POTENTIAL IMPACTS OF CLIMATE CHANGE ON AGRICULTURE: A CASE OF STUDY OF COFFEE PRODUCTION IN VERACRUZ, MEXICO

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Abstract. This paper explores the relation between coffee production and climatic and economic variables in Veracruz in order to estimate the potential impacts of climate change. For this purpose, an econometric model is developed in terms of those variables. The model is validated by means of statistical analysis, and then used to project coffee production under different climatic conditions. Climate change scenarios are produced considering that the observed trends of climate variables will continue to prevail until the year 2020. An approach for constructing simple probability scenarios for future climate variability is presented and used to assess possible impacts of climate change beyond what is expected from changes in mean values.

The model shows that temperature is the most relevant climatic factor for coffee production, since production responds significantly to seasonal temperature patterns. The results for the projected climate change conditions for year 2020 indicate that coffee production might not be economically viable for producers, since the model indicates a reduction of 34% of the current production.

Although different economic variables (the state and international coffee prices, a producer price index for raw materials for coffee benefit, the national and the USA coffee stocks) were considered as potentially relevant, our model suggests that the state real minimum wage could be regarded as the most important economic variable. Real minimum wage is interpreted here as a proxy for the price of labor employed for coffee production. This activity in Mexico is very labor intensive representing up to 80% of coffee production costs. As expected, increments in the price of such an important production factor increase production costs and have strong negative effects on production. Different assumptions on how real minimum wage could evolve for the year 2020 are considered for developing future production scenarios.

1. Introduction

The Working Group II of the Intergovernmental Panel on Climate Change (IPCC, WGII, 2001), concluded in its Third Assessment Report with "high confidence" (90 to 99% of confidence) that Latin America is highly vulnerable to climate change, given its current low adaptive capacity, particularly to extreme events. In this context, it is also highly probable that the crop yields will diminish significantly, that pests will expand their range and that biodiversity will be highly threatened.

Previous climate change studies for Mexico (Gay et al., 1995, 1996; Gay, 2000) concluded that the country would be likely to experience higher temperatures and hence higher evaporation rates with a doubling of CO_2. Statistical downscaling methods also indicate that summer rainfall might decrease in most of the country and increase during winter in the northern region, similar to those conditions

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experienced during strong El Niño events (Magaña et al., 1997, 1999). The models used to test the sensitivity of different sectors in different regions (Villers et al., 1997; Mendoza et al., 1997; Conde et al., 1997), project that the coastal zones and the northern and central regions could be the most vulnerable to climate change. In those studies, socioeconomic conditions were not taken into account to evaluate the possible social consequences and the possible strategies that could be develop to overcome the climatic change impacts. It is important to notice that this is the first quantitative integrated study to assess the potential impacts of climate change in coffee production in Mexico.

Recent studies on agricultural adaptation (Eakin, 2002; Conde et al., 2003b) have shown that, as far as individual producers' strategies, non-climatic factors are frequently more important than climatic ones (O-Brian et al., 2000). Nevertheless, it is risky to ignore the potential impacts that present and future climate can have on agriculture, especially if climate change occurs, and/or the frequency and intensity of extreme weather events increase. This is particularly dangerous for products that have highly volatile markets and for regions where socioeconomic conditions are deficient, since the producers' vulnerability is already high and their adaptation capacity is limited. This is the case of coffee producers in Veracruz. Until now, climate conditions have not been one of their main concerns because they have to deal with more immediate, imperative threats (such as policy changes and market instability) than climate factors represent today. Nevertheless, climate factors can determine the physical and economical viability for producing a particular crop (Liverman et al., 1991; Conde et al., 1997), depending on how sensitive the crop turns out to be to climate changes and on how significant those changes are for the region.

Kaufmann (2001) proposed a methodology for estimating a hybrid model for corn yield in the United States that integrates social and climatic determinants that correspond to phenological stages of the crop. He states that the main advantage of multiple regression models over crop weather models is that even though the latter simulates yield based on crop physiology, regression models can integrate socioeconomic and physical variables.

Chang (2002) estimated the potential impacts of climate change on 59 crops in 15 regions of Taiwan introducing an econometric model for pool data that integrates climate and economic variables. The effect of climate change in general was positive for vegetables, and negative for pulses and cereals. A similar model specification was used in this paper to estimate the effect of economic variables and the non-monotonic[1] effect of temperature and precipitation changes over crop production. Special attention was paid to the statistical evaluation of the model to show its limitations and strengths. In many cases the importance of statistical evaluation of models is overlooked, and is reduced to testing for autocorrelation in the errors, mostly by checking the Durbin-Watson statistic which is valid only for first order autocorrelation. This is a common but deficient practice that can lead to erroneous conclusions and to not statistically valid results. This paper offers a brief review of some of the tests that are used in econometrics for assessing the statistical quality of models. The issue of multicollineality and its implications is also discussed. The adjusted R squared is proposed as an alternative criterion to infer if regressors should be excluded from the model when the t-statistic becomes unreliable.

This study focuses on the sensitivity of coffee production in Veracruz to changes in temperature and precipitation as well as to changes in economic variables. Afterward, trends and variability of climate variables are analyzed and climate change scenarios are used to asses the potential impact on coffee production. Some possible socioeconomic implications are discussed under these varying conditions.

The results presented here are part of an investigation that is taking place under the AIACC[2] project, which main objective is to make an integrated assessment of social vulnerability and adaptation to climate variability and change. For that purpose, a case study is being developed in the state of Veracruz, Mexico, with an interdisciplinary approach (meteorology, climatology, sociology, economics and biology). For this project key regional stakeholders (producers, decision makers, NGOs leaders) were involved, collecting their opinions during several workshops. Also, several interviews and surveys were conducted during 2002 and 2003, to understand the perceptions and strategies applied by producers (Castellanos et al., 2003; Conde et al., 2003b).

Veracruz is located in the eastern part of Mexico, between latitudes 17°09′ and 22°28′ North and longitudes 93°36′ and 98°39′ West, and borders the Gulf of Mexico. The state accounts for 3.7% of Mexico's total surface. Veracruz has large altitude variations: lands near the coast are flat and low, but, as distance increases from the coast, it rises up to 3,000 meters over sea level at its highest point. These altitude differences produce great diversity of climates, although most of the state (about 84%) has a warm, humid and sub-humid climate. As it is shown in Table I, both annual temperature and precipitation in Veracruz have a fairly symmetrical distribution with an average value of 23.56 °C and a standard deviation of 0.55 °C, and average of 2,527.07 mm with a standard deviation of 470.3 respectively. These climatic conditions are favorable for agriculture, especially for coffee production. In the same table it can be seen that as for seasonal temperature winter is the most variable season with a standard deviation of 0.8 °C and a range of 3.6 °C. In the case of seasonal precipitation the wet (summer, fall) and dry seasons (spring, winter) are clearly differentiated.

Douglas (1993) defined 18 climatological regions for Mexico according to similarities in slope aspect, station elevation, the amount of data on temperature and precipitation available for the period 1947–1988. Veracruz corresponds to Douglas' region number 15. According to this classification, climate conditions for different areas within the state can be well approximated using data for the whole region, including the municipalities of Coatepec, Xico and Huatusco where 90% of the state's coffee production comes from.[3]

Agriculture in Veracruz is very important. It generates 7.9% of the state's GDP and provides jobs for 31.7% of the state's labor force (Gobierno del Estado de

TABLE I
Temperature and precipitation in Veracruz for the period 1969–1998

Variable	Mean	StDev	Minimum	Q1	Median	Q3	Maximum	Range	Skew	Kurt
Temperature 1969–1998										
Annual	23.57	0.56	22.85	23.14	23.34	23.98	24.92	2.07	0.76	−0.16
Spring	25.18	0.73	24.02	24.60	25.09	25.58	26.86	2.84	0.56	−0.02
Summer	24.96	0.75	23.52	24.42	24.92	25.56	26.42	2.90	0.13	−0.67
Fall	23.37	0.74	22.31	22.73	23.09	24.13	24.70	2.39	0.50	−1.20
Winter	20.75	0.80	18.74	20.29	20.88	21.34	22.35	3.61	−0.53	0.32
Precipitation 1969–1998										
Annual	2527.10	470.30	1723.40	2148.40	2567.60	2792.80	3611.00	1887.60	0.39	−0.04
Spring	81.35	28.93	14.72	66.81	86.70	98.64	147.33	132.61	−0.39	0.40
Summer	426.00	120.90	163.80	360.10	409.40	514.90	722.90	559.20	0.23	0.57
Fall	270.80	60.80	192.70	218.90	264.00	318.50	394.90	202.20	0.67	−0.52
Winter	64.91	18.55	30.75	49.42	61.52	79.30	100.09	69.34	0.15	−0.78

Veracruz, 2001). Coffee production contributes notably to these numbers. Veracruz ranks as Mexico's second largest coffee producer although coffee plantations (*Coffea arabica*) in the state are relatively recent, becoming an important agricultural activity after the '50s decade, particularly due to the good prices after the Second World War (Bartra, 1999). According to the state government[4] the types of Coffea arabica cultivated are Typica (22%), Bourbon (19%), Caturra (19%), Garnica (19%) and Mundo Novo and others (22%). Until the eighties, governmental policies favored an increase of nearly 75% of the production and a duplication of the number of coffee producers in the country, with plantations of less than 10 Ha. However, since the nineties there has been a combination of national and international factors that have put coffee producers in Mexico in a critical situation. In "Perspectives of coffee production in Mexico", the Consejo Mexicano del Café (2001) states that the main international factors affecting coffee production in Mexico are the international prices of coffee that have been decreasing, that the coffee market is saturated because world's production has increased notably, specially with low quality coffee from Asian countries such as Vietnam and India[5] while coffee demand has remained almost constant. At the national level, since the INMECAFE (Mexican Coffee Institute) disappeared in the early 1990's, there has not been a coordinating institution to help designing and implementing production and market strategies (and policies) to cope with the price crisis. National and international coffee prices are so low that in many cases producers are not able to cover their production costs and are now facing strong competition from low-priced coffee . Even though the quality of that coffee is very low compared to the Mexican product, it is preferred by industries of processed coffee.

What it is now an apparent national coping strategy in the rural areas in Mexico, particularly in Veracruz, is rural migration to urban areas or, preferably, to the United States of America, where 50,000 Mexicans migrate every year (Pérez, 2005).

Climatic extreme events, such as droughts, floods, frosts and heat waves affect coffee production in Veracruz (Conde et al., 2005). Drought conditions or heat waves during summer diminish the quality of the production or can even imply important losses in the overall production. Also, frosts events during winter have affected coffee plantations in Veracruz, leading to the almost total loss of coffee plants in 1970 (La Red, 2004).

As discussed in detail in Conde (2003), observed trends in spring precipitation and in summer temperature in Veracruz result in climatic conditions similar to those during El Niño events: important decreases in precipitation and increases in temperature, which may explain why producers in the region are concerned with drought (Castellanos et al., 2003; Conde et al., 2003c).

Coffee development also requires a "relative drought" during the onset of the spring season (Nolasco, 1985; Castillo et al., 2003). However, a persistent dry spell or, on the contrary, heavy rains during this season can spoil the flowering stage.

Adaptation measures to climatic extreme conditions are not simple and neither will be to adapt to future changes, even if they are gradual. Coffee producers in Mexico have a resistance to change and have never radically modified their agricultural strategies (Castellanos et al., 2003).

The 1992 Coffee Census (Consejo Mexicano del Café, 1996) reveals that in Veracruz 153,000 hectares are devoted to coffee production, involving 67,000 producers from 82 municipalities and generating around 300,000 permanent jobs and 30 million daily wages[6] each year. Socioeconomic conditions in the state are deficient: in the year 2000 about half of the municipalities were classified as under very high and high poverty levels.[7] Resource limitations and lack of income flexibility of small-scale producers limit their adaptation options to climate variability (Eakin, 2000) and thus their vulnerability could be exacerbated in the future.

2. Econometric Model

This paper adopts a multiple regression model that integrates climatic and economic determinants of coffee production in Veracruz. The objective was to construct a production function that could give information on how this activity responds to changes in economic and climatic variables.

The general regression model (Equation 1) includes the economic variables described below, a linear and a quadratic term for seasonal climatic means, and a term for the seasonal variance of climatic variables to capture how extreme events can affect coffee production.

$$P_{\text{Coffee}} = f\left(T_i, T_i^2, P_i, P_i^2, V_{ij}, \text{ECONOMIC}\right) \quad (1)$$

where:

T_i = mean seasonal temperature.
P_i = mean seasonal precipitation.
V_{ij} = variance.
i = Spring, Summer, Fall, Winter.
j = temperature, precipitation.
ECONOMIC = real minimum wage paid in Veracruz, state coffee prices, international coffee prices, state population, coffee stocks in Mexico, coffee stocks in USA and producer index price for raw materials for coffee benefit.

According to literature on coffee production in Mexico, labor is the main input for coffee production, representing about 80% of total production costs (Consejo Mexicano del Café, 2001). Two economic variables were considered for the labor component that serve as proxies for costs and availability of labor. Real minimum wage[8] in Veracruz was used as a proxy for the wage paid to coffee workers. There are no data about the wage that is actually paid to coffee workers in the state but considering real minimum wage as a reference price and an opportunity cost for unqualified labor in the state, it is reasonable to assume that both wages will be closely related. The state population series[9] was included as an approximation for labor availability. Given the high percentage of total production costs that labor represents, other production costs could be considered irrelevant. Nevertheless, a producer index price for raw materials for coffee benefit[10] was also included.

Within the AIACC LA29 project, workshops were held with coffee producers in Veracruz and a survey to find out what factors they consider more threatening was conducted. Results show that their main concerns are coffee prices and agricultural policy changes. For the econometric model, state and international coffee prices[11] were considered.

Coffee prices have dramatically fallen and since 1990 they have reached their lowest level for the period of study. As will be shown latter, prices might be their main preoccupation but apparently these have not been such an important factor in their production decisions. One of the main reasons for this is that in order to maintain a coffee tree healthy, it has to be harvested every season, regardless of the market price (TecnoServe, 2003). When prices fall, producers absorb part of the losses and are partly compensated by government subsides[12] resulting in that coffee production is quite inelastic and production level does not seem to respond, or it responds very slowly, to changes in prices. An example of this is that in the last decade prices have been very low, and production has not decreased. Besides, there is a widespread belief among producers that the current market conditions are transitory and prices will rise in the short term.

The producer's decision when choosing the production level could be also influenced by how saturated is the market of the product. Although this is closely related to international prices, coffee stocks in Mexico and USA were regarded as potentially relevant to model coffee production.[13]

For the climatic component, the average and variance of temperature and precipitation were considered as the main climatic factors. Data on this component was obtained from the Tropical Meteorology research group of the Centro de Ciencias de la Atmósfera (UNAM). According to literature on coffee phenology, seasonal mean values are more important than yearly average values[14] (Nolasco, 1985; Castillo et al., 2003). This allows to relate weather and plant phenology in a more direct way. Seasonal averages and variances were defined as follows: Spring corresponds to March, April and May; Summer to June, July and August; Fall to September, October and November; and Winter to December and next year's January and February.

A quadratic functional form was chosen to capture the effect of temperature and precipitation on coffee plants. Even though this functional form generates multicollineality problems, it works better for modeling the plant's response to changes in climatic variables than a linear specification because the latter would imply that there are no optimum values and that the effect of these variables over production is monotonic. On the other hand, the quadratic functional form permits to find optimum climatic values for coffee production and to calculate how production will be affected as we get farther from these optimum values.

Multicollineality in this case arises because of the inclusion of linear and quadratic terms of the same variable. In this case the determinant of the matrix $x'x$ is very small (close to zero), which causes the estimator variance to increase.

$$\mathrm{Var}(\hat{\beta}) = \sigma_u^2 (x'x)^{-1} = \sigma_u^2 \frac{\mathrm{coef}\,(x'x)}{|x'x|} \tag{2}$$

As the estimator variance increases the t-statistic value must necessarily decrease. This makes the t-statistic value unreliable to conclude whether the estimated coefficients are significant or not. Therefore, we propose the use of the adjusted R-squared statistic to decide if it is worth to add a regressor to the model. Even though the adjusted R-squared statistic is not a measure of significance, it penalizes the addition of regressors that do not contribute to the explanatory power of the model. If a regressor does not contribute to the latter, the adjusted R-squared value will decrease.

The model specification used in this paper is similar to the one used by Chang (2002). The explanatory variables used by Chang are seasonal averages of precipitation and temperature (linear and quadratic) and their variations from a 20 years mean value, the percentage of full-time farm households, land slope and a time trend to account for technology changes. The statistical significance of the independent variables is not tested because of the presence of multicollineality, resulting in that the proposed variables are taken to be relevant from the start. No statistical diagnosis tests are presented either. In this study the relevance of regressors is deduced using the adjusted R-squared as an alternative criterion to decide whether to keep a variable in the model when multicollineality problems are present and t-statistic becomes unreliable. A thorough statistical diagnosis is performed in order to validate our model. In addition, simple future climate scenarios are generated which include changes in the frequency of occurrence of certain values. This is generally not considered (in similar studies) and ignoring these changes, as will be shown below, can produce an important bias to underestimate possible impacts of climate change.

Due to the limited number of available production data[15] it was not convenient to include all explanatory variables at the same time, so different models were constructed using the same modeling approach for different combinations of variables and then diagnostic tests were applied to assess their statistical quality. These test included omitted-variables tests for evaluating if variables not included in a specific model were not relevant. The model with best statistical quality and highest adjusted R-squared was chosen. The methodology for arriving at the best model is illustrated in what follows.

A reductive approach was followed including all climatic variables (linear and quadratic for all seasons), real minimum wage, state population and state coffee prices. Regressors with higher p-values (smaller t-statistic value) were excluded one by one. If the exclusion of a regressor produced a positive change in the adjusted R-squared value, it was left out and subsequently tried with the next regressor that had the highest p-value. Regressors with the highest p-values were excluded until the change in the adjusted R-squared was negative, which was the case of precipitation during Spring. This process produced the following model:

$$\begin{aligned} P_{\text{coffee}} = & -35965262 + 2296270(T_{\text{summ}}) - 46298.67(T_{\text{summ}})^2 \\ & +658.01618(P_{\text{spr}}) + 813976.3(T_{\text{win}}) - 20318.27(T_{\text{win}})^2 \\ & -3549.71(\text{MINWAGE}) \end{aligned} \quad (3)$$

where:

T_{summ} is the average temperature during Summer.
P_{spr} is the average precipitation during Spring.
T_{win} is the average temperature during Winter
MINWAGE is real minimum wage.

The model (Equation 3) has an adjusted R-squared value of 0.692, so 69.2% of the variance of the dependant variable is explained by the independent variables. Figure 1 shows fitted and actual series.

The tests that were carried out to assess the statistical quality of the model were: multicollineality, functional form, structural change, serial correlation, heteroskedasticity, normality and omitted variables test.

As expected, strong multicollineality exists between linear and quadratic terms used to model the effect of temperature over coffee production as reflected by the

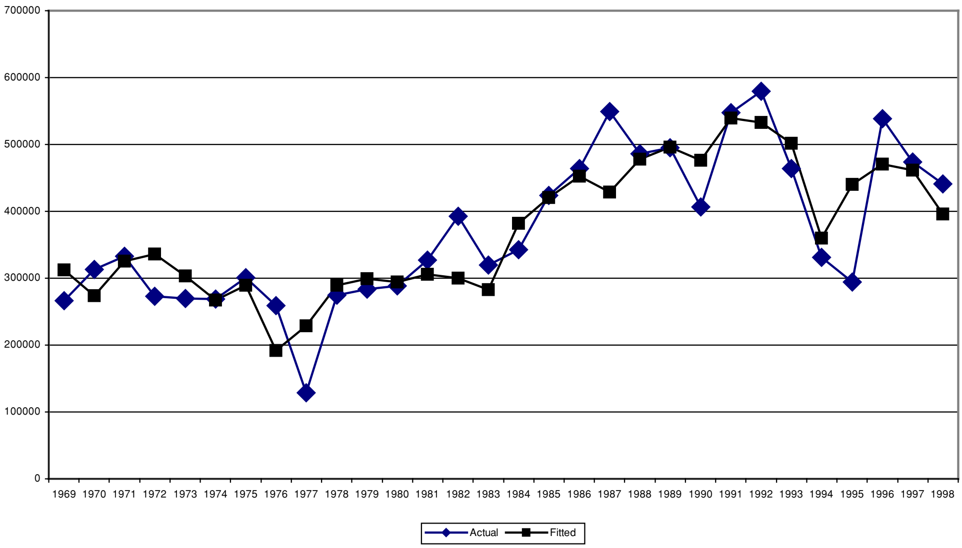

Figure 1. Actual and fitted series for coffee production in Veracruz.

high correlation between linear and quadratic terms of the same variable. Since the correlation value of these regressors is higher than the R-squared value, we can infer that multicollineality is present. Auxiliary regressions were performed to confirm the presence of multicollineality. Their R-squared value of 0.999, led us to conclude that there is a multicollineality problem. Based on the Ramsey RESET test, it was considered that the quadratic functional form chosen for the model was correct. Structural change tests were used to find parameter instability. The CUSUM and CUSUMQ tests were performed and confirmed that there was no structural change and regression coefficients remain constant during the sample period. Recursive coefficients estimates tests results revealed that coefficients achieve convergence quickly giving a strong indication of stability.

Serial correlation tests evaluates whether the residuals are correlated with their own lagged values. Using Durbin Watson statistic (DW value = 2.020532) and the the Breusch Pagan tests, it was found that no serial correlation existed for 1st to 4th orders.

For heteroskedasticity, the White and ARCH tests were performed to evaluate if the variance of residuals was constant. Results showed that the estimators where not inefficient, and no autoregressive conditional heteroskedasticity was found. Finally, the Jarque Bera test was applied for normality evaluation (value = 1.0083) which revealed that residuals were normally distributed.

In order to infer how climate change can affect production it is necessary to preserve trends in data, because we are trying to see the effect (if any) of long run variations in climatic variables over coffee production. This raises the problem of spurious regressions, when a regression between two or more non-stationary series that have no real relation between them, appear to have good explanatory power . Cointegration tests were conducted in order to determine if there is a real long term relation between the variables in the model. These tests confirmed that the series are cointegrated and that a long run relation between them exists, so it is correct to preserve trends in our model.

Once it was verified that these regression assumptions hold, omitted variables tests were performed. For climate variables other seasons' precipitation and temperature averages and variances were tested, while for economic variables we included international coffee prices, coffee stocks in Mexico and USA and the producer index price for raw materials for coffee benefit. None of these variables contributed to the model explanatory power or were significative. Tests results show that these variables were correctly omitted.

It's important to notice that no statistical evidence was found to support that prices (national and international) constitute a relevant factor in the production level decision process and that coffee production in the state is indeed very inelastic to changes in prices. There are several factors that can make coffee supply rigid. For example, changing to another crop not only involves the costs from cutting down trees but it represents a permanent decision that coffee producers are not willing to make because they believe that the prices will rise again and because of tradition.

On the other hand, it has to be considered that coffee production has been severely distorted by government subsides, and coffee production has not necessarily been determined by market forces, although since the disappearing of INMECAFE there has been a reduction in government support.

3. Empirical Results

3.1. MODEL INTERPRETATION

The model (Equation 3) allows the exploration of the production's sensitivity to changes on the relevant variables . In the case of temperature, linear and quadratic terms permit the finding of an optimal temperature for coffee production in Veracruz.

3.1.1. *Average Summer Temperature*

$$\begin{aligned} P_{\text{coffee}} = {} & -35965262 + 2296270(T_{\text{summ}}) - 46298.67(T_{\text{summ}})^2 \\ & +658.01618(P_{\text{spr}}) + 813976.3(T_{\text{win}}) - 20318.27(T_{\text{win}})^2 \\ & -3549.71(\text{MINWAGE}) \end{aligned} \tag{4}$$

The first order condition for maximizing coffee production with respect to average Summer temperature is:

$$\frac{\delta P_{\text{coffee}}}{\delta T_{\text{summ}}} = 2296270 - 2(46298.67)T_{\text{summ}} = 0 \tag{5}$$

Then the optimum value is:

$$T_{\text{summ}} = \frac{2296270}{92597.34} = 24.79 \tag{6}$$

According to the model, the average summer temperature that maximizes coffee production in Veracruz is 24.79 °C. Any temperature below or above this optimum value will lead to a lower production level. Figure 2 shows the effect of gradual changes in average summer temperature over coffee production while other climatic variables are fixed at their average values and real minimum wage is fixed at its 2001 value. In the X-axis we plot summer temperature and in the Y-axis the percentage of production obtained, considering 1 as the maximum production at the optimum temperature. This graph shows that for average temperatures greater or equal to 28.29 °C, production becomes zero. It's important to notice that the effect of changes on climatic variables over coffee production can be overestimated because the model does not include any adaptation strategy.

Average summer temperature for the 1969–1998 period is 24.96 °C, which is a little higher than the obtained optimum value. Any increase in average summer temperature will decrease production. But, as shown in Figure 3, average summer

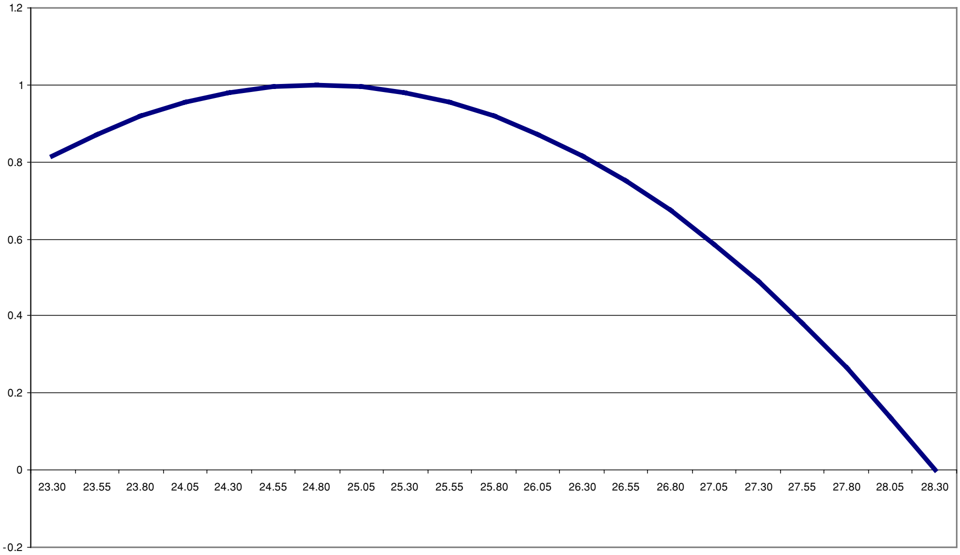

Figure 2. Effect of gradual changes on average summer temperature over coffee production.

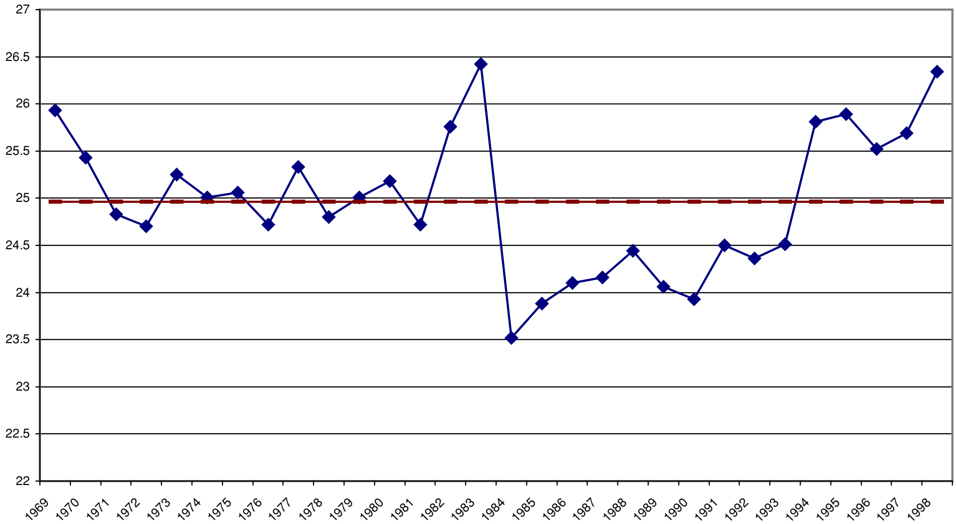

Figure 3. Average summer temperature from 1969 to 1998.

temperature for the 1969–1998 period does not show a tendency to increase or decrease. If this trend continues in the future, relatively small effects from this variable could be expected over production, although effects caused by its variability could be important.

3.1.2. *Average Winter Temperature*

The first order condition for maximizing coffee production with respect to average winter temperature is:

$$\frac{\delta P_{\text{coffee}}}{\delta T_{\text{win}}} = 813976.3 - 2(20318.27)T_{\text{win}} = 0 \tag{7}$$

$$T_{\text{win}} = \frac{813976.3}{40636.54} = 20.03 \tag{8}$$

The estimated optimum average winter temperature is 20.03 °C. As with summer temperature, any temperature below or above this value will lead to a lower production level. Figure 4 shows the effect of gradual changes in average winter temperature over coffee production while other variables are fixed as before. For average temperatures greater or equal to 25.35 °C production becomes zero.

The average winter temperature in Veracruz is 20.75 °C, slightly higher than the estimated optimum value, so an increase in this temperature could lead to a lower production level. Contrary to average summer temperature, average winter temperature does show a clear upward trend during the 1969–1998 period (Figure 5).

3.1.3. *Average Spring Precipitation*

The quadratic term for spring precipitation was not included in the model because it did not contribute to the explanatory power of the model. Nevertheless, it is interesting that the sign of this term was positive. This would mean that the more it rains during spring the better, which lead us to infer that observed precipitation during this season could be far from the inflection point, where its effect over production becomes negative. If we are far from this point, using just a linear term

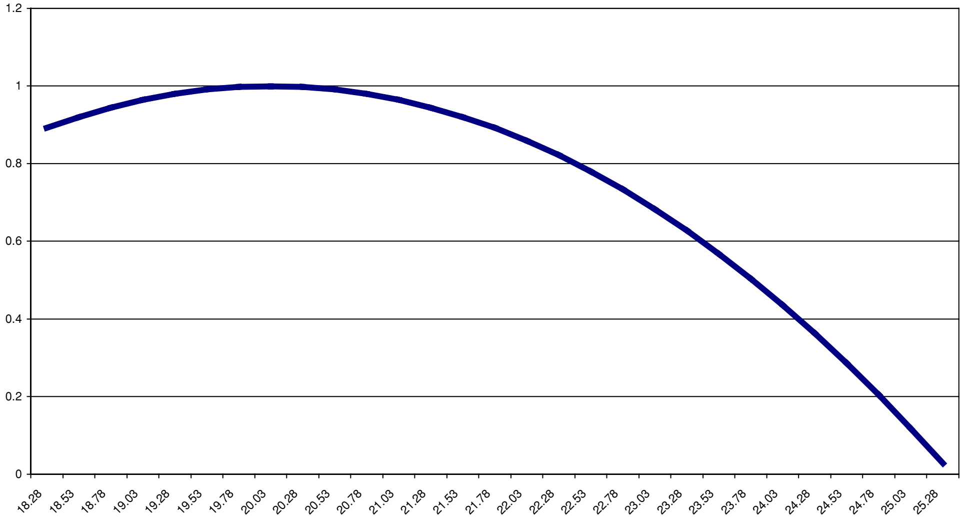

Figure 4. Effects of average winter temperature over coffee production.

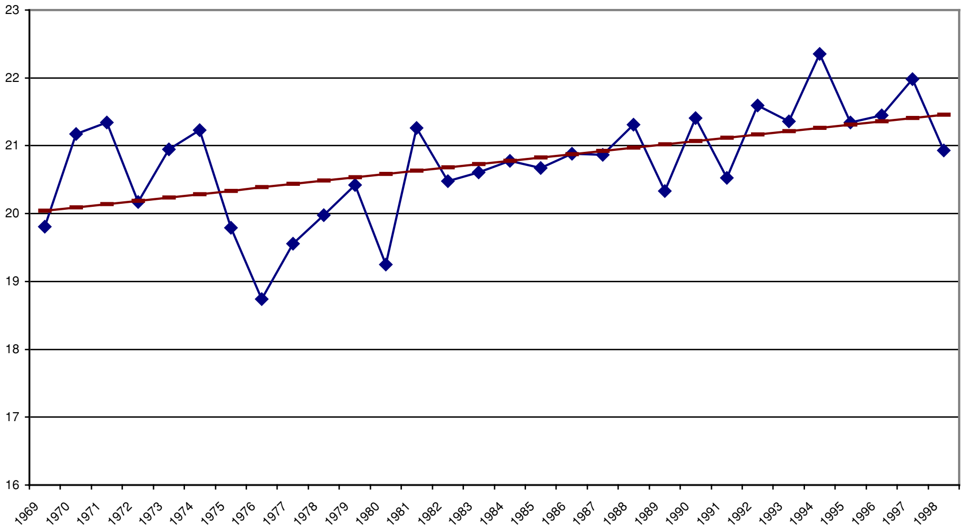

Figure 5. Average winter temperature from 1969 to 1998. Average winter temperature increased an average of 0.048 °C per year during the period of study.

can be the best way to model the effect of spring precipitation over production. Low levels of precipitation or droughts in spring will affect negatively coffee production.

The spring precipitation elasticity was calculated to estimate the effect of a relative change on average spring precipitation over coffee production:

$$\eta_{\mathrm{Pspr}} = 658.0618\left(\frac{\overline{P_{\mathrm{spr}}}}{\overline{P}}\right) = 658.0618\left(\frac{81.35}{368740.09}\right) = 0.1451 \qquad (9)$$

The relation between these variables is positive and coffee production is inelastic with respect to spring precipitation, which means that changes on average spring precipitation produce less than proportional changes in coffee production. For example, if nothing else changes, a variation of 10% in average precipitation will produce a variation of 1.4% in production.

Figure 6 shows that average spring precipitation for the 1969–1998 period has a downward trend. The spring precipitation has decreased about 0.92 mm a year. If this trend continues in the future, coffee production could be negatively affected.

3.1.4. *Yearly Average Temperature and Precipitation Trends*

Even if most of the literature on coffee phenology states the importance of the distribution of climatic variables during different seasons of the year, optimal values are expressed in yearly values (Nolasco, 1985; Infoaserca, 2002). This is why we extend our analysis to yearly totals and averages, even though we did not use these variables in our model. Yearly total precipitation and yearly average temperature show trends that are relevant for our study. Yearly precipitation has decreased an

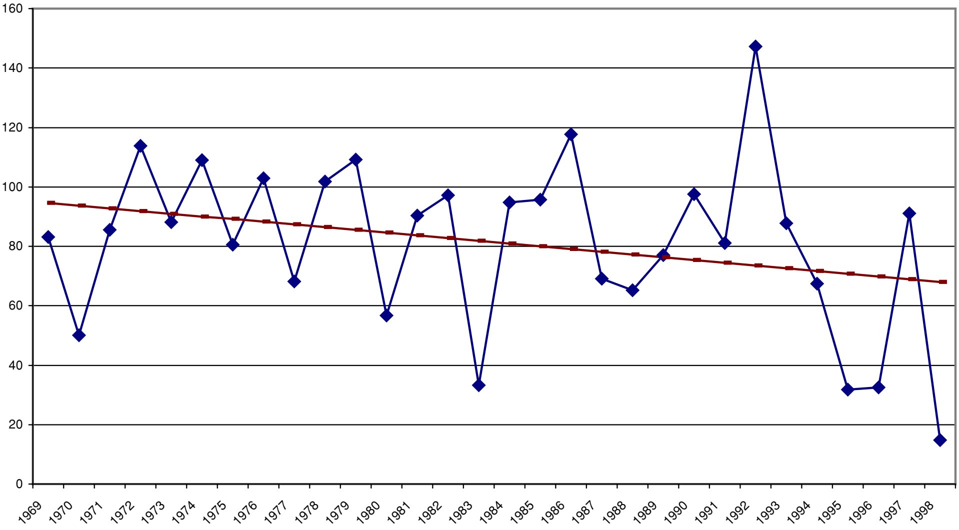

Figure 6. Average springer precipitation from 1969 to 1998. Average Springer precipitation decreased an average of 0.92 mm per year during the period of study.

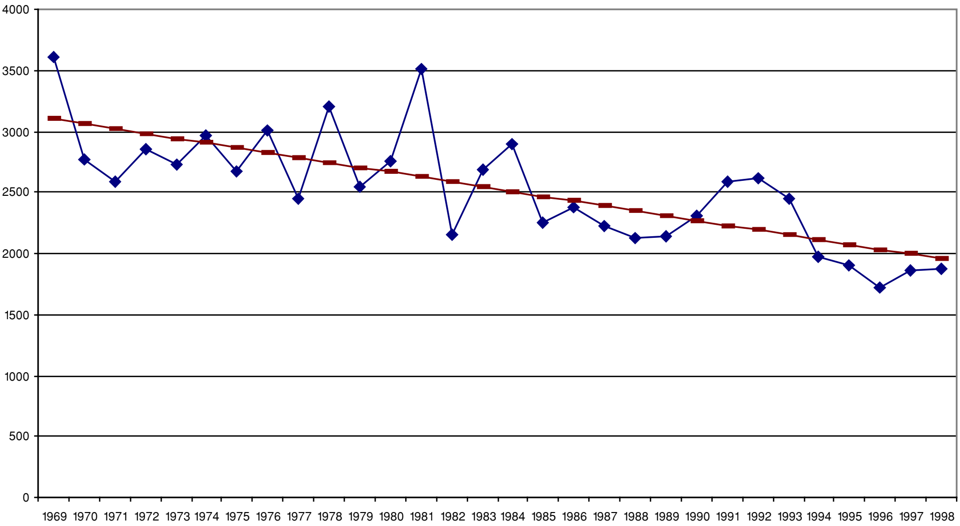

Figure 7. Yearly precipitation from 1969-1998 in Veracruz. Yearly precipitation decreased 39.53 mm per year during this period.

average of 39.53 mm per year during the 1969–1998 period, while yearly average temperature has increased 0.019 °C per year. These trends show that the region has been changing to a warmer and dryer place. Figure 7 and 8 show yearly total precipitation and average temperature during the period of study.

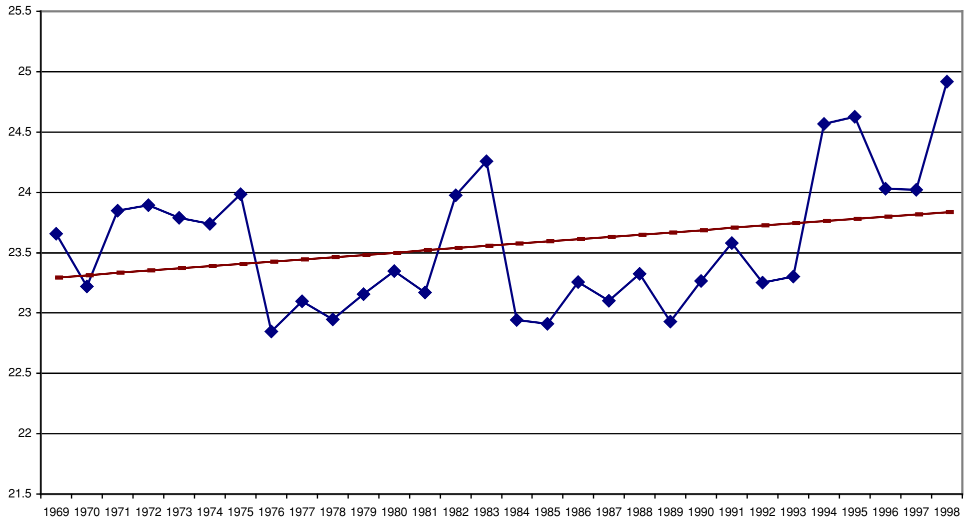

Figure 8. Yearly average temperature from 1969–1998 in Veracruz. Yearly average temperature increased 0.019 °C per year during the period of study.

3.1.5. *Climate-Phenology Relation*

According to different sources[16] the optimum yearly average temperature range is from 17 to 24 °C. Observed yearly average temperature in Veracruz is 23.56^{0}C with a tendency to increase 0.018 °C a year. Even though no information on optimal seasonal average temperatures was available, yearly optimum values reinforce the model's conclusion that if temperature increases coffee production level could be lower. Another important relation between temperature and production is that higher temperatures favor coffee plagues. According to experts (Naturland, 2000), increases in temperature can produce more severe cases of "broca" (*Hypothenemus hampei*), which affects directly the coffee fruit and spreads to temperate regions when temperature increases.

The optimal level for yearly precipitation is between 1500 and 2500 mm (Nolasco, 1985; Infoaserca, 2002). Yearly precipitation in Veracruz is 2,527.07 mm with a tendency to decrease at a rate of 39.53 mm a year. According to these sources, this average value corresponds to the upper limit for coffee production, thus a decrease in this variable should not have a negative impact on this activity. Nevertheless, the distribution of precipitation over the year can be more important than the yearly total because water supply on some stages of the development of the fruit can be crucial (Nolasco, 1985; Castillo et al., 2003). This is the case of precipitation during spring. Blooming takes place just after the first rains of spring, if there is not enough water available, flowers are not produced and neither are fruits[17]. This information about weather-phenology reinforces the importance of including spring precipitation in our model, and that the relationship between this variable and production is positive.

TABLE II
Relations between coffee phenology and relevant climatic factors

Climatic factors (relevant according to our model)	Precipitation	Temperature		Temperature	
Fenology	Leaf fall / blooming	Fruit growth / ripening	Ripening/ harvest	Ripening/ harvest	Harvest
Season	Spring	Summer	Fall	Winter	Spring
	March	June	September	December	March
	April	July	October	January	April
	May	August	November	February	May

Table II summarizes the relationships between the relevant climatic factors and coffee phenology. Spring precipitation corresponds to leaf fall and blooming, while summer and winter temperature correspond to fruit growth, ripening and harvest.

3.1.6. *Real minimum wage paid in Veracruz*
Production elasticity with respect to real minimum wage is:

$$\eta_{\text{MINWAGE}} = -3549.71\left(\frac{\overline{\text{MINWAGE}}}{\overline{P}}\right) = -3549.71\left(\frac{38.11}{368740.09}\right) = -0.3668 \quad (10)$$

There is an inverse relation between these variables, to a higher minimum wage corresponds a smaller production. When labor price rises, production costs increase, then the producer will not be able to hire the optimal level of labor to harvest and production most necessarily decrease. Coffee production is inelastic: changes in minimum wage produce less than proportional changes in production. As expected, this variable has an important effect on production: a change in minimum wage will produce a change in production one-third the size of the original.

Real minimum wage during this period has decreased at a rate of \$3.11 pesos a year, although during the last few years it has become more stable (Figure 9). However, the National Commission for Minimum Wages (CNSM), estimates that more than three decades will be necessary for the minimum wage to regain the value it had during the 70's. This would be possible only if Mexico's economy grew at a constant rate of two percent and if no economic crisis occurs[18]. It is important to realize that economic crisis have a profound effect in real minimum wage and that its periodicity has to be considered for forecast purposes. The results from a change-point analysis performed to the real wage series reveals three large downward breaks (at 99% significance levels) occurring in 1983, 1988 and 1995 which produced a drop in the level of the series of a 40%, 30% and 20% respectively. These change points are associated to economic crisis that occurred after every

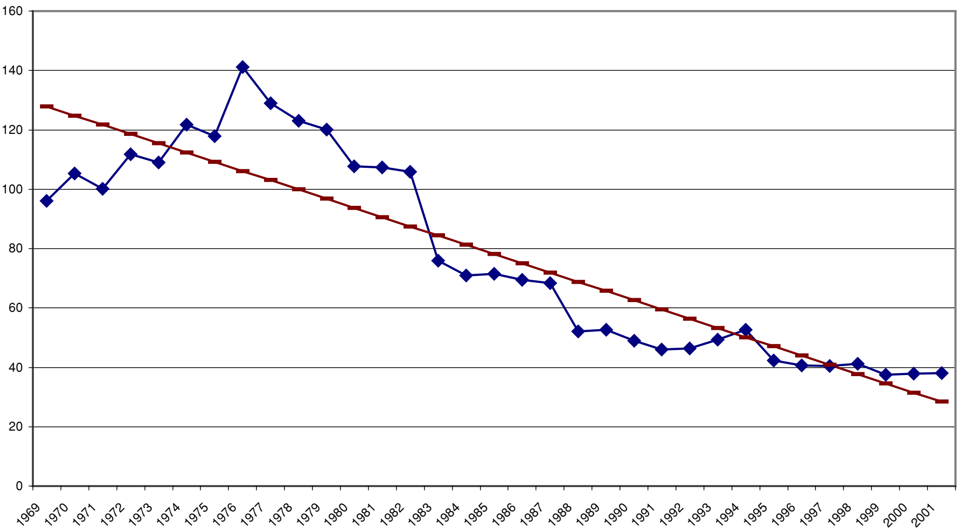

Figure 9. Minimum wage in Veracruz from 1969 to 2001. Minimum wage decreased 3.11 pesos a year during this period.

presidential succession since the 1980's with the exception of 2000. All these crisis were largely caused by macroeconomic instability and devaluation. Control of macroeconomic variables and a floating exchange rate have helped reducing inflation and avoiding recurrent economic crisis. These conditions have permitted stability and a slow recuperation in real minimum wage in the last few years.

3.2. SCENARIOS FOR THE YEAR 2020

3.2.1. *Coffee Production*

3.2.1.1. *Potential Changes in Production Caused by Changes in the mean Value of Relevant Variables.* A baseline scenario was constructed in order to compare the current situation with possible future scenarios. This baseline was calculated using the average value of climatic variables for the period 1969 – 1990, and the value of real minimum wage in 2001. For future scenarios the value of climatic variables was calculated assuming that the trends shown by the series do not change. For the year 2020, average spring precipitation would decrease from 81.35 mm to 47.87 (41.15%); average summer temperature would increase slightly (0.01%); and winter temperature would increase from 20.75 to 22.53 (8.58%).

For the real minimum wage five possibilities were considered: (1) it does not change in the future, so we can see the isolated effect of the changes in climatic values over production; (2) it increases at an annual rate of 0.5% (a total increment of 9.5%); (3) it increases at an annual rate of 1% (a total increment of 19%) and;

TABLE III
Baseline scenario and future scenarios

Scenario	Average spring precipitation	Average summer temperature	Average winter temperature	Real minimum wage	Production (tons)	Change in production (with respect to baseline scenario)
1	81.35 mm	24.96 °C	20.75 °C	\$38.11	565,402.18	
2	47.87 mm	24.96 °C	22.53 °C	\$38.11	426,647.03	−24.54%
3	47.87 mm	24.96 °C	22.53 °C	\$41.73 (0.5% annual increment)	413,725.48	−26.81%
4	47.87 mm	24.96 °C	22.53 °C	\$45.35 (1% annual increment)	400,933.94	−29.08%
5	47.87 mm	24.96 °C	22.53 °C	\$52.59 (2% annual increment)	375,240.84	−33.63%
6	47.87 mm	24.96 °C	22.53 °C	\$30.49 (20% drop)	453,695.82	−19.16%

(4) it increases at an annual rate of 2% (a total increment of 38%); (5) an economic crisis similar to the one that occurred in 1995 producing a drop in the current level of the series of a 20%. Table III shows the baseline scenario and these five different scenarios for year 2020.

Labor for coffee production is becoming scarce in the state because of migration. This is an increasing concern for coffee producers because young people are migrating the most, and the labor force they can employ is older and not as productive. If labor becomes scarce, its price will tend to increase and scenarios 2, 3 and 4 can also be interpreted as the result of a change in labor availability for this activity.

Scenario 2 of Table III shows that if the real minimum wage does not change, the isolated effect of changes in climatic variables would bring a drop of 24.54% in production. Scenarios 3 to 5 show three possible values for the minimum wage in 2020. All of them are optimistic regarding minimum wage evolution (or pessimistic regarding labor availability): Scenario 3 assumes a 9.5% increase for year 2020; Scenario 4 a 19%; and Scenario 5 a 38%. The drop in production can be up to a 33.63%, most of it caused by the change in climatic values. Although in Scenario 6 labor price falls a 20% and a greater production could be expected, the production possibilities are limited by the future climatic conditions resulting in a reduction of 19.16% in production.

TABLE IV
Potential impacts of one and two current standard deviations in winter and summer temperatures

Variation	Value	Average summer temperature in year 2020 plus variation	Production (Tons)	Change in production (with respect to baseline scenario)
Plus one standard deviation	0.75 °C	25.71 °C	389,053.75	−8.81%
Plus two standard deviations	1.5 °C	26.46 °C	299,374.47	−29.83%
Minus one standard deviation	−0.75 °C	24.21 °C	412,154.30	−3.39%
Minus two standard deviations	−1.5 °C	23.46 °C	345,575.57	−19.00%
Variation	Value	Average winter temperature in year 2020 plus variation	Production (Tons)	Change in production
Plus one standard deviation	0.80 °C	23.33 °C	331,808.92	−22.22%
Plus two standard deviations	1.60 °C	24.14 °C	210,728.84	−50.60%
Minus one standard deviation	−0.80 °C	21.72 °C	495,243.16	16.07%
Minus two standard deviations	−1.60 °C	20.92 °C	537,597.31	26.00%

3.2.1.2. *Potential Changes in Production Caused by Climate Variability.* Once average climatic values have changed, future climate variability could have a greater impact on production than it does now. Table IV shows the isolated effect of variation of one and two current standard deviations in winter and summer temperatures. This table shows that given the average temperatures in summer and winter, positive variations (increments in average temperature) have the greatest impact over production.

3.2.1.3. *Present and Future Probabilities and Expected Production.* Calculating the probabilities of different values of climatic variables we can determine present and future expected production and infer how producers' income could be affected. Table V presents the probabilities of having seasonal average temperature/precipitation on different intervals of values: "mean" $(-\sigma, \sigma)$ for values within mean plus/minus one standard deviation; "plus one standard deviation" for values

TABLE V
Present probabilities of mean, one and two standard deviations intervals for climatic variables

	Mean $(-\sigma, \sigma)$	Plus one standard deviation $(\sigma, 2\sigma)$	Plus two standard deviations $\geq 2\sigma$	Minus one standard deviation $(-\sigma, -2\sigma)$	Minus two standard deviations $\leq 2\sigma$
T_{win}	0.73	0.07	0.03	0.13	0.03
T_{summ}	0.60	0.20	0.00	0.20	0.00
P_{spr}	0.73	0.07	0.03	0.13	0.03

falling into the interval $[\sigma, 2\sigma)$; "plus two standard deviations" for values greater than 2σ. Intervals for minus one and minus two standard deviations are defined in the same way.

At the present time, the probability of climatic variations reaching two current standard deviations above/below their mean values is very small, but if the trends shown by climatic variables do not change, reaching these values can become more frequent. Studies on the future climate conditions suggest that the incidence of extreme climate values will increase. The IPCC's Third Assessment Report (Smit and Pilifosova, 2001) states that there is enough evidence to conclude that climate change is already occurring and that there will be an increment in the frequency (and sometimes intensity) of extreme weather events.

Time analogs were used for estimating the probabilities of future climatic variations reaching the different intervals defined above. This concept uses past variability shown by the series as an approximation of its future variability. In other words, past variability is added to the trend of climatic variables. Future probabilities are shown in Table VI.

Under these assumptions the future probability of variables falling in the interval $(-\sigma, \sigma)$ decreases, as in the case of average winter temperature which falls by 21%. Accordingly, variations reaching one and two current standard deviations will be more frequent in the future.

TABLE VI
Future probabilities of current mean, one and two current standard deviations intervals for climatic variables

	Mean $(-\sigma, \sigma)$	Plus one standard deviation $(\sigma, 2\sigma)$	Plus two standard deviations $\geq 2\sigma$	Minus one standard deviation $(-\sigma, -2\sigma)$	Minus two standard deviations $\leq 2\sigma$
T_{win}	0.52	0.21	0.17	0.08	0.02
T_{summ}	0.56	0.21	0.00	0.23	0.00
P_{spr}	0.69	0.06	0.02	0.17	0.06

Present and future joint probabilities of all possible combinations of the intervals $(-\sigma, \sigma)$, $[\sigma, 2\sigma)$, $\geq 2\sigma$, $[-\sigma, -2\sigma)$, $\leq -2\sigma$ of temperature and precipitation in a year were calculated as follows:

$$P(Sspr_i, Tsumm_i, Twin_i) \tag{11}$$

Where i refers to the intervals: $(-\sigma, \sigma)$, $[\sigma, 2\sigma)$, $\geq 2\sigma$, $[-\sigma, -2\sigma)$, $\leq -2\sigma$

Production levels associated with each of these combinations were calculated to estimate present and future expected production. The first is very similar to the potential production that could be reached with the optimum value of climatic variables, because present climatic conditions (mean values and variability) are very favorable for coffee production. However, when the mean values and variability for 2020 are introduced, expected production drops 34% with respect to the present production.

3.2.2. *Socioeconomic Considerations*

If climate conditions change as estimated, the drop in production could have great socioeconomic impact. How much will the producers' income change? Would it still be economically viable to produce coffee in the region?

Present and future expected production could help answer these questions. Using the information on the number of producers and hectares dedicated to coffee production provided by the Coffee Census (Consejo Mexicano del Café, 1996) of the Mexican Coffee Council, present and future income for an average producer can be estimated. Approximately 73% of coffee producers in Veracruz own two or less hectares. For the calculations shown in Table VII we assume that the average producer owns 2.26 hectares. Coffee price was fixed at an average value of $3,508.40[19] because coffee market is very unstable, and modeling coffee price was not the objective of this paper. Nevertheless, we can provide some interpretations regarding coffee prices: market structure has changed with the introduction of Asian countries, making it unlikely for coffee prices to return to the price level it had before the crisis; coffee production responds to price changes very slowly, in part because it is a perennial crop and production decisions are planned for

TABLE VII
Present and future expected production and income

	Expected production (Tons)	Yield	Tons/ producer	Producer's net income	Hectares	Producers	Hectares/ producer	Coffee price (Pesos/Ton)
Present	549,158	3.60	8.16	$10,516.76	152,457	67,227	2.26	3,508.40
Year 2020	362,037	2.37	5.38	$751.41				
Change	−187,120	−1.22	−2.78	−$9,765.34				

long term; coffee market is distorted internally by government subsidies and the international coffee market saturated by excess supply and high coffee stocks in producer countries and mostly in consumer countries. The coffee market does not behave as a competitive market; prices paid to producers are a very small fraction of what consumers pay for the final product, giving a great benefit margin to intermediaries.

According to a report by TechnoServe (in collaboration with McKinsey & Company) the current crisis is different from all the previous coffee price crisis because not only the price is volatile, but in the last 10 years the coffee industry structure has changed with the entrance of cost-efficient competitors, innovations[20] and the increasing demand for Robusta coffee (that has lower production costs than Arabica). This means that while coffee prices will recover from their current historic low, the long term coffee price level will remain below its historical averages and will make this activity unprofitable for many producers. Most of the world's 25 million coffee producers have been facing coffee prices lower than their production costs during the last three years, and in Central America more that 500,000 coffee workers have been displaced.

In a case study (Eakin, 2003) conducted in one of the municipalities of Veracruz, Ursulo Galván, costs for producing coffee for small scale producers were estimated at an average of $8,000 per hectare. Assuming that costs are approximately the same for all the state, the average producer with 2.26 hectares faces total annual costs of $18,142.40 pesos. As it is shown in Table VI, this represents a net profit of $10,516.76 which corresponds to a monthly income of $876.40 pesos (less than $3 USD a day). On the other hand, in the last few years coffee prices have been so low that if we do the same calculation using the average price of 2001 ($1,390.84 pesos/ton, instead of the 13 years average price of $3,508.40), the producer faces a loss of $6,871 pesos. It is important to notice that this calculation does not take into account subsidies nor reductions in production costs (using less fertilizer, pruning, clearing, etc.).

Given the expected drop in productivity by year 2020 due to changes in climatic variables, the production of a ton of coffee becomes relatively more expensive (same costs, less production per hectare) and the average producer will have losses of $751.41 pesos a year.[21]. This evidently would affect the economic viability of coffee production in Veracruz, the average producer would not be able to cover production costs. If market conditions do not improve, this will probably make producers rely more on subsidies and government policies, to change crop selection or land use, and drive out people to other productive activities.

4. Discussion and Model Limitations

The econometric model developed for this paper presents high multicollineality. This problem is generated by the quadratic functional form chosen for the model, which includes a linear and quadratic terms for temperature. This does not necessarily affect the predictive power of the model but it makes estimators less accurate (Gujarati, 2003). In spite of this, the quadratic form offers important advantages. On the one hand, the model's quadratic functional form provides a better way to capture the non-monotonic effect of temperature over coffee production: for temperatures lower than the optimum value, an increase on temperature will be positive for production; for temperatures higher than the optimum value an increase on temperature will be negative for production. And on the other hand, according to literature on coffee phenology, current temperature observed in Veracruz is close to the inflection point where increments in temperature begin to have a negative effect on production. In addition, results of other recent studies (UNEP[22], Aggarwal (downloaded from http://www.unep.org/dpdl/indiaworkshop/documents/TS1_2_1.doc)) conducted in other parts of the world using different modeling techniques (GIS, crop models) to assess coffee production response to climate change have also found that if the temperatures increase coffee production will decrease.

The statistical quality of the model was thoroughly examined performing all the relevant econometric tests. Cointegration tests were performed to exclude the possibility of spurious regression. The model's explanatory power is quite good (69% of the observations).

The model shows that coffee production responds significantly to seasonal temperature patterns and to changes in minimum wage. Furthermore, changes in climatic variables expected for year 2020 could make coffee production not economically viable for producers. Temperature is shown as the most relevant climatic factor. The model reveals that present temperature is already slightly higher than the optimum value for coffee production. This implies that any increment in temperature would cause a drop in the productivity of current coffee production areas. According to the simple climate model used in this paper, average winter temperature is particularly important because it shows an upward trend, greater variance, and its mean interval has a smaller probability. These factors make average winter temperature potentially more harmful than any other climatic variable included in the model. In contrast, average summer temperature would not be as harmful because the expected change in this variable is marginal.

In the estimation process of the econometric model, the quadratic term proposed for spring precipitation was removed because it did not contribute to the explanatory power of the model. Nevertheless, it is interesting that the sign of the estimated parameter for this term was positive, because it implies that present spring precipitation is far from its optimum value and from the value where production begins to be negatively affected. Consequently, for the values contained in the series, the relation between precipitation and production appears to be monotonic, and using a linear term should be the best way to model this relation. The latter should hold for future values of spring precipitation given that the downward trend shown by the series implies future reductions in precipitation. It is important to express that even if our climate model is very simple, based only on trends and time analogies, predictions for the region are similar to the ones obtained using more complicated models.

The model shows that production is inelastic with respect to real minimum wage, but as expected, it has a significant effect over coffee production. Some production scenarios built using different assumptions on how real minimum wage could evolve for the year 2020 are provided.

The result of comparing present and future expected coffee productions suggests that the changes on temperatures and precipitation could cause a reduction of up to 34% in coffee production in Veracruz for year 2020. The expected fall in production would have important repercussions on producers' income and on coffee production economic viability. If we keep coffee price constant, the income of the average producer in year 2020 would not be enough to cover production costs. This situation could lead to government intervention increasing subsidies, crop change and land use change. At the present time, coffee production already relies heavily on subsidies and thus producers are very vulnerable to policy changes (Aguirre Saharrea, 2003; Ávila, 2001). Expected future production could make them rely even more on a subsidy that will be increasingly expensive and inefficient, and that will not contribute to solve the economic situation faced by coffee producers and workers. Adding the international market situation to this picture, makes the vulnerability of the producers more serious. It is important to note that adaptation measures to reduce the effect of climate change are not considered, but it is also important to notice that given the size and instability of producers' income, their adaptation possibilities are very slim.

Forest and ecosystem preservation as well as other environmental services are being explored to make coffee production in the state more economically viable. Nevertheless, the relation between coffee production and forest preservation may not be so clear under climate change. In the previously cited study supported by UNEP, a change in climatic variables similar to the one presented in this paper, would make the areas where now coffee is produced too hot to grow coffee, and make producers move to higher, cooler areas where there are forests today. This adaptation strategy would generate deforestation and land use change in higher lands and probably changes of crops or land uses to more profitable ones, not so environmental friendly, on areas where coffee was grown.

In order to adapt to market conditions TechnoServe (2003) suggests two main lines of action: support high-quality producers to move to specialty coffee and help in-crisis coffee producers and regions to diversify into other livelihoods. While the low production costs of Brasil and Vietnam will make it very difficult for other countries to be competitive, there is an opportunity for high-quality producers to enter more profitable markets such as specialty coffee. In the case of producers and regions that cannot compete in costs or differentiation, the recommended strategy is to search for alternative economic opportunities to diversify their income.

Nevertheless, in the past, coffee producers in Veracruz have shown a limited capacity to adapt to climatic and economic stressors, and this capacity will probably decrease in the future if governmental policies and international market conditions prevail. There are five main reasons the AIACC LA29 has identified to limit the most their adaptation capacity: First, money and access to credit. Most of the coffee producers in Veracruz are small producers and have been seriously affected by the drop in prices, so they have very limited resources (if any) to invest. In addition, access to credit for small producers in Mexico is virtually null. It's possible that some producers can implement some adaptation strategies such as migrating to higher altitudes in case of a warmer climate, or changing to specialty coffee in order to have access to higher prices (probably not small producers but some larger-scale producers that have more economic resources and access to credit) but it is not a very feasible option for most of them.

Second, coffee plantations are a long term investment. For a coffee plant to by productive it has to reach its productive stage (about 3 to 6 years). Taking into account that most of the coffee producers in Veracruz are small scale with very limited resources, moving to another area, changing to specialty coffee or to another crop represents a long term investment that not many of them can afford.

Third, land availability. In Mexico most of the land with agricultural potential already has a owner. The land at higher elevations could be occupied.

Fourth, government support. While there are some palliative government programs like the Fondo de Estabilización del Café (Coffee Stabilizing Fund) that have had a relative success on partially reducing the impact of the coffee price crisis on the livelihood of producers, there is little government support on developing long term solutions, planning and in technical issues.

Fifth, tradition. There is a high component of tradition in coffee production in Mexico. Most of the coffee production developed in the state is denominated "rustic", that is grown inside the forests and in small plantations, inherited from one generation to another. It is almost impossible to conceive that coffee producers will accept radical changes. An example of this is the failure of an institutional effort to limit coffee production and to improve its quality, by reconverting productive lands below 700 meters to crops other than coffee. This has not been accepted by producers and one of their main reasons is tradition.

As is shown in this paper, the potential impacts of climate change on agriculture could be very large. Unfortunately, until now Mexican agriculture institutions do not consider climate change when designing policies, which could turn out to be a very expensive mistake. In the mid-term climate conditions could seriously affect the economic viability for some crops and regions. Further research on adaptation and on exploring new alternatives for producers is required for decision makers to develop effective strategies and policies to overcome future climate impacts and its socioeconomic consequences.

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Notes

[1]A non-monotonic function has a second derivative different from zero. That is, the ratio of the change in the dependent variable to changes in the independent variable is not constant for the domain of the independent variable.

[2]Assessments of Impacts and Adaptation to Climate Change in Multiple Regions (AIACC).The Group of Climate Change and Radiation of the Center for Atmospheric Sciencies, UNAM coordinates the research project "Integrated Assessment of Social Vulnerability and Adaptation to Climate Variability and Change Among Farmers in Mexico and Argentina" supported by the Global System for Analysis, Research and Training (START), the Third World Academy of Sciences (TWAS), and the United Nations Environment Programme (UNEP).

[3]Climate data used for this study corresponds to Douglas' region because it was considered more reliable than the data from meteorological stations located in these municipalities due to their poor quality (Bravo et al., 2005).

[4]Source: http://www.veracruz.gob.mx/secciones.html?seccion=cafe@cafe_en_ver

[5]Coffee production in Vietnam increased from representing a 5% of the world's production in 1991 to the 13% in 2000. Source: http://www.ico.org/frameset/priset.htm.

[6]A daily wage is the economic retribution paid to a temporary worker for a day's work.

[7]Consejo Estatal de Población, Xalapa, Veracruz (http://coespo.ver.gob.mx/boletin11dejulio.htm).

[8]Minimum wage is the lowest legal remuneration for a day's work. Source: INEGI and the Comisión Nacional de Salarios Mínimos.

[9]Source: INEGI and Consejo Nacional de Población.

[10]Obained from the Banco Nacional de México.

[11]Source: SAGARPA and International Coffee Organization.

[12]For example, in 2002 the Mexican Agriculture Ministry instrumented the Fondo de Estabilización del Café (Coffee Stabilization Fund) for partially compensating the producers' income up to $20 USD when the prices are below $70 USD per 100 pounds (source: http://www.sagarpa.gob.mx/sdr/progs2002/fe_cafe.pdf). According to a survey conducted by the Institute for Rural Development of Veracruz (INVEDER), in 2001 a coffee producer received an average of $73 USD per hectare per year from government subsidies.

[13]Coffee stocks in the USA was selected as a potentially relevant variable for the model because the country is the world's largest coffee importer followed by Germany and Japan. Source: International Coffee Organization.

[14]Source: Instituto Mexicano de la Propiedad Industrial, http://www.impi.gob.mx/impi/jsp/indice_all.jsp?OpenFile=docs/marco_j/ext_cafe_veracruz.html

[15]Reliable coffee production statistics for Veracruz were available from SAGARPA for the period 1969–2002. Production data was standardized to tons of arabica cherry coffee.

[16]International Coffee Organization (http://www.ico.org/), the National Federation of Coffee Producers of Colombia (http://www.cafedecolombia.com/), the Coffee Research Institute (http://www.coffeeresearch.com), Naturland 2000, Nolasco 1985.

[17]Infoagro, 2003 (http://www.infoagro.com/).

[18]Instituto para el Desarrollo Técnico de las Haciendas Públicas. http://www.indetec.gob.mx/Coyunturas/Aspectos.asp?start=351.

[19]This is the last 13 years average price in pesos per ton.

[20]In the case of Brasil innovations include cultivating in areas less prone to frosts, improved mechanical harvesting, increased use of irrigation and fetilization and increased use of financial and risk management tools. These innovations have helped to achieve labor productivity levels ten times higher than other producing countries and have allowed lowering production costs.

[21]Considering the fixed average price from the last 13 years. If prices are fixed at their 2001 value, the loss amounts to $10,652.34.

[22]http://www.grida.no/db/maps/prod/level3/id_1243.htm, http://www.useu.be/Categories/Climate Change/Nov0801UNEPCropyields.html

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