deviation from the mean rainfall was defined as "low." As will be explained later, these dummy variables were constructed on the belief that decreases in crop yields are due not just to rainfall itself, but to extreme increases or decreases in it.[13]

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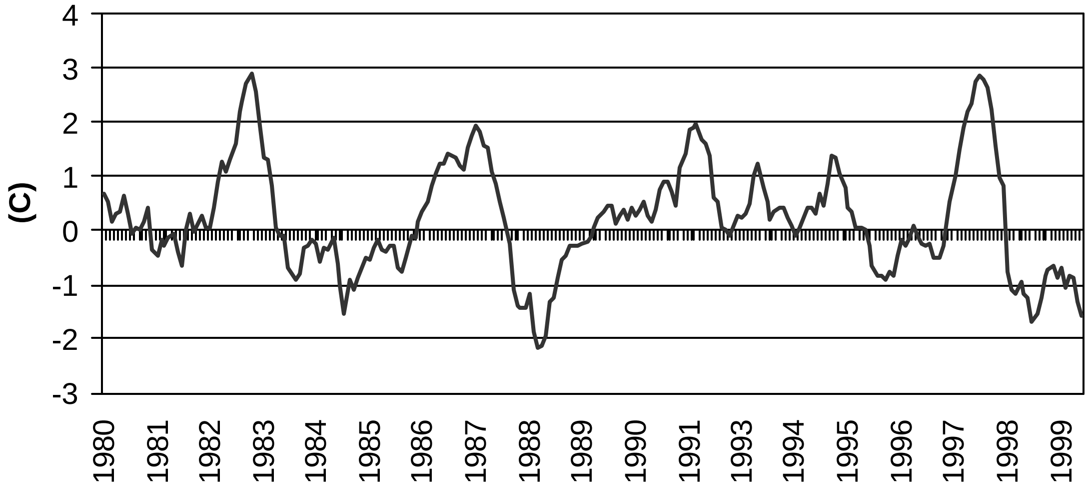
[11] In the SAM framework, households receive capital income indirectly via the "enterprise account." The enterprise account first collects payments from the capital account, and then it pays taxes and foreign receipts. The remainder is then distributed to the households. See Harris (Forthcoming) for further details of this specification.

[12] The model distinguishes between agricultural capital and non-agricultural capital, but within non-agricultural capital, it does not specify if the capital is used in the formal or informal markets. Thus the non-agricultural capital used by rural households (and perhaps poor urban households as well) may refer to that used in informal activities such as kiosks, carts, cleaning materials, etc.

[13] Due to data inavailability, important data covering the 1997/98 El Niño event is missing from this analysis.

The ENSO variable is an index which measures the sea-surface temperature anomaly (SSTA) for the Niño 3.4 region of the Pacific Ocean.[14] It comes from the Climate Prediction Center. This is a continuous variable: as it increases from the normal temperature (i.e., the sea surface temperature rises), the severity of an El Niño event increases and as it decreases, the severity of a La Niña event increases. Figure 3 plots the SSTA over the period 1980-1996. These data are used to determine the connection between ENSO events and rainfall, as seen in the next section.

Figure 3. Monthly Sea Surface Temperature Anomolies (deviations from normal)



source: Climate Prediction Center (2001).

[14] SSTAs from this region, in the central part of the Pacific Ocean, are commonly used to predict ENSO events in Mexico. For example, see Magaña (1999).

Table 7. Household income by source (percentages)

	LABOR					LAND		CAPITAL	
	AGRIC	UNSK	BL. COL	WH. COL	PROF	DRY	IRR	NON-AG	AG
UP	-	5	31	30	20	-	-	3	-
UM	-	7	16	21	27	-	-	29	-
UR	-	3	17	16	31	-	-	34	-
RP-NW	19	16	28	-	-	2	-	25	10
RM-NW	20	8	-	15	25	12	-	14	7
RR-NW	21	-	-	-	-	9	45	17	8
RP-NC	10	19	27	20	-	7	-	13	3
RM-NC	17	14	18	6	15	14	-	12	3
RR-NC	11	5	9	9	-	8	22	31	4
RP-C	9	23	13	19	4	2	-	29	2
RM-C	3	11	15	15	35	6	-	11	3
RR-C	4	4	8	-	56	2	20	-	5
RP-PS	19	40	4	14	14	3	-	-	5
RM-PS	13	8	15	9	31	17	-	-	6
RR-PS	10	10	20	21	-	4	19	-	15
RP-SE	10	43	11	29	2	2	-	-	2
RM-SE	7	14	16	17	24	11	-	9	3
RR-SE	6	5	9	9	39	3	2	26	1

Note: Rows sum to 100%

Key:

UP = Urban Poor	RM = Rural Medium	-NW = North West	-PS = Pacific South
UM = Urban Medium	RR = Rural Rich	-NC = North Central	-SE = South East
UR = Urban Rich	RP = Rural Poor	-C = Central	

Source: Social Accounting Matrix constructed by author. See footnote 8 for details on the data sources used to construct the SAM.

5. Model Framework

The basic model contains two components: a standard CGE model which has been adapted to incorporate stochastic elements and a regression component which relates ENSO events to rainfall and therefore agricultural yields. In this section, the basic framework of the CGE model is described, followed by an explanation of how risk and weather-related events are included in the model. This includes a description of the regression techniques involved. Finally, the simulation experiments are described.

A. Basic Structure of CGE Model

The CGE model is neoclassical in spirit, with agents (producers and consumers) responding to product and factor price changes.[15] The model is Walrasian, determining only relative prices. Product prices, factor prices and the equilibrium exchange rate are defined relative to the consumer price index, which serves as the price numeraire. The country is "small" in the sense that it takes world prices as given. Figure 4 presents a circular flow diagram of an economy. It shows the direction of goods and services and payments flows in opposite directions in an economy, and demonstrates that in a CGE model, total expenditures must equal total payments. In the current study, ENSO and risk impacts are incorporated *via* their initial effects on agricultural production sectors.

The production technology is a nested function of constant elasticity of substitution (CES) and Leontief functions, as seen in Figure 5. At the top level, domestic output (the activity) is a linear combination of value added and intermediate inputs. Value added is a CES function of the primary factors of production (land types, labor types and capital types) and intermediate input demand is determined according to fixed input-output coefficients. Commodity output is a composite of different activities, which combine according to fixed yield coefficients. These activities are imperfectly substitutable: thus this framework allows multiple activities to produce one commodity, as discussed in the SAM description. Producers decide to supply their output to either the export or domestic market according to a constant elasticity of transformation (CET) function, which permits some degree of independence from international prices. The composite consumption good is a CES function of imported and domestically produced commodities. This treatment, known as the Armington specification, permits imperfect substitutability, and therefore, two-way trade, between imported and domestically produced goods. Figure 6 depicts the flow of marketed commodities in the model; the nexus of supply and demand is of the composite commodity in the figure.

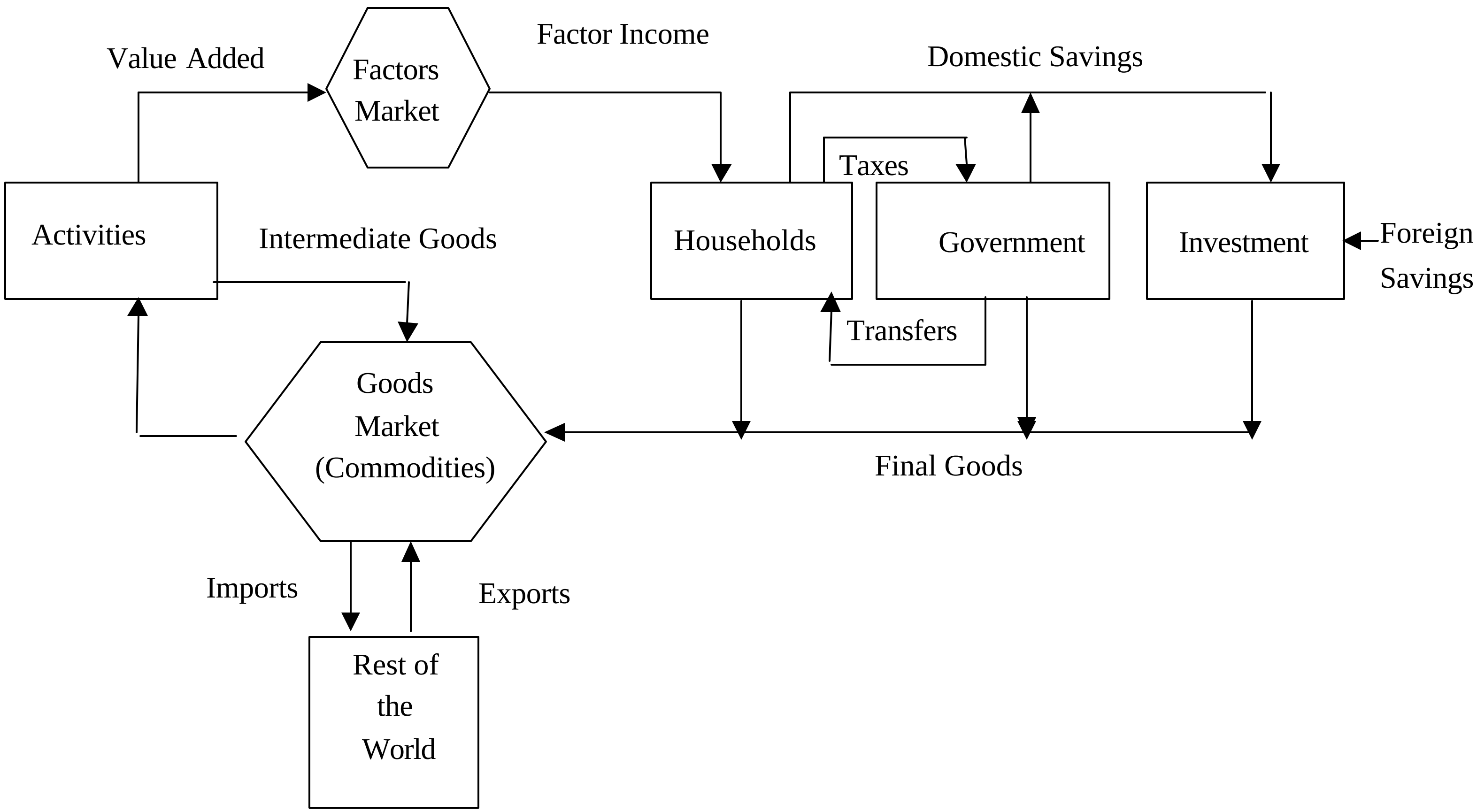
Households receive income from factor payments (land, labor and capital payments) net of factor taxes, government transfers, and transfers from the rest of the world. They consume goods according to a linear expenditure function (LES), purchasing goods from the market as well as from home production (in rural areas only). They also pay taxes on their monetary income and save a share of their total income. Enterprises serve as the conduit between the capital factor account and the other institutions (households,

[15] See Löfgren, *et al* for a more complete description of the "Standard Model," developed by IFPRI, on which the current model is based. Appendix Table 2 lists the equations used in the model.

government and rest of the world). They receive capital income minus capital payments to the rest of the world, as well as government transfers. Enterprises transfer that payment, net of depreciation and taxes, to households. Government income is the sum of all taxes: direct taxes on households and enterprises, value-added taxes, producer taxes, import tariffs, export taxes, social security taxes and sales taxes. The government consumes commodities according to fixed shares (given in the SAM) and also spends money on transfers to domestic institutions. Real government expenditure, real investment and foreign savings are all held fixed as a share of absorption. Land and labor may be mobile, depending on the simulation, while capital is always sectorally fixed.

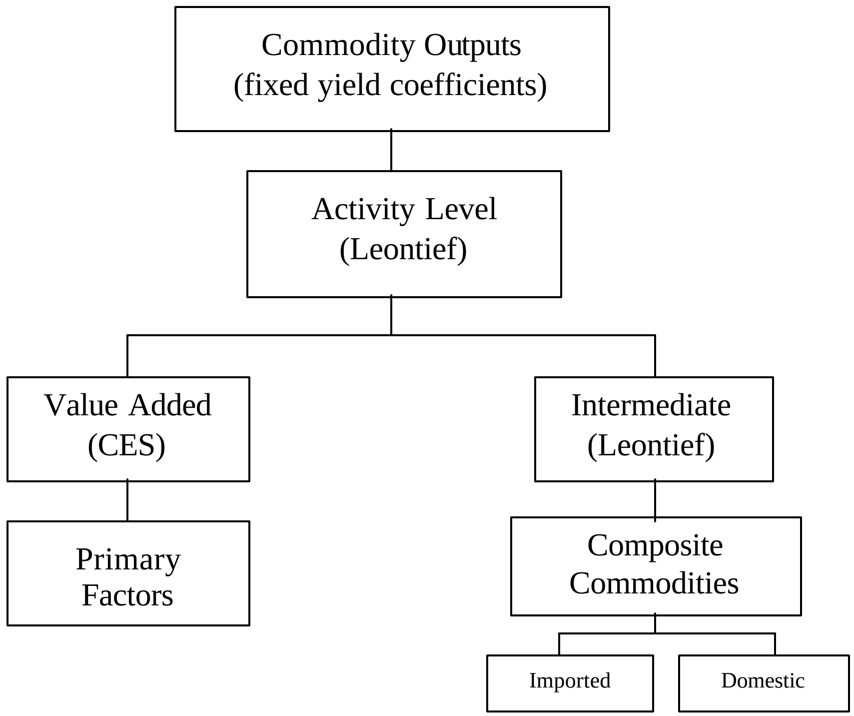
The CGE model is first solved to replicate the base-year (or "benchmark") equilibrium. This ensures that the base-year SAM is replicated and thus that the parameters are properly specified. The benchmark equilibrium is the solution to the CGE model when there are no exogenous shocks and can provide a point of comparison for the simulation results.

Figure 4. Circular Flow Diagram of CGE Structure



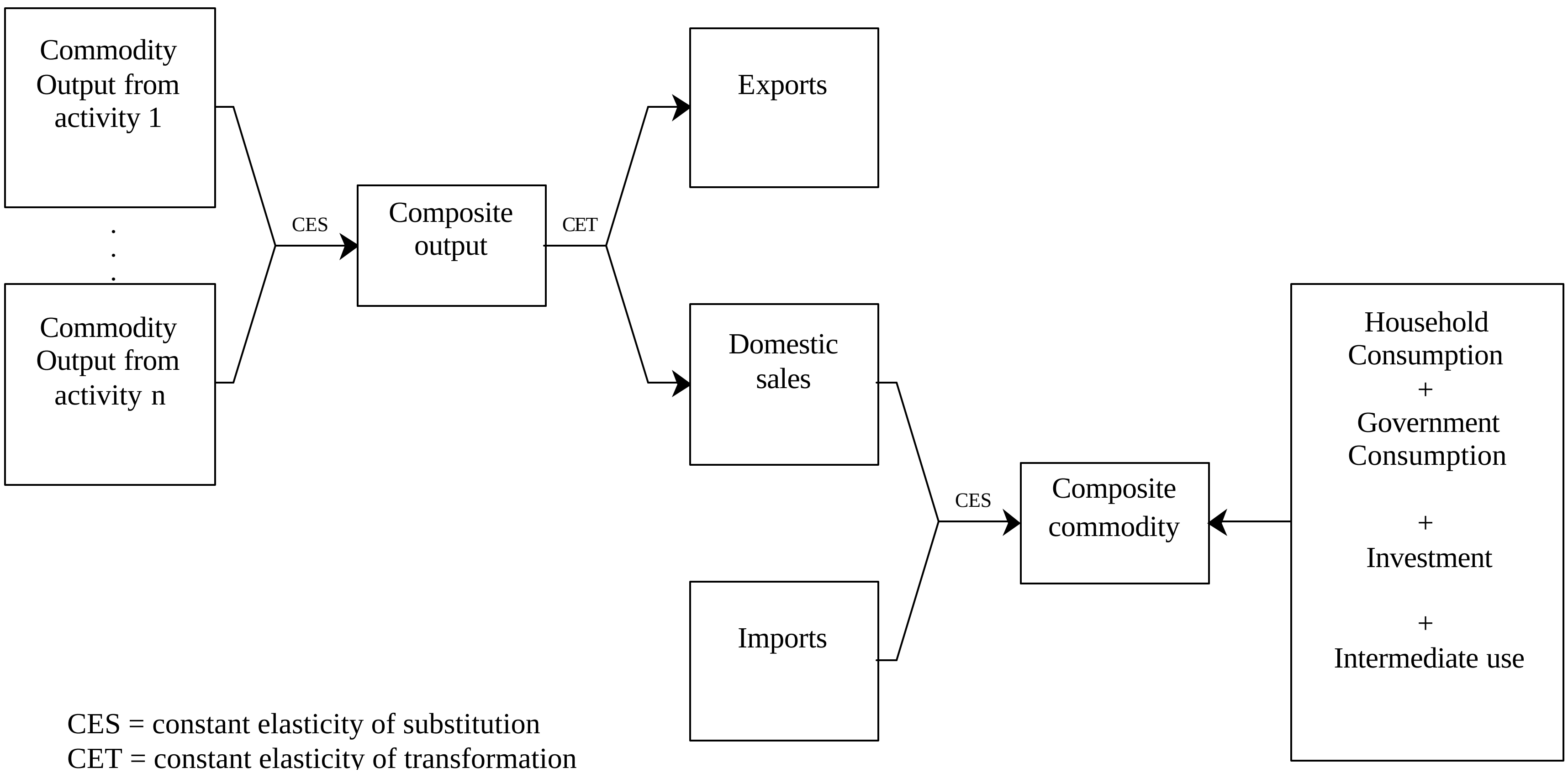
Note: ENSO shocks enter CGE model *via* agricultural activities.

Figure 5. Production Technology



Note: ENSO shocks enter CGE model *via* agricultural activities.

Figure 6. Flow of Marketed Commodities



CES = constant elasticity of substitution
CET = constant elasticity of transformation

B. Incorporating Uncertainty and ENSO Events into Model

This section describes the stochastic component added to the CGE model. In the simulations, stochastic behavior – representing general uncertainty in agriculture and/or uncertainty caused by ENSO events – is incorporated into the model as a random shock to the agricultural production functions, *via* the CES production function parameter α_{ag}, for each agricultural activity, *ag*, as follows:

$$(1) \qquad QVA_{ag} = \left(x_{ag} \cdot \boldsymbol{\alpha}_{ag} \right) \cdot \left(\sum_{f} \boldsymbol{\delta}_{f,ag} \cdot QF_{f,ag}^{-\rho_{ag}} \right)^{1/\rho_{ag}}$$

where QVA_{ag} = value-added for *ag*

$\boldsymbol{\delta}_{f,ag}$ = CES share parameter for factor *f* in *ag*

$QF_{f,ag}$ = factor *f* used in *ag*

$\boldsymbol{\rho}_{ag}$ = transformation of CES elasticity of substitution of factors in ag, σ_{ag},

where $\sigma_{ag} = \dfrac{1}{1+\boldsymbol{\rho}_{ag}}$

x_{ag} = random shocks to *ag*

The random shocks, x_{ag}, represent Hicks-neutral technological shocks, meaning that the proportion of inputs for each output remains the same. In this study, there are three possible sources of x_{ag} as will be described below: x^{G}_{ag} represents "general" fluctuations to agricultural productivity; x^{GE}_{ag} represents general fluctuations in the presence of ENSO events; and, x^{R}_{ag}, represents fluctuations in agricultural productivity due to variation in rainfall caused specifically by ENSO events.

In the initial set of experiments, agriculture is only subjected to the general random shock, x^{G}_{ag}. This shock may be caused by a variety of factors, not limited to ENSO events or even to weather in general. This set enables an examination of how the system reacts to random events generally, without regard to the source of the variability. Thus for the first set of experiments, equation (1) may be rewritten as:

$$(2) \qquad QVA_{ag} = \left(x^{G}_{ag} \cdot \boldsymbol{\alpha}_{ag} \right) \cdot \left(\sum_{f} \boldsymbol{\delta}_{f,ag} \cdot QF_{f,ag}^{-\rho_{ag}} \right)^{1/\rho_{ag}}$$

in which the random shock x_{ag} is composed of the general agricultural productivity shock, x^{G}_{ag}. As will be seen below, this random shock is calibrated from historical data and may be interpreted as the "normal" variability in agriculture faced by a farmer in any given year.

In the second set of experiments, ENSO events are explicitly included in the model, by separating the effects that ENSO events have on rainfall (which then impacts agriculture) from the general fluctuations experienced by agriculture. The ENSO-induced rainfall parameter contains a stochastic component, reflecting the variability of the impact that an ENSO event has on rainfall (and, by implication, other climate and/or agricultural indicators).[16] The total rainfall coming from a given ENSO event is converted into a shock to agricultural productivity, x^{R}_{ag}, and agricultural productivity is also affected by general agricultural shocks, x^{GE}_{ag}. Now equation (1) is rewritten as:

$$(3) \qquad QVA_{ag} = \left(x^{GE}_{ag} \cdot x^{R}_{ag} \cdot \alpha_{ag} \right) \cdot \left(\sum_{f} \delta_{f,ag} \cdot QF_{f,ag}^{-\rho_{ag}} \right)^{1/\rho_{ag}}$$

where x_{ag} from equation (1) now comprises two types of random shocks, i.e., the general agricultural productivity shock, x^{GE}_{ag}, and the shock from ENSO-induced rain fluctuations, x^{R}_{ag}.

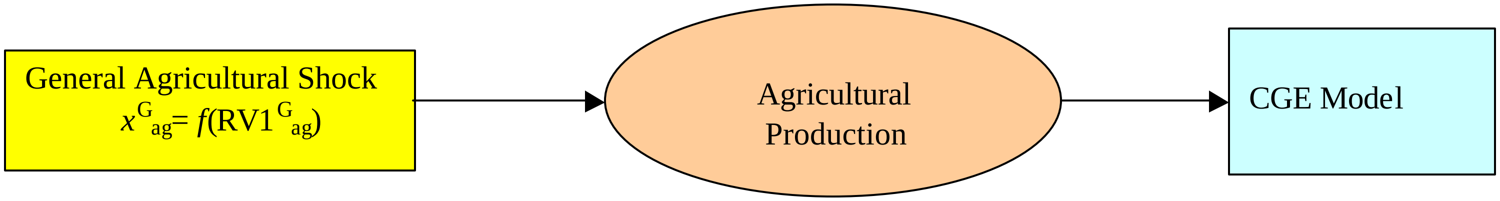
The third set of experiments compares the general agricultural variability with the variability that occurs from rain fluctuations caused by ENSO. These experiments are further described below and are also summarized in Table 8. Figures 7a and 7b show a diagrammatic representation of the causal chains in effect for the first two experiment sets.

Table 8. Summary of Model Simulations

SET	Simulation	Mean,Variance of "general" shock to Agriculture	Mobility of Ag. Factors (agricultural labor and land)	Source(s) of Variability
1	SURP-1	0,1	NO	General
	VAR-1	0,.5	NO	General
	MOB-1	0,.5	YES	General
	PROD-1	0.2,.5	YES	General
2	SURP-2	0,1	NO	General/ENSO Rainfall
	VAR-2	0,.5	NO	General/ENSO Rainfall
	MOB-2	0,.5	YES	General/ENSO Rainfall
	PROD-2	0.2,.5	YES	General/ENSO Rainfall
3	SURP-GEN	0,1	NO	General
	SURP-ENSO	0,1	NO	ENSO Rainfall

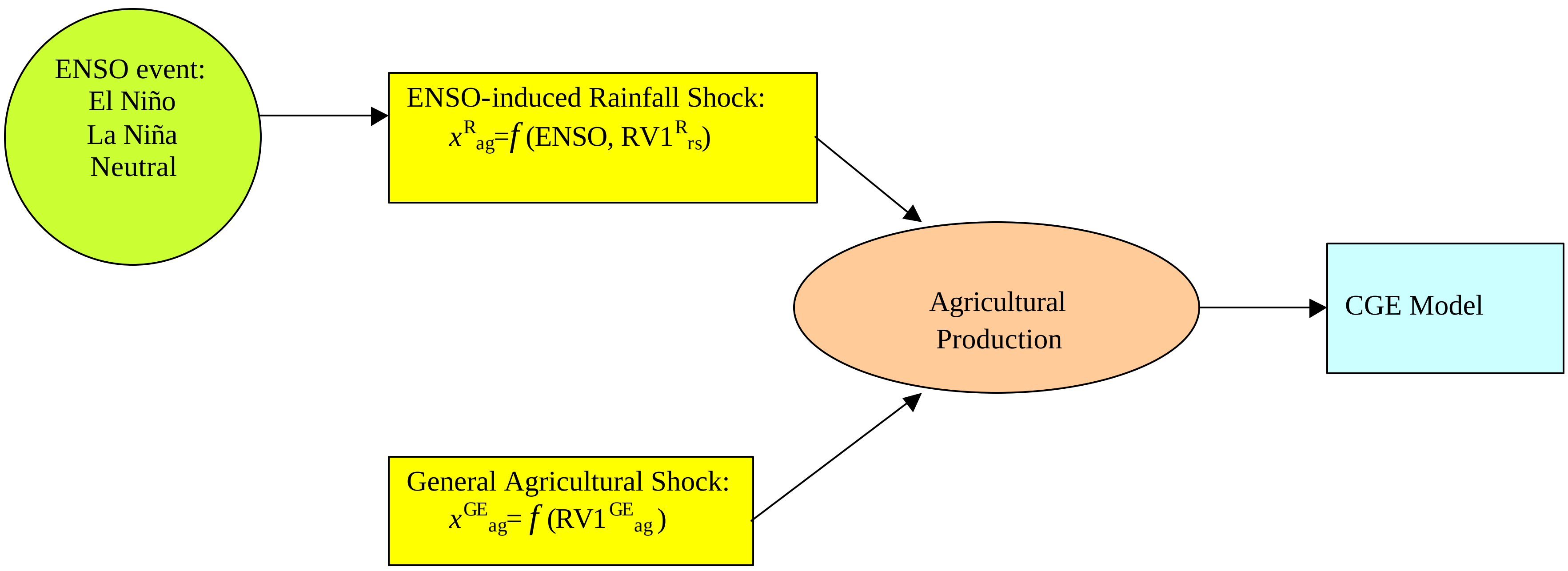
[16] While rainfall is not the only determinant of agricultural output, this is the best way to link ENSO to agriculture in the current context. Dilley (1997), for example, shows that either local monthly precipitation or ENSO indicators can explain maize yields in the Valley of Oaxaca. See Naylor, *et al* for another example of using rainfall as this link in Indonesia.

Figure 7a. Diagrammatic Description of Experiment Set 1.



$\mathrm{RV1}^{G}_{ag}$ = random variable, representing general shocks to agriculture, derived from historical yields. See Equation (4) in text.

Figure 7b. Diagrammatic Description of Experiment Set 2.



$\mathrm{RV1}^{GE}_{ag}$ = random variable, representing general shocks to agriculture during ENSO event, derived from SUR residuals. See Equation (8) in text.
$\mathrm{RV1}^{R}_{ag}$ = random variable, representing ENSO-induced rainfall, derived from SUR residuals. See Equation (7) in text.

i. Experiment Set 1. General Agricultural Variability

In the first set of experiments, the only source of variation is due to general agricultural risk. This is carried out by drawing a random variable, $RV1^{G}_{ag}$, which is parameterized to represent a percentage shock, x^{G}_{ag}, as described below. Then x^{G}_{ag} is multiplied by á$_{ag}$, and the model is solved. This is repeated 100 times. This stochastic shock may represent risk due to weather (ENSO-induced or otherwise), human error, bad seeds, pests or other variables which may affect agricultural output generally. This treatment enables us to examine how variability in agricultural production – from any source – affects key variables of the model.

Because of the covariate relationships among the activities of a given region and season, the random variable for each agricultural activity per season and region, $RV1^{G}_{ag}$, is computed from a multivariate distribution as follows:

(4) $$RV1_{ag}^{G} = m_{ag}^{G} + \sum_{ag^{1}} T_{ag,ag'}^{G} \cdot RV0_{ag'}^{G}$$

$RV0^{G}_{ag}$ is a random variable drawn for each agricultural activity, *ag* (recall that the set *ag* covers agricultural activities per region-season), which is multiplied by $T^{G}_{ag,ag'}$, the square root of the variance-covariance matrix of agricultural activities of the same season and region.[17] This is then added to ì$^{G}_{ag}$, the mean yield of the activity.

The agricultural data used to calculate $T^{G}_{ag,ag'}$ come from the 17 years of yield data described above, so that risk is based on historical variances of yields. This data, covering the years 1980-1997, includes both ENSO and non-ENSO years. First the data are converted into an index around the yield mean for each crop per region and season and then converted into natural logarithms. This follows the assumption that errors on the agricultural yields are distributed log-normally. After calculating $RV1^{G}_{ag}$ from this data, using equation (4), x^{G}_{ag} is calculated as the exponent of $RV1^{G}_{ag}$. This ensures that the shock, x^{G}_{ag}, is a positive number, centered around 1, and thus representative of a percentage shock.

As seen in Table 8, there are four different simulations in this experiment set, representing different levels of preparedness for unforeseen events. In the first run of the model, SURP-1, the logarithm of the random variable is specified as normally distributed, with a mean of zero and a variance of one. Agricultural factors of production are immobile, implying that the shock is a surprise and thus farmers cannot move their factors of production in order to counteract the shocks.

In the second level of preparedness, simulated in experiment VAR-1, agricultural factors are still immobile, but the variance of the shock is reduced by half. This may be indicative of improved crop varieties or other technologies which lower agricultural production risk. In the next simulation, MOB-1, the risk is again reduced by half from

[17] The matrix T is the lower triangular matrix, such that TT' = Ó, where Ó is the variance-covariance matrix of agricultural activities. T is derived from the Cholesky decomposition. See Greene (1997).

SURP-1, but agricultural labor and land are allowed to move within their region and season. This simulates early warning systems that enable farmers to adapt and to move their factors of production from a negatively affected crop to a more productive one. In the final simulation, PROD-1, agricultural labor and land are allowed to move, and the random variable is distributed as in VAR-1 and MOB-1, but now the mean of the random variable is raised by 20%. This represents a productivity enhancement, such as an improvement in technology, as well as improved forecasting and lowered variance. In all scenarios, agricultural capital (as well as non-agricultural capital) is kept fixed, to reflect the short-to-medium term nature of climate forecasts.

ii. Experiment Set Two – Agricultural Variability under ENSO Events

The next set of experiments adds variability due to the difficulty of predicting the effects that ENSO events have on rainfall. As opposed to the first set of experiments, in which agricultural variability is based on historical variability, this set uses regression analysis to determine it, as well as relates it to the uncertain effects of ENSO events on rainfall. The regression analysis is carried out using seemingly unrelated regression (SUR) techniques.

The analysis starts by estimating the following two blocks of equations for each region-season:

(5) $$YIELD_{ag} = \beta_1 + \beta_2 RAINHI_{rs} + \beta_3 \cdot RAINLO_{rs} + e^1$$

(6) $$RAIN_{rs} = \alpha_1 + \alpha_2 \cdot ENSO_s + e^2$$

In the first equation block, YIELD measures crop yield per region-season and RAINHI and RAINLO represent, respectively, dummy variables for the presence of rainfall that is more than one standard deviation higher or lower than average rainfall per region-season, *rs*. The dummy variables are constructed on the basis of the rainfall data described earlier, covering 1980-1996. This equation is run for all crops in a given region-season. In the second equation, RAIN (rainfall per region-season) is a function of the ENSO event of its season, *s*. There is one equation for each region-season. Since it is believed that the errors of these two blocks of equations, e^1 and e^2 are correlated, the SUR technique is most appropriate way to estimate them. The functional form of equation (5) was chosen on the belief that yields are a function not of rainfall, *per se*, but of "extreme" amounts of rainfall – i.e., a deluge can be equally harmful to crops as a drought.[18]

The results for the relationship between the rainfall dummies and yields are shown in Appendix Table 3. While most of these estimates are not significant even at a 90% confidence level, the errors are captured in the Monte Carlo experiments, as seen below. The weakness of the connection between ENSO-induced rain and yields is not surprising,

[18] Several other specifications were attempted to capture the relationship between ENSO and agriculture, including a direct link in which agricultural yields were a function of ENSO events and other explanatory variables such as rainfall or percentage of crop under irrigation, with variables defined in levels and in differences. These results, available from the author, were not particularly strong or robust.

given how localized rainfall effects are. In the EPIC model of Rosenberg, *et al* (1997), in which yields are simulated across 23 representative farms around Mexico, even crops located "near" each other may be affected differently by an ENSO event. For example, in their study, rainfed land maize yields increased, on average, by 0.5 tons per hectare during an El Niño event. This includes the decrease of 2.04 tons per hectare in Puebla, and the increases in Guanajuato, the state of Mexico and Morelos, of 0.11 tons per hectare, 0.44 tons per hectare, and 0.08 tons per hectare, respectively. The aforementioned states are all in one region of the current model (Central), along with other states not included in the Rosenberg study.[19] See Appendix 4 for a short discussion on validating the model's results.

Similar to the Rosenberg study, the regression results do show that crops may be affected differently according to region and season. Maize in the Central region, for example, experiences a 4.7% increase under "high" rainfall in the summer (associated with La Niña), but falls by 8.6% under the same conditions in the Pacific South. Maize in both regions falls by 4.9% under "low" rainfall in the summer (associated with El Niño events), making it even more difficult to generalize about yield patterns.

The regressions show the expected relationship between ENSO events and rainfall; namely, during an El Niño event, winter rainfall increases and summer rainfall decreases, while the opposite holds true for a La Niña event. All of these estimates are robust at a 90 to 95% confidence level, except for winter rain in the South East. These estimates are interpreted as the change in rainfall for a 1 unit (in which the units are natural logarithms of the percent deviation from normal temperature) change in the SSTA. The "total" ENSO effect is then calculated by multiplying these estimates by coefficients representing the actual change in the SSTA for a given ENSO event. These coefficients come from the deviation in the SSTA for a "strong" El Niño event and a "strong" La Niña event, in correspondence with classifications of the Climate Prediction Center.[20] Appendix Table 5 presents the regression results as the percent deviation from normal rainfall when a strong El Niño event or strong La Niña event occurs, for each region and season.

The results are incorporated into the CGE model as follows: First, an ENSO event is chosen from 3 types: a strong El Niño, Neutral, or strong La Niña.[21] The impact of the ENSO event on rainfall is then taken from the resulting "total" ENSO effect as described

[19] Ideally, one of the EPIC models of Mexico would be broken down into the same aggregation of crops as in the current model, using farms representative of the regions of the current model. However, the enormous amount of data input this would require makes this undertaking infeasible in practice.

[20] These coefficients are equivalent to a 9 percent increase in the SSTA during an El Niño event and a 7 percent decrease in the SSTA during a La Niña event. These SSTA numbers correspond with the El Niño event in the winter of 1983 and the La Niña event in the winter of 1989.

[21] Only three phases of the ENSO cycle, a strong El Niño, a neutral event, and a strong La Niña are simulated in this study. This is due to the belief that an ENSO early warning system is most effective during extreme ENSO events (see WMO 2001). In addition, in the current modeling framework, the rainfall and thus agricultural production results from a weaker El Niño (La Niña) would be dampened but would not change in direction from the results of a strong El Niño (La Niña). This may deviate from reality, as seen in Rosenberg, *et al*, in which a regular El Niño may have the opposite impact on agricultural technology (measured in yields) from a "severe" El Niño.

in the preceding paragraph. This impact is added to an equation for random rainfall, which is similar to equation (2) above:

$$(7) \qquad RV1_{rs}^{R} = m_{rs}^{R} + \sum_{rs^{1}} T_{rs,rs'}^{R} \cdot RV0_{rs'}^{R}$$

The random variable for rain in each region-season, $RV1^R{}_{rs}$, is determined by multiplying a random variable, $RV0^R{}_{rs}$, by $T^R{}_{rs,rs'}$, the square root of the variance-covariance matrix of rainfall per region-season, and added to mean rainfall, $ì^R{}_{rs}$. Then "total rainfall," i.e., the sum of the random rainfall and the rainfall resulting from the ENSO event, is classified as high, low, or normal, in accordance with the dummy variable definitions from the regressions, as described earlier.

Next, the shock on agriculture is determined with two components. First, the shock from the ENSO-resulting rainfall, the parameter $x^R{}_{rs}$ in Equation (3), is calculated. It is the effect of rainfall on agriculture as given in the regression results, corresponding to if the total rainfall falls into one of the dummy variable classifications (i.e., "high" rain or "low" rain). Second, the general agricultural random shocks, $x^{GE}{}_{ag}$ (seen in Equation (3)) is determined as follows:

$$RV1_{ag}^{GE} = m_{ag}^{GE} + \sum_{ag^{1}} T_{ag,ag'}^{GE} \cdot RV0_{ag'}^{GE} \qquad (8)$$

This equation is similar to equation (4) except that now the T parameter comes from the square root of the residuals matrix from the SUR estimations. This permits the inclusion of the relationships among crop yields in a region-season and captures the errors associated with the regression equations. Both of these shocks, from randomness in rainfall and from randomness in agriculture, get multiplied by the CES shift parameter, $á_{ag}$, as in Equation (3). See Figure 7b for a diagrammatic representation of these impacts.

The simulations for this set of experiments are the same as for the first set and are summarized in Table 8. In all simulations, an ENSO event is chosen which affects rainfall (yielding $x^R{}_{rs}$) and which, in turn, affects agriculture, along with the general random shock to agriculture($x^{GE}{}_{ag}$). In SURP-2, factors are immobile, again simulating that farmers are unprepared for the shocks. In VAR-2, the variance on the shock to agriculture is reduced by half. In MOB-2, the variance is reduced by half, and agricultural factors are mobile. PROD-2 follows MOB-2, with an increased mean of 20%. These four scenarios are repeated for each type of ENSO event (El Niño, Neutral, and La Niña), for a total of 12 simulation runs.

iii. Experiment Set Three – Comparison of Sources of Variability

The final set of simulations compares the variability associated with the uncertain effects of ENSO events with the variability associated with agriculture in general. This is useful in determining which effect is greater, and which effect leads to greater inefficiencies in the economy. The results can shed light on which type of variability is the one policymakers should attempt to minimize, if possible.

This decomposition is done using the El Niño event of the second experiment set under the SURP case in which no adjustments can be made. In the first experiment, SURP-GEN, the random effect on rainfall is removed, implying that the effects of the El Niño event on rainfall are predicted perfectly.[22] In other words, the stochastic term in the rainfall equation, e^2 in equation (6), is effectively eliminated, and all of the "surprise" comes from agricultural variability. In the second experiment, SURP-ENSO, the random effect in agriculture is suppressed (i.e., e^1 in equation (5)), so that all risk is associated with the uncertainty in rainfall prediction from an El Niño event.

C. Evaluating the simulations and caveats

The stochastic CGE runs are able to answer many questions regarding the impacts of risk and weather on agriculture and rural poverty. Macroeconomic effects, such as on total output, trade, and absorption, can also be analyzed easily in this model. However, because agriculture is a small component of total GDP in Mexico (about 5% of GDP – see Table 1), and its spillovers to the processed food sectors are weak, the impact of any agricultural shock on the entire economy is expected to be small. Nevertheless, important *regional* impacts are expected, and in particular, households in different rural regions are expected to feel different effects of an ENSO event. At the same time, the diversity of income sources for rural households implies that the effects of an agricultural shock will be dampened.

Indeed, the model permits a closer examination of the difference between the resulting variance of agriculture and variance of income.[23] Because families rely on more than one source for income, the effects of agricultural shocks are dampened by the time they work their way to incomes. It is, nevertheless, be important to see what those income changes are and how different households are affected.

It would be preferable to have a model in which farmer behavior were directly modeled, but data limitations prohibit this. Instead, activities are broken up regionally (and seasonally), and the activities make their value added payments to different households (distinguished by income levels) in the same regions. This treatment implies that individual risk tolerance cannot be imposed on different farmers, though it is likely that in reality, smaller, poorer farmers have lower risk tolerance than larger, wealthier ones. This tolerance can only be captured indirectly by the extent to which one household receives more factor returns from a particular crop (and in a different ratio) than another household.

This model does not include domestic or international migration. Information on the effects of ENSO on migration is scarce and, with so many other factors affecting migration, hard to quantify. Similarly, given the short-to-medium term nature of the model, it is hard to say if geographic migration fits in the time frame. Since there is no

[22] Note that this experiment differs from those in Experiment Set 1, in that in this set, there is an ENSO event (El Niño) which will affect rainfall. In Experiment Set 1, there is no ENSO event.
[23] These variances are measured using the coefficient of variation (standard deviation divided by mean) in order to compare across variables of different scales.

dynamic component in the model, the migration-induced effects of, for example, damaged land cannot be captured. Finally, as will be seen in the results section, the wage effects – which would be the quantifiable cause of migration in this model – of ENSO are so small in this model that they are unlikely to cause migration.

6. Results

A. Experiment Set 1. General Agricultural Variability

In the first set of experiments, "general" agricultural variability is the only source of agricultural variability. That is, agricultural output may be affected any type of weather – including during ENSO and non-ENSO periods – and also by other uncertainties which affect production. The random shock, x^{G}_{ag} from equation (2), is the only source of variability. This section starts by discussing the overall effect on agricultural output under the four different levels of preparedness: SURP-1, in which there is no preparation or forewarning; VAR-1, in which improved technology reduces the variance of the shocks; MOB-1, which has the reduced variance of the shocks and factor mobility; and PROD-1, which includes the preparedness of MOB-1, plus a 20% productivity enhancement for agricultural sectors. Since PROD-1 is unambiguously better in terms of mean output, regional crop composition is next examined in further detail, along with the impact on rural mean incomes. We then examine any indirect impacts on the urban region. The final subsection looks at the effects on prices and price variability.

i. Agricultural Output

Table 9 shows the changes in the mean value of output for each region, compared to SURP-1, under the different preparedness scenarios. From a regional perspective, solely reducing the variance of the shock does not lead to an increase in output. Indeed, because the mean is constructed to remain the same, the differences between average regional output in SURP-1 and VAR-1 (in which only the variance changes) are small.

In MOB-1, in which the mean is the same but factor mobility is allowed, all regions experience some increase in the mean value of output over SURP-1, from 1.0% in the North to 3.3% in North Central. In North Central, agricultural workers in winter crops move out of *other crops* production and into *fruits and vegetables*, while in the summer, both *other crops* and *fruits and vegetables* use fewer workers, who migrate uniformly to the rest of the agricultural activities. This more efficient allocation of factors allows total output to increase. Compared to SURP-1, the coefficient of variation for regional output decreases – though some individual crops experience greater volatility – but it is generally higher than in VAR-1. This is because of the covariate relationship among crops of the same region and season: if one increases by a large amount due to a more efficient allocation of factors, a negatively correlated crop may experience an even greater decrease, from the loss of factors as well as from its relationship with the first crop.

The mean of the random shock in PROD-1 is higher than that of MOB-1, but both random variables have the same variance. The mean output levels for PROD-1 are unambiguously higher than in MOB-1, and the coefficient of variation of the value of regional output tends to be about the same. The smoothing role of prices is seen by comparing Tables 10a and 10b, which show the coefficient of variation for the value and the volume, respectively, of regional output. The volatility of volume is much larger, but prices serve to dampen the fluctuations of the value of output.

Table 9. Deviation of Mean Value of Regional Output under Experiment Set 1.
(percent deviation from SURP-1)

	VAR-1	MOB-1	PROD-1
North West	-0.2	1.0	20.0
North Central	-1.4	3.3	19.1
Central	-1.2	1.9	18.5
Pacific South	-1.0	1.4	18.2
South East	-0.7	3.2	16.9

Table 10a. Coefficient of Variation of Value of Regional Output under Experiment Set 1.
(percent)

	SURP-1	VAR-1	MOB-1	PROD-1
North West	0.28	0.16	0.24	0.20
North Central	0.66	0.31	0.49	0.41
Central	0.60	0.29	0.49	0.42
Pacific South	0.30	0.15	0.21	0.18
South East	0.73	0.33	0.40	0.37

Table 10b. Coefficient of Variation of Volume of Regional Output under Experiment Set 1.
(percent)

	SURP-1	VAR-1	MOB-1	PROD-1
North West	9.9	4.9	5.9	5.9
North Central	23.7	11.1	17.7	17.7
Central	25.0	11.1	21.9	21.1
Pacific South	13.8	6.6	9.4	9.2
South East	28.1	10.7	16.2	15.5

ii. Regional Crop Composition and Rural Incomes – PROD-1

Looking only at regional output changes hides the distributional implications behind the simulations, even when the most favorable simulation in which variance is lowered and mean is raised (PROD-1) is implemented. Because some crops experience very large increases in output, resources shift out of the other sectors in a region so that the latter do not increase by the same magnitude. Since factor intensities differ by crop, the returns to factors respond unevenly.[24] As a result, while all households benefit from the higher mean in PROD-1, the gains are not spread uniformly. Table 11 shows the changes in mean output under PROD-1 and Table 12 shows changes in mean household income.

In the North West region, winter *fruits and vegetables* – by far the dominant crop in the region – increases by 42%, while winter *maize* increases by 22%. In the summer, the main increase comes from *fruits and vegetables* as well, with an increase of 61%. Winter *maize* and summer *fruits and vegetables* are both relatively irrigated-land intensive, and thus the gains to these products primarily accrue to the rich households, whose income increases over the base-line data by 12.5%. At the same time, because winter *fruits and vegetables* pay 45% of total value-added to labor, there are some smaller gains for the poor and medium households, whose incomes increase by 4% and 5%, respectively.

The gains in North Central from PROD-1 are also quite large, with the benefits also skewed toward wealthy households. Summer *maize* and *beans* increase by 29% and 31%, respectively. Summer *beans* is particularly non-irrigated land intensive (equaling 50% its value-added) and also uses a lot of labor (23% of value-added). Summer *maize* pays about 32% of its value-added to non-irrigated land, and 18% to labor. On the other hand, summer and winter *fruits and vegetables*, with increases of 54% and 70%, respectively, are more irrigated-land intensive. Since summer *fruits and vegetables* is so important in this region's crop production, its benefits to irrigated land overwhelm the gains to the other factors. Rich households gain 7.5% in income over the SURP-1, while poor households gain only 2% and medium households gain just 3%.

The Central region experiences an uneven increase in production. In the base-line data, *maize*, *fruits and vegetables* and *other crops* are all dominant crops in the summer. However, after PROD-1, *fruits and vegetables* clearly leads production with increases of 51%. Since the value added from *fruits and vegetables* in this region is distributed fairly uniformly across the factors of production (for example, paying 29% of its value added to irrigated land and 32% to agricultural labor), the gains to households are also more even. Compared to SURP-1, poor and medium households gain almost 2%, while rich households gain about 5%. Winter production, which is relatively small in this region, has little impact on income distribution

[24] See Appendix Table 1 for a breakdown of value-added by crop.

Table 11. Changes in Output. PROD-1.
(percentage change from SURP-1)

North West	Winter					Summer			
	Maize	Wheat	Oth.Grain	Fruit & Veg	Oth.Crop	Oth.Grain	Fruit & Veg	Oth.Crop	
	22	4	-2	42	19	8	61	19	
North Central	Winter			Summer					
	Oth.Grain	Fruit & Veg	Oth.Crop	Maize	Beans	Oth.Grain	Fruit & Veg	Oth.Crop	
	12	70	14	29	31	7	54	18	
Central	Winter			Summer					
	Oth.Grain	Fruit & Veg	Oth.Crop	Maize	Beans	Oth.Grain	Fruit & Veg	Oth.Crop	
	5	64	14	19	29	1	51	7	
Pacific South	Winter					Summer			
	Maize	Wheat	Oth.Grain	Fruit & Veg	Oth.Crop	Maize	Oth.Grain	Fruit & Veg	Oth.Crop
	22	11	3	42	17	15	7	56	11
South East	Winter				Summer				
	Maize	Oth.Grain	Fruit & Veg	Oth.Crop	Maize	Oth.Grain	Fruit & Veg	Oth.Crop	
	15	18	59	1	31	10	58	7	

Table 12. Mean Household Income Changes Under PROD-1.
(percentage change from SURP-1)

Rural Poor – NW	4.4
Rural Medium – NW	5.2
Rural Rich – NW	12.6
Rural Poor – NC	2.0
Rural Medium – NC	3.1
Rural Rich – NC	7.5
Rural Poor – C	1.7
Rural Medium – C	1.8
Rural Rich – C	5.3
Rural Poor – PS	3.6
Rural Medium – PS	6.0
Rural Rich – PS	9.6
Rural Poor – SE	3.0
Rural Medium – SE	3.8
Rural Rich – SE	2.4

In the base-line data, the majority of Pacific South's summer output is in *maize,* followed by *fruits and vegetables* and *other crops*. Once again, *fruits and vegetables* reaps the benefits of the increased mean, with output rising by 56%. In the winter, *fruits and vegetables* again dominates regional production and sees the largest increases, at 42% over SURP-1. While all crops in this region are relatively more labor intensive than in regions to the north, the gains to households are not distributed as evenly as one might expect, due to the sources of income per household. Poor households, earning 23% of their income from agricultural factors, gain 3.5% from the simulation. Medium households earn 32% of their income from on-farm resources, and gain 6% in income. Rich households are the big winners here. With 40% of their income derived from agriculture, they gain 9.5%.

In South East, production patterns are similar to the Pacific South, in that *maize*, *fruits and vegetables* and *other crops* dominate summer production, and *fruits and vegetables* and *other crops* are the main winter crops (though much smaller in output). Again, *fruits and vegetables* benefit most from PROD-1 in both winter and summer, increasing over 58%. As in the Pacific South, production tends to be more labor and non-irrigated land intensive, but in the South East, agricultural income as a share of total income is more even among the households. Here the benefits are spread out more evenly, with a 3% increase to the poorest households, 3.8% to medium households and 2.4% to the richest households.

The model contains two agricultural sectors which are not regionalized, due to data constraints: namely, *livestock* and *fisheries-forestry*. These sectors are thus not subjected to the regionalized external shocks. Nevertheless, since both of these sectors use agricultural factors of production, they are adversely affected as these factors shift toward the regionalized goods with increased production. *Livestock* output declines by almost 5%, while the *forestry-fisheries* sector loses about 7.4 % of its production as resources move to the other agricultural sectors. These sectors pay the most value-added to agricultural labor and non-irrigated land in the North West and North Central regions, and are likely to have a slight dampening effect on most agricultural wage increases. As we will see in the next sub-section, urban output does not change significantly enough to impact the urban factor wages that rural households receive.

We can summarize by saying that all rural households receive higher mean incomes under PROD-1. At the same time, all households experience greater income risk, which is consistent with the increased variance of agricultural production. Nevertheless, with the exception of rural rich households in Pacific South, the variability in income earnings (as measured by the coefficient of variation) is lower than the variability to the value of agriculture, as seen in Table 13.[25] This result is because of the diverse sources of income that households receive. From a distributional perspective, in all regions except South East, rich households gain more than poor or medium households, since wealthier households tend to own the factors of production of the activities which increase production most.

iii. Non-Agricultural Output and Urban Incomes

PROD-1 has minor spillovers into the non-agricultural sectors, but none of these changes is big enough to affect the average incomes of the urban households. *Corn manufacturing*, *wheat manufacturing*, and s*ugar manufacturing* experience increases of between 1-1.7%, explained by the increases in the raw crops (raw sugar is a large part of the *other crops* commodity). *Processed fruits and vegetables* actually declines, by 2.7%, as a larger share of raw *fruits and vegetables* is sold on the commodity market – including exports, which rise by more than the increase in domestic production. Due to the decrease in *livestock* production, *dairy manufacturing* also declines, by 2.7%. The decline of *livestock* production also adversely affects the *other foods* sector. Of the urban manufacturing sectors, *light manufacturing* feels a slight impact from the agricultural changes: because this sector uses some inputs from the *fisheries-forestry* sector, it declines in output by 1%.

[25] For purposes of model validation, it should also be noted that the coefficient of variation of the agricultural activities' output is identical to that of the historical data. In other words, this model simulation replicates the shocks to agriculture over the 17 year period for which we have data.

Table 13. Comparison of Variability in Value of Agriculture (in bold) and Variability Household Income (in plain type). Experiment PROD-1.

	Risk (coefficient of variation) in percentage
North West Agric.	**0.20**
Rural Poor – NW	0.17
Rural Medium – NW	0.09
Rural Rich – NW	0.18
North Central Agric.	**0.41**
Rural Poor – NC	0.03
Rural Medium – NC	0.02
Rural Rich – NC	0.15
Central Agric.	**0.42**
Rural Poor – C	0.02
Rural Medium – C	0.01
Rural Rich – C	0.10
Pacific South Agric.	**0.18**
Rural Poor – PS	0.04
Rural Medium – PS	0.07
Rural Rich – PS	0.19
South East Agric.	**0.37**
Rural Poor – SE	0.02
Rural Medium – SE	0.02
Rural Rich – SE	0.03

These changes in urban production tend to cancel each other out in the urban factor markets. That is, on net, urban production falls by less than two-tenths of one percent, not enough to cause significant changes in urban wages. As a result, urban households do not experience any changes in their mean income. However, this result should not imply that the variance of their incomes does not increase. There is still variance in urban production, and thus in the returns to urban factors.

iv. Prices

As seen in Table 14, the "surprise" scenario of SURP-1 does cause consumer prices to go up in many of the sectors which are important to poor households.[26] In particular, all of the prices of raw agricultural commodities rise, because these sectors experience declines in production compared to the base-line equilibrium. Spillover effects from these sectors

[26] The consumer price, PQ_c in equation (4) of Appendix 2, is based on commodities.

to urban sectors is evident in the slight price rise of some urban commodities as well. The resulting decline in *livestock*, *forestry/fisheries*, and *dairy manufacturing* leads to increases in the prices of those products, while other urban industries see no change in their consumer prices. Under PROD-1, when productivity increases for agricultural products, the prices of agricultural commodities decrease. Table 14 also shows that volatility in consumer prices, as measured by the coefficient of variation, does not change much between these two scenarios. This outcome occurs because exports or imports adjust to smooth out the amount of consumption goods available in the market. A comparison of the volatility of domestic supply, the composite commodity (i.e., the combination of imports and domestically produced output available for domestic consumption), imports, and exports in Table 15 underscores this point.

Table 14. Comparison of Consumer Prices and Consumer Price Volatility under different Preparedness Levels
Experiment Set 1.

	percent deviation from base-line		coefficient of variation (percentages)	
	SURP-1	PROD-1	SURP-1	PROD-1
Maize	1	-5	1.0	1.0
Wheat	1	-2	1.0	0.8
Beans	1	-4	1.0	1.0
Oth. Grain	1	-4	2.0	1.0
Fruit & Veg	1	-10	2.0	4.4
Oth. Crop	3	-1	3.9	4.0
Livestock	0	5	0.2	1.9
Forest/Fish	0	8	0.3	1.9
Dairy	0	2	0.1	0.7
Fr &Veg Prep	1	0	0.8	1.0
Wheat Flour	0	0	0.2	0.2
Corn Flour	0	1	0.2	0.2
Sugar	1	-1	0.8	0.9
Oth.Food	0	-1	0.3	0.2
Light Manuf	1	1	0.1	0.1
Intermediate	1	0	0.4	0.3
Consumer Goods	2	2	0.0	0.1
Capital Goods	2	0	0.5	0.4
Construction	1	1	0.1	0.1
Prof. Services	0	1	0.2	0.2
Oth. Services	1	1	0.2	0.1
Commerce	1	2	0.2	0.2

Table 15. Comparison of Quantity Variability: PROD-1.
Coefficient of Variation (percentage)

	QQ	QX	QM	QE
Maize	0.5	8.4	5.5	13.7
Wheat	0.3	3.4	3.2	*
Beans	0.3	9.5	5.5	18.1
Oth. Grain	0.4	3.5	6.8	10.0
Frt & Veg.	3.8	17.6	15.6	20.2
Oth. Crops	1.4	24.4	5.0	50.0
Livestock	1.0	1.8	5.8	2.2
Forest/Fish	0.5	1.8	2.5	2.4
Dairy	0.5	1.1	2.7	3.8
Frt & Veg prep	0.2	2.5	1.4	4.4
Wheat Manuf	0.3	0.2	2.2	1.7
Corn Manuf	0.4	0.4	1.8	6.8
Sugar	0.7	3.0	1.0	1.7
Oth. Food	0.2	0.4	0.2	1.1
Light Manuf	0.1	0.3	0.3	0.4
Intermediates	0.3	0.1	0.4	0.9
Consumer Goods	0.3	0.2	0.2	0.3
Capital Goods	0.2	0.3	*	*
Construction	0.2	0.2	*	*
Prof. Services	0.0	0.0	*	*
Oth. Services	0.1	0.1	*	*
Commerce	0.1	0.1	*	*

Key:
QQ = quantity of composite commodity (combination of imports and domestically produced output for domestic consumption)
QX = quantity of domestic output
QM = quantity of imports
QE = quantity of exports
* = goods which are non-tradable, or in the case of wheat, not exported

B. Experiment Set 2. Agricultural Variability under ENSO Events

In this section, the simulations are shocked with two different types of ENSO events: a "strong" El Niño and a “strong” La Niña, and a third event, Neutral (which contains random shocks to agricultural production, but has no specific rainfall effects from an ENSO event). The simulations are done for the 4 preparedness scenarios of SURP-2, VAR-2, MOB-2, and PROD-2.

For the entire country, the mean value of agricultural crops' output falls by almost 3% if there is no forewarning (SURP-2) and either an El Niño event or a La Niña event occurs (compared to a neutral event). In VAR-2, in which the variance of the agricultural random variable is cut in half, mean production falls under all ENSO events.[27] When factors are allowed to move, as in MOB-2 and PROD-2, mean output increases under all ENSO phases. In fact, under a La Niña event, resources reallocate to a more efficient mix of more *beans*, *fruits and vegetables*, and *maize* at the expense of the other crops, such that total output increases to equal the total under Neutral. Agricultural production under an El Niño event continues to lag behind Neutral, by about 3.5%. These results are summarized in Table 16. In terms of total national output, the ENSO events do not make a significant change in GDP (i.e., less than one-tenth of a percent of GDP).[28]

Table 16. Mean Value of Agricultural Crop Output Under Different Levels of Preparedness
(billions of pesos, measured in producer prices)

	SURP-2	VAR-2	MOB-2	PROD-2
Neutral	139	131	143	170
La Nina	135	127	143	170
El Nino	135	126	138	164

[27] Recall that in the first set of experiments the VAR-1 run gave about the same average output as SURP-1. The reason for the difference in the second set of experiments may be traced to the different Cholesky parameter, T, used. In the first set, the Cholesky parameter comes from the historical covariate relationship among crops, whereas in the current set, the parameter comes from the correlation matrix of the error terms from the SUR regression. The latter matrix has much larger numbers (in particular, the numbers on the diagonal matrix are more than double those of the historical matrix), implying that the random variables will be larger in absolute terms. Due to the nature of the logarithmic function (recall that the random number generator is determined with logarithms), there is a greater difference between the exponentiation of a logarithm (as in SURP-2) and the exponentiation of half of the value of that logarithm (as in VAR-2) as numbers get larger (say larger than 1). This property causes the results of VAR-2 to be much lower on average than in SURP-2.

[28] Note that in this study, ENSO only directly impacts agricultural crops. If ENSO has direct impacts on other sectors (for example, transportation or communications), the GDP results here are understated.

i. Agricultural Output

Figures 8.1 – 8.5 show that the regions are affected differently by the ENSO events, and in fact, non-ENSO periods are not necessarily the most productive ones for all regions. These Figures show the mean value of total regional output for each ENSO event, for two preparedness scenarios: SURP-2, in which the ENSO event is a surprise, and PROD-2, in which the most precautions have been taken, including technology to enhance productivity. As expected, PROD-2 always yields the highest mean value of output for all regions and for all ENSO events, and even MOB-2 (not shown in the Figures), which does not have the production enhancement but does allow for factor mobility, is higher than the surprise scenario. As Table 17 shows, the benefits of improved forecasting and technology are somewhat skewed toward the Central, Pacific South and South East regions.

Figure 8.1. Simulation Set 2. Value of Regional Output. North West

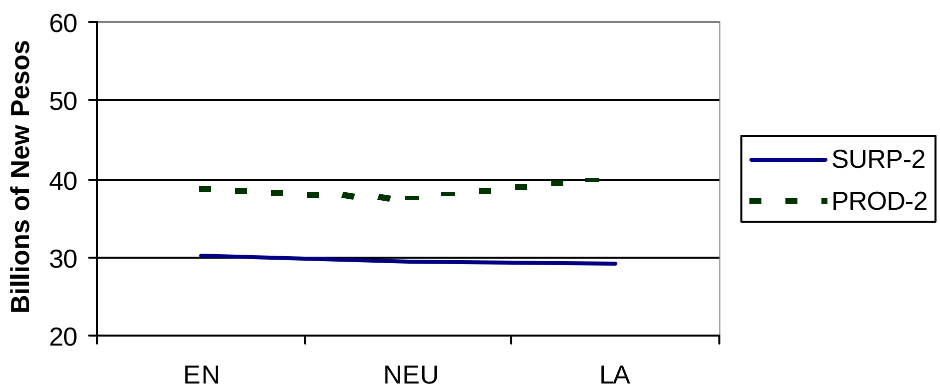


Figure 8.2. Simulation Set 2. Value of Regional Output. North Central

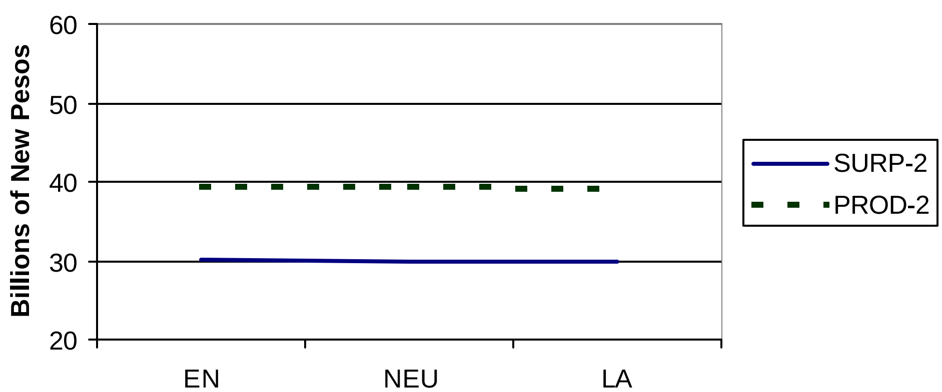


Figure 8.3. Simulation Set 2. Value of Regional Output. Central

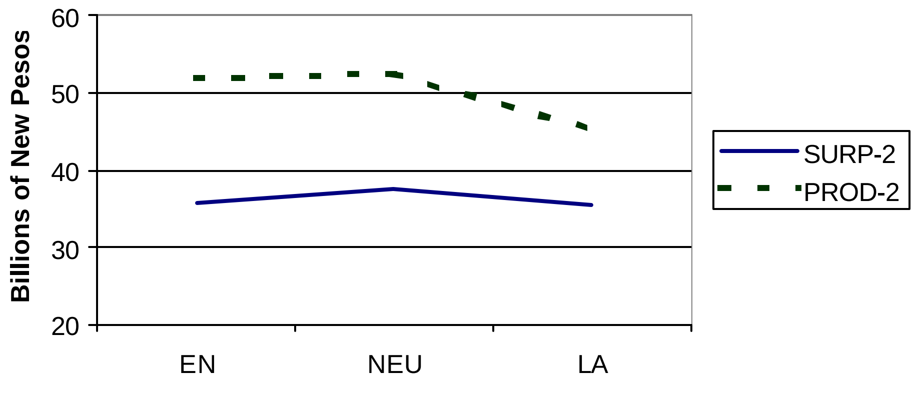


Figure 8.4. Simulation Set 2. Value of Regional Output. Pacific South

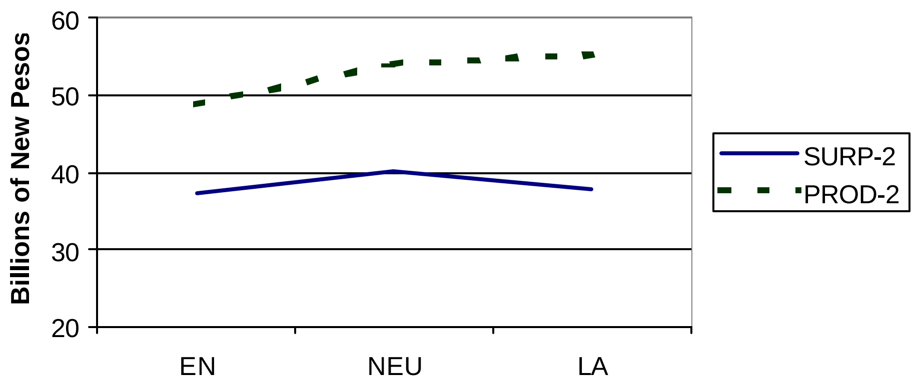


Figure 8.5. Simulation Set 2. Value of Regional Output. South East

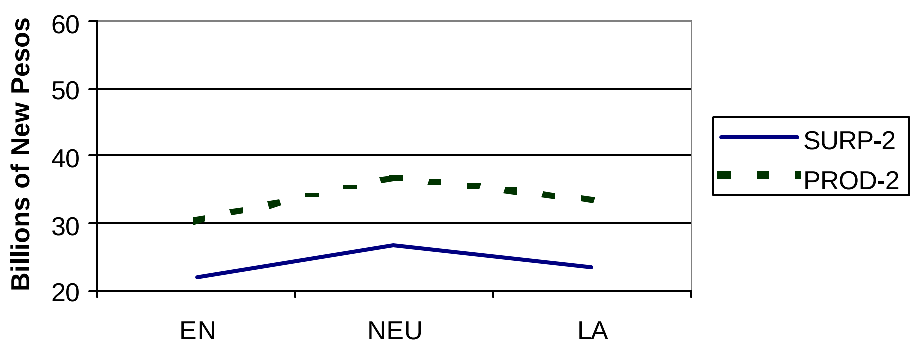


Table 17. Deviations from Mean Value of Regional Output, by ENSO event, under different levels of preparedness
(percent deviation from SURP-2)

	MOB-2	PROD-2
North West		
El Niño	8.8	28.3
Neutral	7.5	27.8
La Niña	15.2	38.9
North Central		
El Niño	8.6	30.2
Neutral	10.5	32.8
La Niña	9.3	31.4
Central		
El Niño	9.5	44.8
Neutral	9.9	40.3
La Niña	8.5	27.3
Pacific South		
El Niño	8.2	30.9
Neutral	10.8	34.5
La Niña	17.0	46.8
South East		
El Niño	13.4	38.2
Neutral	16.9	37.7
La Niña	13.6	42.7

Less obvious are the comparisons among the three different types ENSO events. The mean value of output under a Neutral event tends to be greater than the mean value of output under either ENSO event (i.e., El Niño or La Niña) in the Central, Pacific South, and South East regions. The most damaged area is the South East region, which loses 18% of the mean value of output under an El Niño event and 12.2% under a La Niña event. The North West and North Central regions have rather ambiguous results, perhaps indicative of the weakness of the ENSO signal itself and the weak statistical relationships there. In the North West, a La Niña event causes the mean value of output to decline slightly, compared to a Neutral event, but an El Niño event raises the mean value of output by over 3%. In the North Central region, a La Niña event and the neutral event leave basically the same level of mean value of output, while an El Niño event raises it slightly.

It is also difficult to generalize about national production by crop following either an El Niño or La Niña event. As seen in Table 18a, while total crop production is lower under either an El Niño event or a La Niña event in SURP-2, individual crops behave differently. *Other crops* experiences the largest decline in either event, falling by 13.7% under an El Niño and 17.1% under a La Niña event. *Fruits and Vegetables* sees a greater fall when there is an El Niño event (-4.9%) than a La Niña event (-2.3%). *Other grains* actually increases by 2.5% when there is an El Niño event, particularly due to an increase in winter production in North Central and summer production in Central. Similarly, winter *wheat* production in North West boosts that crops' production under an El Niño event, which increases almost 2% over the neutral scenario. The rest of the crops experience declines under a La Niña event and very slight increases under an El Niño event. Table 18b shows the changes in terms of values, which do not necessarily follow the directional change of the volume figures, due to price changes.[29] Under an El Niño event, total crop production falls by about 3.6 billion pesos, and under a La Niña event, the loss is at about 3.8 billion pesos.

Table 18a. El Niño and La Niña deviations from Neutral Event by national crop. Simulation SURP-2.
(percentage change of metric tons)

	El Niño	La Niña
Maize	-2.7	-4.3
Wheat	1.7	-1.7
Beans	-0.5	-0.5
Other Grain	2.5	-1.4
Fruit & Veg	-4.9	-2.3
Other Crop	-13.7	-17.1
Total	**-5.8**	**-6.4**

Table 18b. El Niño and La Niña deviations from Neutral Event by national crop. Simulation SURP-2.
(millions of pesos)

	El Niño	La Niña
Maize	-60	-480
Wheat	293	230
Beans	246	246
Other Grain	909	856
Fruit & Veg	-1740	-330
Other Crop	-3228	-4316
Total	**-3579**	**-3793**

Although the *aggregate* mean value of output increases in each region as a result of the precautions implied by the MOB-2 and PROD-2, not all individual crops experience

[29]These values are measured in national commodity producer prices, PX_c, as seen in Equation (5) of Appendix 2.

increases. Table 19 shows the percentage change in the mean value of output for MOB-2, compared to SURP-2. *Maize* and *Fruits and Vegetables* are the clear winners from the advanced warning that allows factors to be mobile, while *Beans* benefits under Neutral and La Niña events. Because of the fixed set of resources, the other crops decrease in production. Under PROD-2, *Other Crops*, *Other Grains*, and *Wheat* still experience declines, but not as dramatically so.

Table 19. Change in Mean Value of Output under MOB-2, by crop and by ENSO phase.
(percentage change from SURP-2)

	El Niño	Neutral	La Niña
Maize	16.3	0.4	13.8
Wheat	-6.0	-3.8	-6.2
Beans	-3.0	2.0	2.8
Other Grain	-10.7	-5.1	-15.0
Fruit & Veg	6.5	10.8	19.1
Other Crop	-10.7	-5.1	-15.0
Total	**2.2**	**3.1**	**6.1**

ii. Regional Crops and Income

The benchmark for comparing crop changes under the two ENSO scenarios is the neutral scenario, in which agriculture is subject to random shocks from agriculture, but without any ENSO-specific effects. Some crops benefit from an ENSO event in one region, but lose in another region, due to a combination of weather and technology effects, as well as price effects. Table 20 shows how an El Niño event impacts individual summer crops for three regions under the surprise scenario (SURP-2). Whereas the Pacific South and South East regions lose mean crop value for each crop and for their total mean crop value under an El Niño event, the North Central region gains overall, since *maize* and *fruits and vegetables* rise in mean output. These two crops have positive coefficients for the low rainfall dummy in the SUR analysis, which is explained by their high reliance on irrigated land (which thus cushions them from droughts). This enables North Central to take advantage of the relative rise in producer prices for these crops, caused by the shortfall in other regions. A similar explanation can be made for the increase in production in North West, due to a rise in *other crops* production in both seasons. In all other regions, the activity price (which is specific to the region) for *other crops* rises in response to falling output during an El Niño event, which leads to the rise in the producer price.

Even when there is a large difference in output under the different ENSO scenarios, most households are well-protected from income losses, because they derive so much of their income from non-farm activity. Table 21 shows the percentage change in income for selected households under each ENSO event, compared to the Neutral event, under the surprise scenario (SURP-2). Of the poorest households, those in the Pacific South experience the greatest losses, which are just 1.5% less from an El Niño event than from the neutral event, and down almost 1% under a La Niña event. In the same region, medium households, who earn over one-third of their income from farm activities, lose 1.9% percent more income under an El Niño event. The rich households in the Pacific South also lose from an El Niño event, losing 1.1% compared to the Neutral event.

Table 20. Value of Crop Changes from El Niño

Summer Season

Simulation SURP-2 (percent deviation from Neutral)

North Central	
Maize	23
Bean	-1
Other Grains	-3
Fruit & Veg	9
Other Crops	-11
Total	**2**
Pacific South	
Maize	-3
Other Grains	-5
Fruit & Veg	-15
Other Crops	-16
Total	**-7**
South East	
Maize	-21
Other Grains	-25
Fruit & Veg	-21
Other Crops	-26
Total	**-18**

Table 21. Mean Household Income Change from ENSO
Simulation SURP-2
(percent deviation from Neutral).

	El Niño	La Niña
North West		
Poor	-0.43	-0.69
Medium	-0.27	-0.78
Rich	1.00	-1.39
Pacific South		
Poor	-1.50	-0.95
Medium	-1.93	-1.15
Rich	-1.14	-0.30

Some households are even better off during ENSO events than under the neutral situation. For example, rich households in North Central experience a 2.5% increase in income during a La Niña event under SURP-2. This result is primarily because irrigated land in the summer receives much higher returns under a La Niña event, due to a shifting of resources toward *other crops* production. Rich households in North West gain about one percent under an El Niño event when it is unforeseen, again because of an increase in irrigated land returns in the winter. Production increases in winter *wheat* and *other crops* are the source of the land return increases.

All poor and medium households see a slight decreases in their incomes during either an El Niño event or a La Niña event and the surprise scenario. Those in Pacific South and South East experience the highest declines compared to a Neutral event. Worst off among poor households are those in the South East under an El Niño event, losing 1.5% of income. Among medium households, the biggest losers are in Pacific South losing nearly 2% of income.

Not all households experience income increases when the agricultural factors are mobile under MOB-2. In particular, rural poor households in Central lose less than half a percent of income under MOB-2, compared to the surprise scenario, SURP-2. Rural rich households in Central lose 0.9% more under a La Niña event, 1.7% more under an El Niño event, and 2.4% more under a Neutral event, compared to the surprise scenario. This result is due to slight decreases in the returns to agricultural labor and irrigated land. For the most part, the rest of the households do gain when MOB-2 is enacted, and they gain even more with the enhanced productivity of PROD-2. Table 22 shows the percent changes in income for poor rural households compared to the surprise scenario, under different phases in the ENSO cycle, under two preparedness scenarios. While rich households do not always fare better than their poor counterparts following MOB-2 (such as the rich households in Central), under the productivity boost of PROD-2, they do much better. For example, rich households in the North West see increases of 12.3% under El Niño events and 14.6% under La Niña events, compared to the increases of poor households in that region, of 3.1% and 5.7%, respectively. This is because of the dramatic increase in the production of *fruits and vegetables*, an activity which most benefits rich households.

A comparison of the coefficients of variation shows that income variability is not affected much by the phase of the ENSO cycle. This finding occurs because even in the neutral phase, there is still variability in the system. Indeed, Section C below will compare the sources of variability in greater detail. In all ENSO events, the richest rural households, with the exception of those in South East, experience the highest income variability, because they depend most on agricultural factors of production. Table 23 shows income variability under a neutral event for the surprise scenario, SURP-2, which is similar to the results for an El Niño or La Niña event.

Table 22. Income Changes to Poor Households, by type of ENSO event and level of preparedness
(percentage change from SURP-2)

		MOB-2	PROD-2
North West			
	El Nino	0.09	3.13
	Neutral	0.95	6.11
	La Nina	1.83	5.66
North Central			
	El Nino	0.07	1.83
	Neutral	0.32	2.92
	La Nina	0.32	2.18
Central			
	El Nino	-0.39	1.06
	Neutral	-0.34	2.95
	La Nina	-0.22	1.03
Pacific South			
	El Nino	-0.41	2.60
	Neutral	0.45	5.17
	La Nina	0.49	3.83
South East			
	El Nino	-0.04	2.00
	Neutral	0.36	3.71
	La Nina	0.70	2.93

Table 23. Income Variability under Neutral Event.
Experiment SURP-2. (Coefficient of Variation, %)

	PROD-2
Urban	
Urban Poor	0.00
Urban Medium	0.00
Urban Rich	0.00
North West	
Rural Poor	0.03
Rural Medium	0.03
Rural Rich	0.08
North Central	
Rural Poor	0.01
Rural Medium	0.03
Rural Rich	0.06
Central	
Rural Poor	0.04
Rural Medium	0.03
Rural Rich	0.11
Pacific South	
Rural Poor	0.02
Rural Medium	0.04
Rural Rich	0.06
South East	
Rural Poor	0.03
Rural Medium	0.04
Rural Rich	0.03

iii. Non-Agricultural Output and Urban Incomes

Since *national* agricultural output does not change dramatically following either ENSO event, the spillover to urban production is slight. In either case, *sugar manufacturing* takes the biggest hit, falling by almost 1% under an El Niño event and by 1.4% under a La Niña event in the surprise scenario (SURP-2). This is due to the decline in the production of *other crops*, which includes raw sugar. Even in this case, the fall is tempered by the increase in imports and decrease in exports, allowing for more *sugar manufacturing* to reach the market. Indeed, trade in raw agricultural products appears to compensate for many of the changes in domestic production.

As a result, urban production sees very few changes among sectors, and as a whole, it stays about the same. This outcome implies that urban wages barely change, and thus urban incomes are not strongly affected by ENSO events. As seen in Table 23, variation as a percentage of income is negligible.

C. Experiment Set 3. Comparsion of Sources of Variability

In this section, an El Niño event is simulated with the no-reaction scenario, under two different types of random shocks. In the first simulation, SURP-GEN, the only random effect on agriculture comes from general agricultural variability; it is assumed that the ENSO effects on rainfall are perfectly predicted. The second simulation, SURP-ENSO, tests the opposite case in which there is no variability from agriculture *per se*, and the only source of variability comes from the uncertain relationship between an El Niño event and rainfall. The comparison between these two simulations helps clarify which source of risk is more important, and thus sheds light on where to focus policy efforts.

The variability of agricultural output, measured using the coefficient of variation, is generally much greater under SURP-GEN than under SURP-ENSO. This result is to be expected, given the nature of the two types of random shocks: the agricultural shock directly feeds into agricultural output, while the ENSO shock affects the rain variable and only affects agricultural output if it helps the rain variable reach the threshold of "too much" or "too little" rain. While there is a robust connection between ENSO and seasonal rainfall, the effect of rain on agriculture is much weaker. Thus while the coefficient of variation ranges from 0 to 38% for the value of national commodity output under SURP-GEN, it only ranges from 0 to 4% under SURP-ENSO. Table 24 presents the variability for commodities.

As expected, agricultural variability is also responsible for the bulk of volatility in income, as seen in Table 25. However, because of the varied sources of income, the volatility in income is not as dramatic as the volatility in agriculture. These results suggest that while improving ENSO forecasting is important for minimizing risk in agriculture, it is even more important to help farmers with general uncertainties related to agriculture.

Table 24. Sources of Variability in Value of Commodity Output
(measured by the coefficient of variation)

	SURP-GEN	SURP-ENSO
Maize	26.08	0.90
Wheat	16.41	1.10
Beans	34.77	0.16
Other Grain	8.31	0.58
Fruits & Veg	38.31	1.25
Other Crops	14.75	3.60
Livestock	0.84	0.11
Forestry	1.00	0.14
Dairy	0.41	0.05
Fr & Veg Prep	3.13	0.08
Manuf. Wheat	0.58	0.08
Manuf. Corn	1.43	0.20
Manuf. Sugar	1.77	0.30
Other Food	1.14	0.12
Light Manuf.	0.83	0.13
Intermediates	1.20	0.17
Cons Durables	0.75	0.12
Capital Goods	2.06	0.27
Construction	0.97	0.14
Prof. Services	0.65	0.09
Other Services	0.44	0.07
Commerce	0.77	0.10

Table 25. Sources of Volatility in Income
(measured by coefficient of variation, %)

	SURP-GEN	SURP-ENSO
Urban		
Urban Poor	0.4	0.1
Urban Medium	0.3	0.0
Urban Rich	0.2	0.0
North West		
Rural Poor	2.9	0.3
Rural Medium	3.4	0.4
Rural Rich	8.1	1.4
North Central		
Rural Poor	1.7	0.1
Rural Medium	2.7	0.1
Rural Rich	6.1	0.1
Central		
Rural Poor	4.3	0.3
Rural Medium	3.6	0.2
Rural Rich	12.2	1.1
Pacific South		
Rural Poor	2.4	0.3
Rural Medium	4.1	0.5
Rural Rich	6.4	0.9
South East		
Rural Poor	2.0	0.4
Rural Medium	2.9	0.6
Rural Rich	1.9	0.5

7. Conclusions and Recommendations

This study has used a stochastic CGE model to evaluate the impacts of ENSO events on agriculture in Mexico under different states of preparedness, defined by improvements in forecasting and technology. In each scenario, the model is able to analyze how changes in agriculture affect all production sectors as well as levels of income of various types of households. Particular attention is paid to how poor rural households are affected by ENSO events and the extent to which early warning systems benefit them.

In Mexico, where agriculture is a relatively small part of the national economy, ENSO events do not have a large effect on the total value of economic output. The simulations show almost no net impact on the value of total output, and a small influence even on mean agricultural GDP. Under an El Niño event, about 3.6 billion pesos (around US$410 million) worth of agricultural output is lost, and under a La Niña event, about 3.8 billion pesos (around US$430 million) is lost, according to the simulations. These losses are equal to less than 3% of the total of crop output, valued at 138 billion pesos. Agricultural crop output, in turn, is a just 5% of total output. <u>If the analysis looked solely at the *aggregate* impacts of ENSO events, we would conclude that the economy as a whole is quite robust in the face of such climate shocks.</u>

Though these losses are small as a share of the overall economy, <u>the results show that improved forecasting can eliminate these losses</u>. Under an El Niño event, early warning that allows farmers to change their methods of production (i.e., by moving their factors of production) increases the value of agricultural output by almost 3 billion pesos, and under a La Niña event, that improved information increases the value of agricultural output by over 8 billion pesos. There are clearly large potential gains to reallocating resources during ENSO events. These potential increases in output not only make up for the losses that would have to be endured under a "surprise" scenario, but may leave resources to spare.

<u>The simulations also show that early warning systems can play a large role in attenuating negative impacts from random events, ENSO-induced or otherwise</u>. All of the experiments show unambiguous improvements in mean output when factor mobility is allowed. Thus if rural producers are given enough forewarning of weather anomalies to allow them to change their methods of production (i.e., by moving their land, labor, and capital), they may further cushion the negative effects, if not overcome them.

If, in addition to investing in improved early warning systems, agricultural technology is improved to allow for the productivity enhancement demonstrated in these simulations, the benefits are even greater: the value of total agricultural output would increase by 29 billion pesos under an El Niño event and 35 billion pesos under a La Niña event.

The results also show that some regions are affected differently from others, underscoring the importance of regionalizing the agricultural components of the model. This result also suggests that policies to ameliorate the negative impacts of ENSO events should be carried out at a regional level. The current study shows that El Niño events have the largest negative impact on agricultural output in three regions of the country, Central, Pacific South and South East, with the mean value of losses from 4.5% to 18%. Agricultural output in these regions feel the biggest losses under La Niña events, with the mean value of losses from 5% to 12.2%. Improved forecasting has the biggest positive impacts for agricultural production in these regions. The North Central and North West regions, using more irrigated-intensive technologies, are more impervious to rain fluctuations, and thus their losses from a surprise event are always lower. And, within the regions, producers of some crops can take advantage of the production shortfalls left by the other regions by increasing output and receiving a higher price. Finally, the urban region sees very little change in mean output or mean incomes as a result of either ENSO event. <u>Since the regions most negatively affected by ENSO events – Central, Pacific South, and South East – are also the regions with higher poverty, policy makers who are concerned with alleviating the effects of ENSO events on the poor should focus policy efforts on these regions.</u>

The simulations also demonstrate the need to regionalize households and categorize them by income. Different households are, indeed, affected differently, depending on their sources of income and geographic area. <u>Generally, poor households are the least able to take advantage of improvements in forecasting, since at higher levels of preparedness agricultural production shifts to sectors from which poor households receive less income</u>. Rich households in the North and Central are the beneficiaries of El Niño events that hurt the rest of the country, including mean income declines to rich households in the other rural regions. The rural rich households in Central are the sole beneficiaries of La Niña events, though the losses are not great for any households. Urban households feel no significant effects on their mean incomes.

Adding a stochastic component to the CGE framework allows us break apart the sources of volatility to agricultural production and determine their relative importance. <u>In the case of Mexico, rural households have a built-in safety net to income volatility in that they receive income from a wide range of sources.</u> Thus, even poor households are somewhat less vulnerable to agricultural production swings than in other developing countries, since they rely less heavily on agricultural-based income. Nonetheless, the household disaggregation of this model, in which "poor" rural households are defined as those with the bottom 40% of national income, may be hiding what is occurring to the very poorest households. Since extremely poor households rely much more heavily on agricultural income, including home consumption, it is likely that they are more adversely affected by ENSO events. In addition, some of the poorest farming households probably are least likely to be able to adapt to ENSO-induced weather conditions. Even if weather is properly forecast, they may not be able afford technologies which would counteract adverse weather, or they may not be able to switch their crop mix or input mix. <u>Longer term policies – such as income supports and rural development schemes to produce off-farm employment – must be enacted in order to ensure that *all* types of households can take advantage of information from improved forecasting</u>.

In Mexico, agriculture is more adversely affected from general variability to agricultural production than variability caused by ENSO events. It might be better to focus efforts on the former problem, in terms of improved agricultural seeds, extension services, and schemes to protect already fragile lands. To some extent, the *PROCAMPO* program, which gives decoupled income support to farmers in Mexico, has helped in this regard.[30] These efforts would have the additional benefit of helping to attenuate the effects of ENSO events, predicted or not.

There are ways to improve this study, starting with improved data on relationship between ENSO and agriculture. There is some work being done on specific crops on "representative" farms in Mexico (i.e., Tiscareño *et al*, 2000). Ideally, a farm model would have the same disaggregation of sectors as the CGE model and the "representative farms" of the farm model would be representative of the regions of the CGE model. If the results from a more precise farm model led to more dramatic effects in the CGE model, it would also be worthwhile to incorporate a migration module to incorporate movements of people both internally as well as internationally. This, too, would require more knowledge on the effects of ENSO on migration.

Is this modeling framework appropriate for other countries? The current model is a suitable analytical tool for any country in which ENSO events have large direct or indirect effects on the economy. It allows the analyst to determine where the impacts occur and which social or productive sectors are harmed, as well as points out the beneficiaries. In addition, in countries with different regional effects, this type of model helps to determine the extent to which policy efforts should be regionalized. This framework also highlights where policy change can be most effective and can shed light on the relative returns to different policy interventions.

However, multisectoral modeling is a very data-intensive exercise, compounded by the dearth of information on key factors conditioning the impacts of ENSO events. A thorough analysis of the effects of ENSO events requires in-depth research on agricultural technology, specifying clearly the relationships between inputs and outputs and how those relationships are effects by changes in weather. The connection between ENSO events and weather conditions, including rainfall (both amount and distribution), sunlight, humidity, and other factors not included in the current study, should also be specified. This underscores the need for social scientists and climatologists to work more closely together in order to fully capture the linkages between ENSO events and socio-economic impacts

[30] See Harris (2001) for a description of the *PROCAMPO* program.

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Appendices

Appendix Table 1. Value-added by crop percentages)

NORTH WEST	Winter					Summer			
	Maize	Wheat	Oth.Grain	Fruit & Veg	Oth.Crop	Oth. Grain	Fruit & Veg	Oth.Crop	
Ag. Labor	26	30	28	45	31	26	31	22	
Non-Irrigated Land	0	0	0	1	11	29	0	4	
Irrigated Land	59	46	48	29	58	27	51	60	
Ag. Capital	15	24	24	24	0	19	19	14	
NORTH CENTRAL	Winter			Summer					
	Oth.Grain	Fruit & Veg	Oth.Crop	Maize	Beans	Oth.Grain	Fruit & Veg	Oth.Crop	
Ag. Labor	27	36	37	18	23	18	32	27	
Non-Irrigated Land	40	3	5	32	51	58	0	21	
Irrigated Land	12	42	36	49	10	13	50	40	
Ag. Capital	22	19	22	1	16	11	17	12	
CENTRAL	Winter			Summer					
	Oth.Grain	Fruit & Veg	Oth.Crop	Maize	Beans	Oth.Grain	Fruit & Veg	Oth.Crop	
Ag. Labor	18	30	16	25	19	23	32	34	
Non-Irrigated Land	12	2	0	39	43	50	14	0	
Irrigated Land	56	58	71	20	26	8	29	48	
Ag. Capital	14	10	13	16	12	20	25	18	
PACIFIC SOUTH	Winter					Summer			
	Maize	Wheat	Oth.Grain	Fruit & Veg	Oth.Crop	Maize	Oth.Grain	Fruit & Veg	Oth.Crop
Ag. Labor	34	27	29	42	37	36	30	35	47
Non-Irrigated Land	12	22	42	43	13	25	46	22	15
Irrigated Land	53	30	9	15	22	5	4	11	11
Ag. Capital	1	20	19	0	28	35	19	32	27
SOUTH EAST	Winter				Summer				
	Maize	Oth.Grain	Fruit & Veg	Oth.Crop	Maize	Oth.Grain	Fruit & Veg	Oth.Crop	
Ag. Labor	45	17	51	45	41	22	36	41	
Non-Irrigated Land	30	70	41	41	59	60	27	28	
Irrigated Land	10	0	8	13	0	4	3	1	
Ag. Capital	15	12	0	0	0	15	34	29	

Appendix Table 2. Equations of CGE Model

SETS

Symbol	Explanation	Symbol	Explanation
$a \in A$	activities	$c \in CMN(\subset C)$	commodities not in *CM*
$c \in C$	commodities	$f \in F$	factors
$c \in CD(\subset C)$	commodities with domestic sales of domestic output	$i \in INS$	institutions (domestic and rest of world)
$c \in CDN(\subset C)$	commodities not in *CD*	$i \in INSD(\subset INS)$	domestic institutions
$c \in CE(\subset C)$	exported commodities	$i \in INSDNG(\subset INSD)$	domestic non-government institutions
$c \in CEN(\subset C)$	commodities not in *CE*	$h \in H(\subset INSDNG)$	households
$c \in CM(\subset C)$	imported commodities		

PARAMETERS

$cwts_c$	weight of commodity c in the CPI	$\overline{qinv}_c$	base-year quantity of private investment demand
$dwts_c$	weight of commodity c in the producer price index	$shif_{if}$	share for domestic institution i in income of factor f
ica_{ca}	quantity of c as intermediate input per unit of activity a	$shii_{ii'}$	share of net income of i' to i (i' ∈ INSDNG'; i ∈ INSDNG)
$icd_{cc'}$	quantity of commodity c as trade input per unit of c' produced and sold domestically	ta_a	tax rate for activity a
$ice_{cc'}$	quantity of commodity c as trade input per exported unit of c'	te_c	export tax rate
$icm_{cc'}$	quantity of commodity c as trade input per imported unit of c'	tf_f	direct tax rate for factor f
$inta_a$	quantity of aggregate intermediate input per activity unit	$\overline{tins}_i$	exogenous direct tax rate for domestic institution i
iva_a	quantity of aggregate intermediate input per activity unit	$tins01_i$	0-1 parameter with 1 for institutions with potentially flexed direct tax rates
$\overline{mps}_i$	base savings rate for domestic institution i	tm_c	import tariff rate
$mps01_i$	0-1 parameter with 1 for institutions with potentially flexed direct tax rates	tq_c	rate of sales tax
pwe_c	export price (foreign currency)	$trnsfr_{i\,f}$	transfer from factor f to institution i
pwm_c	import price (foreign currency)	tva_a	rate of value-added tax for activity *a*
$qdst_c$	quantity of stock change	x_{ag}^{A}	random agricultural shock
$\overline{qg}_c$	base-year quantity of government demand	x_{ag}^{R}	random rain shock

cont. Appendix Table 2

PARAMETERS (Greek)			
a_a^a	efficiency parameter in the CES activity function	d_c^t	CET function share parameter
a_c^{ac}	shift parameter for domestic commodity aggregation function	g_{ch}^m	subsistence consumption of marketed commodity c for household h
a_c^q	Armington function shift parameter	g_{ach}^h	subsistence consumption of home commodity c from activity a for household h
a_c^t	CET function shift parameter	q_{ac}	yield of output c per unit of activity a
b_{ach}^h	marginal share of consumption spending on home commodity c from activity a for household h	r_a^a	CES production function exponent
b_{ch}^m	marginal share of consumption spending on marketed commodity c for household h	r_c^{ac}	domestic commodity aggregation function exponent
d_a^a	CES activity function share parameter	r_c^q	Armington function exponent
d_{ac}^{ac}	share parameter for domestic commodity aggregation function	r_c^t	CET function exponent
d_c^q	Armington function share parameter		

EXOGENOUS VARIABLES			
$\overline{CPI}$	consumer price index	$\overline{MPSADJ}$	savings rate scaling factor (= 0 for base)
$\overline{DTINS}$	change in domestic institution tax share (= 0 for base; exogenous variable)	$\overline{QFS}_f$	quantity supplied of factor
$\overline{FSAV}$	foreign savings (FCU)	$\overline{TINSADJ}$	direct tax scaling factor (= 0 for base; exogenous variable)
$\overline{GADJ}$	government consumption adjustment factor	$\overline{WFDIST}_{fa}$	wage distortion factor for factor f in activity a
$\overline{IADJ}$	investment adjustment factor		

ENDOGENOUS VARIABLES			
DPI	producer price index for domestically marketed output	PE_c	export price (domestic currency)
EG	government expenditures	$PINTA_a$	aggregate intermediate input price for activity
EH_h	consumption spending for household	PM_c	import price (domestic currency)
EXR	exchange rate (LCU per unit of FCU)	PQ_c	composite commodity price
$GOVSHR$	government consumption share in nominal absorption	PVA_a	value-added price (factor income per unit of activity)
$GSAV$	government savings	PX_c	aggregate producer price for commodity
$INVSHR$	investment share in nominal absorption	$PXAC_{ac}$	producer price of commodity c for activity a
MPS_i	marginal propensity to save for domestic non-government institution (exogenous variable)	QA_a	quantity (level) of activity
PA_a	activity price (unit gross revenue)	QD_c	quantity sold domestically of domestic output
PDD_c	demand price for commodity produced and sold domestically	QE_c	quantity of exports
PDS_c	supply price for commodity produced and sold domestically	QF_{fa}	quantity demanded of factor f from activity a

cont. Appendix Table 2			
QG_c	government consumption demand for commodity	$QXAC_{ac}$	quantity of output of commodity c from activity a
QH_{ch}	quantity consumed of commodity c by household h	$TABS$	total nominal absorption
QHA_{ach}	quantity of household home consumption of commodity c from activity a for household h	$TINS_i$	direct tax rate for institution i (i $\in$ INSDNG)
$QINTA_a$	quantity of aggregate intermediate input	$TRII_{ii'}$	transfers from institution i' to i (both in the set INSDNG)
$QINT_{ca}$	quantity of commodity c as intermediate input to activity a	WF_f	average price of factor
$QINV_c$	quantity of investment demand for commodity	YF_f	income of factor f
QM_c	quantity of imports of commodity	YG	government revenue
QQ_c	quantity of goods supplied to domestic market (composite supply)	YI_i	income of domestic non-government institution
QVA_a	quantity of (aggregate) value-added	YIF_{if}	income to domestic institution i from factor f
QX_c	aggregated quantity of domestic output of commodity		

cont. Appendix Table 2

EQUATIONS

#	Equation	Domain	Description
Price Block			
1	$PM_c = pwm_c \cdot (1 + tm_c) \cdot EXR$	$c \in CM$	Import Price
2	$PE_c = pwe_c \cdot (1 - te_c) \cdot EXR$	$c \in CE$	Export Price
3	$PDD_c = PDS_c$	$c \in CD$	Demand price of domestic non-traded goods
4	$PQ_c \cdot (1 - tq_c) \cdot QQ_c = PDD_c \cdot QD_c + PM_c \cdot QM_c$	$c \in (CD \cup CM)$	Absorption
5	$PX_c \cdot QX_c = PDS_c \cdot QD_c + PE_c \cdot QE_c$	$c \in C$	Marketed Output Value
6	$PA_a = \sum_{c \in C} PXAC_{ac} \cdot \boldsymbol{q}_{ac}$	$a \in A$	Activity Price
7	$PINTA_a = \sum_{c \in C} PQ_c \cdot ica_{ca}$	$a \in A$	Aggregate intermediate input price
8	$PA_a \cdot (1 - ta_a) \cdot QA_a = PVA_a \cdot QVA_a + PINTA_a \cdot QINTA_a$	$a \in A$	Activity revenue and costs
9	$\overline{CPI} = \sum_{c \in C} PQ_c \cdot cwts_c$		Consumer price index
10	$DPI = \sum_{c \in C} PDS_c \cdot dwts_c$		Producer price index for non-traded market output
Production and commodity block			
11	$QVA_a = x_a^A \cdot x_a^R \cdot \boldsymbol{a}_a^{va} \cdot \left(\sum_{f \in F} \boldsymbol{d}_{fa}^{va} \cdot QF_{fa}^{-r_a^{va}} \right)^{-\frac{1}{r_a^{va}}}$	$a \in A$	Value-added and factor demands
12	$PA_a \cdot (1 - ta_a) \cdot QA_a = PVA_a \cdot QVA_a + PINTA_a \cdot QINTA_a$	$a \in A$	Aggregate value-added function
13	$W_f \cdot \overline{WFDIST}_{fa} = PVA_a \cdot (1 - tva_a) \cdot QVA_a \cdot \left(\sum_{f \in F'} \boldsymbol{d}_{fa}^{va} \cdot QF_{fa}^{-r_a^{va}} \right)^{-1} \cdot \boldsymbol{d}_{fa}^{va} \cdot QF_{fa}^{-r_a^{va}-1}$	$a \in A$ $f \in F$	Factor demand
14	$QVA_a = iva_a \cdot QA_a$	$a \in A$	Demand for aggregate value-added
15	$QINTA_a = inta_a \cdot QA_a$	$a \in A$	Demand for aggregate intermediate input

cont. Appendix Table 2

16	$QINT_{c\,a} = ica_{c\,a} \cdot QINTA_{a}$	$a \in A$ $c \in C$	Disaggregated intermediate input demand
17	$QXAC_{a\,c} + \sum_{h \in H} QHA_{a\,c\,h} = \boldsymbol{q}_{a\,c} \cdot QA_{a}$	$a \in A$ $c \in C$	Commodity production and allocation
18	$QX_{c} = \boldsymbol{a}_{c}^{ac} \cdot \left(\sum_{a \in A} \boldsymbol{d}_{a\,c}^{ac} \cdot QXAC_{a\,c}^{-r_{c}^{ac}} \right)^{-\frac{1}{r_{c}^{ac}-1}}$	$c \in C$	Output Aggregation Function
19	$PXAC_{a\,c} = PX_{c} \cdot QX_{c} \left(\sum_{a \in A'} \boldsymbol{d}_{a\,c}^{ac} \cdot QXAC_{a\,c}^{-r_{c}^{ac}} \right)^{-1} \cdot \boldsymbol{d}_{a\,c}^{ac} \cdot QXAC_{a\,c}^{-r_{c}^{ac}-1}$	$a \in A$ $c \in C$	First-Order Condition for Output Aggregation Function
20	$QX_{c} = \boldsymbol{a}_{c}^{t} \cdot \left(\boldsymbol{d}_{c}^{t} \cdot QE_{c}^{r_{c}^{t}} + (1-\boldsymbol{d}_{c}^{t}) \cdot QD_{c}^{r_{c}^{t}} \right)^{\frac{1}{r_{c}^{t}}}$	$c \in (CE \cap CD)$	Output Transformation (CET) Function
21	$\frac{QE_{c}}{QD_{c}} = \left(\frac{PE_{c}}{PDS_{c}} \cdot \frac{1-\boldsymbol{d}_{c}^{t}}{\boldsymbol{d}_{c}^{t}} \right)^{\frac{1}{r_{c}^{t}-1}}$	$c \in (CE \cap CD)$	Export-Domestic Supply Ratio
22	$QX_{c} = QD_{c} + QE_{c}$	$c \in$ $(CD \cap CEN)$ $\cup$ $(CE \cup CDN)$	Output Transformation for Non-Exported Commodities
23	$QQ_{c} = \boldsymbol{a}_{c}^{q} \cdot \left(\boldsymbol{d}_{c}^{q} \cdot QM_{c}^{-r_{c}^{q}} + (1-\boldsymbol{d}_{c}^{q}) \cdot QD_{c}^{-r_{c}^{q}} \right)^{-\frac{1}{r_{c}^{q}}}$	$c \in (CM \cap CD)$	Composite Supply (Armington) Function
24	$\frac{QM_{c}}{QD_{c}} = \left(\frac{PDD_{c}}{PM_{c}} \cdot \frac{\boldsymbol{d}_{c}^{q}}{1-\boldsymbol{d}_{c}^{q}} \right)^{\frac{1}{1+r_{c}^{q}}}$	$c \in (CM \cap CD)$	Import-Domestic Demand Ratio
25	$QQ_{c} = QD_{c} + QM_{c}$	$c \in$ $(CD \cap CMN)$ $\cup$ $(CM \cap CDN)$	Composite Supply for Non-Imported Outputs and Non-Produced Imports
26	$QT_{c} = \sum_{c' \in C'} \left(icm_{c\,c'} \cdot QM_{c'} + ice_{c\,c'} \cdot QE_{c'} + icd_{c\,c'} \cdot QD_{c'} \right)$	$c \in CT$	Demand for Transactions Services

cont. Appendix Table 2

Institution block			
27	$YF_f = \sum_{a \in A} WF_f \cdot \overline{WFDIST}_{f\,a} \cdot QF_{f\,a}$	$f \in F$	Factor Income
28	$YIF_{i\,f} = shif_{i\,f} \cdot \left[\left(1 - tf_f\right) \cdot YF_f - trnsfr_{row\,f} \cdot EXR\right]$	$i \in INSD$ $f \in F$	Institutional factor incomes
29	$YI_i = \sum_{f \in F} YIF_{i\,f} + \sum_{i' \in INSDNG'} TRII_{i\,i'} + trnsfr_{i\,gov} \cdot \overline{CPI} + trnsfr_{i\,row} \cdot EXR$	$i \in INSDNG$	Income of domestic, non-government institutions
30	$TRII_{i\,i'} = shii_{i\,i'} \cdot (1\text{-}MPS_{i'}) \cdot (1\text{-}TINS_{i'}) \cdot YI_{i'}$	$i \in INSDNG$ $i' \in INSDNG'$	Intra-Institutional Transfers
31	$EH_h = \left(1 - \sum_{i \in INSDNG} shii_{i\,h}\right) \cdot \left(1 - MPS_h\right) \cdot (1\text{-}TINS_h) \cdot YI_h$	$h \in H$	Household Consumption Expenditure
32	$QH_{c\,h} = g_{c\,h} + \dfrac{b^m_{ch} \cdot \left(EH_h - \sum_{c' \in C} PQ_{c'} \cdot g^m_{c'h} - \sum_{a \in A} \sum_{c' \in C} PXAC_{ac'} \cdot g^h_{ac'h}\right)}{PQ_c}$	$c \in C$ $h \in H$	Household Consumption Demand for Marketed commodities
33	$QHA_{ach} = g^h_{ach} + \dfrac{b^h_{ach} \cdot \left(EH_h - \sum_{c' \in C} PQ_{c'} \cdot g^m_{c'h} - \sum_{a \in A} \sum_{c' \in C} PXAC_{ac'} \cdot g^h_{ac'h}\right)}{PXAC_{ac}}$	$a \in A$ $c \in C$ $h \in H$	Household Consumption Demand for Home Commodities
34	$QINV_c = \overline{IADJ} \cdot \overline{qinv}_c$	$c \in CINV$	Investment Demand
35	$QG_c = \overline{GADJ} \cdot \overline{qg}_c$	$c \in C$	Government Consumption Demand
36	$YG = \sum_{i \in INSDNG} TINS_i \cdot YI_i + \sum_{f \in F} tf_f \cdot YF_f + \sum_{a \in A} tva_a \cdot PVA_a \cdot QVA_a$ $+ \sum_{a \in A} ta_a \cdot PA_a \cdot QA_a + \sum_{c \in CM} tm_c \cdot pwm_c \cdot QM_c \cdot EXR + \sum_{c \in CE} te_c \cdot pwe_c \cdot QE_c \cdot EXR$ $+ \sum_{c \in C} tq_c \cdot PQ_c \cdot QQ_c + \sum_{f \in F} YF_{gov\,f} + trnsfr_{gov\,row} \cdot EXR$		Government Revenue
37	$EG = \sum_{c \in C} PQ_c \cdot QG_c + \sum_{i \in INSDNG} trnsfr_{i\,gov} \cdot \overline{CPI}$		Government Expenditures
System Constraint Block			
38	$\sum_{a \in A} QF_{f\,a} = \overline{QFS}_f$	$f \in F$	Factor market

cont. Appendix Table 2.

39	$QQ_c = \sum_{a \in A} QINT_{c\,a} + \sum_{h \in H} QH_{c\,h} + QG_c + QINV_c + qdst_c$	$c \in C$	Composite Commodity Markets
40	$\sum_{c \in CM} pwm_c \cdot QM_c + \sum_{f \in F} trnsfr_{row\,f} = \sum_{c \in CE} pwe_c \cdot QE_c + \sum_{i \in INSD} trnsfr_{irow} + \overline{FSAV}$		Current Account Balance for RoW (in Foreign Currency)
41	$YG = EG + GSAV$		Government Balance
42	$TINS_i = \overline{tins}_i \cdot \left(1 + \overline{TINSADJ} \cdot tins01_i\right) + \overline{DTINS} \cdot tins01_i$	$i \in INSDNG$	Direct institutional tax rates
43	$MPS_i = \overline{mps}_i \cdot \left(1 + \overline{MPSADJ} \cdot mps01_i\right) + DMPS \cdot mps01_i$	$i \in INSDNG$	Institutional savings rates
44	$\sum_{i \in INSDNG} MPS_i \cdot (1 - TINS_i) \cdot YI_i + GSAV + EXR \cdot \overline{FSAV} =$ $\sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c$		Savings-Investment Balance
45	$TABS = \sum_{h \in H} \sum_{c \in C} PQ_c \cdot QH_{c\,h} + \sum_{a \in A} \sum_{c \in C} \sum_{h \in H} PXAC_{ac} \cdot QHA_{ach}$ $+ \sum_{c \in C} PQ_c \cdot QG_c + \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c$		Total Absorption
46	$INVSHR \cdot TABS = \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c$		Ratio of Investment to Absorption
47	$GOVSHR \cdot TABS = \sum_{c \in C} PQ_c \cdot QG_c$		Ratio of Government Consumption to Absorption

Appendix Table 3. SUR results. Effect of rainfall dummies on crop yields, by region and season, in percentage changes, with R^2 for each equation.
(An asterisk denotes significance at the 90% confidence level)

	Rainfall Dummies		
	"High"	"Low"	R^2
NORTH WEST			
Winter			
Maize	-0.2	5.2	0.00
Wheat	7.9	-1.2	0.02
Other Grain	15.1	-34.5	0.23
Fruit & Veg	3.2	4.9	0.04
Other Crop	50.4*	-27.3	0.05
Summer			
Other Grain	4.1	6.9	0.31
Fruit & Veg	16.1*	-11.1	0.31
Other Crop	-38.4*	10	0.09
NORTH CENTRAL			
Winter			
Other Grain	15.9	7.7*	0.02
Fruit & Veg	-8.4	0.5*	0.10
Other Crop	20.1	-0.5	0.38
Summer			
Maize		34.1*	0.46
Beans		-0.8	0.02
Other Grain		-0.6	0.01
Fruit & Veg		14.1	0.00
Other Crop		-16.6	0.00
CENTRAL			
Winter			
Other Grain	16.5*	-6.5	0.07
Fruit & Veg	3.9	-0.7	0.10
Other Crop	-15.2	43.9	0.14
Summer			
Maize	4.7	-4.9	0.00
Beans	-2.4	0.1	0.02
Other Grain	-2.3	9.2	0.07
Fruit & Veg	-18.6*	0.9	0.38
Other Crop	-29	-44.2	0.04

cont. Appendix Table 3.

	Rainfall Dummies		
	"High"	"Low"	R2
PACIFIC SOUTH			
Winter			
Maize	-3	4.2	0.01
Wheat	-11.2	-3	0.15
Other Grain	10.5*	-7.4	0.08
Fruit & Veg	-6.5	-0.1	0.12
Other Crop	-15.1	-22.4	0.16
Summer			
Maize	-8.6	-4.9	0.01
Other Grain	-8.1	-5.5	0.07
Fruit & Veg	-2	-20.8*	0.08
Other Crop	-48.8	-22.4*	0.13
SOUTH EAST			
Winter			
Maize	12	-1.2	0.09
Other Grain	-18.4	5.5	0.08
Fruit & Veg	-6.7	-6.1	0.07
Other Crop	-69.7	-22.4*	0.15
Summe r			
Maize	-0.6	-6.6	0.05
Other Grain	17.0*	-8.5	0.23
Fruit & Veg	7.3	-20.8	0.02
Other Crop	-26.3	-22.4	0.18

Appendix 4. Model Validation

There are very few studies to verify the relationships between ENSO events and Mexican agriculture found in this study. Although Magaña (1999) cites a figure that 2 million tons of basic grains were lost in 1997, that entire change cannot be contributed solely to the El Niño event of 1997/98, nor even to other weather phenomenon occurring then. Surely other factors, nationally and worldwide, contributed to this loss. Indeed a report by the U.S. Department of Agriculture's Foreign Agricultural Service in 1997 suggested that the economy was still experiencing "adjustment problems" from the recent liberalization of the agricultural sector and economy-wide changes. Isolating the effects of ENSO events on agriculture must be done through a modeling exercise.

One such model is the EPIC model by Rosenberg, *et al* (1997), referred to in the main text of this paper. Unfortunately, it is difficult to compare the results of this very thorough crop growth simulation model with the SUR regressions used in the CGE model for two reasons: First, the crops are disaggregated much differently. In the EPIC model of Mexico, only three types of crops are simulated: maize, wheat, and beans. And, they are themselves divided by land-type used, so that there is an irrigated maize crop, a non-irrigated maize crop, and so on. The CGE sectors, as noted earlier, combine land use so that there is only one type of maize which uses both irrigated and non-irrigated land. Furthermore, the sectors in the CGE model are divided by season, such that there is a winter maize crop and a summer maize crop. The second factor making it difficult to use the results of the EPIC model for validating the SUR results is that the regions are defined differently. The EPIC model has 32 "representative" farms scattered throughout the country, whereas the CGE model contains 5 regions, encompassing the entire country. A further difficulty of comparing the results is that the Rosenberg, *et al*, study looks at four phases of the ENSO cycle: Neutral, El Niño, Severe El Niño, and La Niña.

Nevertheless, the results from Rosenberg, *et al*, may at least give some idea of the qualitative or directional results of this study. Appendix Table 4 reports the results from Rosenberg, *et al*, for maize yield as a percentage deviation from Neutral. For ease of comparison, the representative farms are sorted into the regions of the CGE model. Although these results are not defined by season, they can be compared with the SUR results (in Appendix Table 3) by noting the relationship between the ENSO phase, the season and the change in rainfall. For example, for the summer crops of the CGE model, the "Low" rainfall dummy coefficient is in effect for an El Niño event and the "High" rainfall dummy coefficient is in effect for a La Niña event. Thus, the relevant numbers for comparison for summer maize in the Pacific South for an El Niño year would be –4.9 percent from the SUR regressions (i.e., the coefficient on the "Low" dummy) versus a range from –10.4 to +1.0 percent from Rosenberg, *et al*.

The SUR results were also presented to one of the EPIC modelers, Mario Tiscareño, who was able to comment on some of the crops. With the exception of *other crops* (a sector which is perhaps too broadly defined and was therefore difficult to evaluate), and summer *maize* in North Central, Dr. Tiscareño found that most of the results were "reasonable."

Appendix Table 4. Rosenberg, *et al*, results

	from Rosenberg, *et al*			
Region of CGE model	El Niño	Severe El Niño	La Niña	Land Type
North West	-3.7	-2.6	1.6	non-irrigated
	-2.0	-2.9	4.9	irrigated
	-6.3	-2.5	-2.5	irrigated
North Central	-4.8	-2.4	68.0	non-irrigated
	-15.4	2.3	0.8	non-irrigated
	136.1	-22.2	-12.3	non-irrigated
	0.9	-0.1	1.6	irrigated
	-0.7	0.0	0.6	irrigated
	-0.8	-8.3	2.7	irrigated
	3.1	15.2	6.5	irrigated
Central	1.9	3.2	1.6	non-irrigated
	1.8	-19.6	15.3	non-irrigated
	12.2	19.7	-14.4	non-irrigated
	-40.1	21.6	5.1	non-irrigated
	0.8	0.9	0.9	irrigated
	-29.9	-10.3	-10.3	irrigated
	-5.6	-0.9	1.4	irrigated
Pacific South	-4.2	-4.0	-0.4	non-irrigated
	1.0	-9.9	-1.8	non-irrigated
	-1.8	1.5	3.2	non-irrigated
	-10.4	8.9	-2.2	non-irrigated
	-3.4	-0.4	-4.2	non-irrigated
	0.4	0.2	9.9	irrigated
	-4.1	5.2	-0.8	irrigated
South East	-0.6	-2.9	-1.7	non-irrigated
	-1.3	-5.7	2.8	non-irrigated
	-13.4	-50.5	15.4	non-irrigated
	2.8	13.7	5.9	non-irrigated

Appendix Table 5. SUR results. Effect of ENSO events on rainfall, by region and season (expressed as percentage deviation from Neutral)

	El Niño			**La Niña**	
	winter	summer		winter	summer
North West	6	-3		-4	3
North Central	4	-6		-3	5
Central	7	-2		-6	2
Pacific South	5	-3		-4	3
South East	0	-2		0	2

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