EFECTOS CLIMÁTICOS Y PRODUCTIVIDAD EN LECHERÍAS DE WISCONSIN: UN ANÁLISIS PRELIMINAR[1]

A PRELIMINARY ANALYSIS OF CLIMATIC EFFECTS ON THE PRODUCTIVITY OF WISCONSIN DAIRY FARMS

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1. INTRODUCTION

Policy makers and public interest groups are increasingly concerned about the impact of climate change on food safety and agricultural sustainability. Climatic factors, such as temperature and rainfall, have a strong impact on agricultural output (IPCC, 2014). According to the U.S. Environmental Protection Agency (EPA, 2013a), global surface air temperature over land and oceans has risen continuously over the last 100 years, while occurrences of extreme weather events have become commonplace. Climatic variation can be separated into two components: 1) short-term climate variability; and 2) long-term climate change. Short-term climate variability impacts agricultural output directly, while the long-term change induces adaptation strategies that can lead to structural changes in farming (Mendelsohn, Nordhaus and Shaw, 1994). Therefore, comprehensive analyses of the connection between climatic effects and agricultural productivity of dairy farms are of increasing importance.

The agricultural sector, which contributes at least $200 billion to the U.S. economy per year (USGCRP, 2009), is more sensitive and vulnerable to climate change than other sectors (IPCC, 2014). The livestock sector is particularly vulnerable to hot weather, especially in combination with high humidity, which can lead to significant losses in productivity and, in extreme cases, to animal death (Boyles, 2008; Mader, 2003). Besides its direct effect on animals, climatic conditions also affect feed supplies by influencing the growth of silage and forage (Hill et al., 2004).

The focus of this paper is the dairy industry, which is the fourth largest agricultural subsector in the United States. There is a significant body of animal and dairy science literature, briefly reviewed below, that clearly establishes the susceptibility of dairy cows to extreme weather conditions (Calil et al., 2012; IPCC, 2014). However, the economic literature on this subject remains quite limited. Thus, the need to introduce climatic effects into models of dairy production economics is an important motivation for this research.

The general objective of this study is to contribute to the understanding of the effect of climatic variables on dairy farm productivity. The specific objectives are to explore appropriate definitions and measures of climatic effects, and then use alternative stochastic frontier panel data models to analyze the relationship between dairy productivity and climatic effects using panel data for the state of Wisconsin. The specification of our model makes it possible to calculate a total climatic effect as well partial effects for temperature, precipitation and seasons. This analysis is a novel contribution to the dairy productivity literature.

A noteworthy feature of this analysis is that Wisconsin is the second largest dairy producing area in the U.S. where winters can be very cold and snowy, and summers hot and humid. Thus, it is an ideal geographical region to examine the effects of a range of climatic factors on dairy production.

The paper is organized as follows. The next section provides an overview of the literature on the effects of climatic conditions on dairy productivity and on crop growth. The data and a general model are discussed in Section 3, and then Section 4 presents alternative panel data production frontier models and the climatic effect index. Section 5 contains the analysis and results, and Section 6 presents a summary and our main conclusions.

2. LITERATURE REVIEW

In general, research on the connection between climatic variables and livestock has focused on output related effects. Dairy cattle experience stress when their core body temperature is out of the thermoneutral zone (Allen et al., 2013; West 2003) and core body temperature is normally higher than ambient temperature (Collier, Dahl and VanBaale, 2006). When heat or cold stress requires the cow to increase the amount of energy used to maintain body temperature, less energy is available for milk production (Collier et al., 2011). The thermoneutral zone is between 41 F° and 77 F°, and depends on many factors such as age, breed, feed intake, diet, production, and housing (Roenfeldt, 1998). For example, under the same housing conditions, the "comfort zone" of European cattle was found to be between about 30 F° and 60 F° while for Indian cattle this zone was found to be between 50 F° and 80 F°. A temperature outside of this zone has adverse effects on livestock productivity (Brody, 1956).

Heat stress is much more likely to occur in lactating cows during hot and humid summer days. Heat stress is not only related to temperature, but also to air humidity, and it affects the capacity of the cow to dissipate heat. Consequently, the Temperature Humidity Index (THI) has been developed and widely used (Kadzere et al., 2002) to measure heat stress suffered by dairy cattle. It is based on ambient temperature and Relative Humidity (RH). THI values above 68 (71.96 F° with 45% RH to 80.06 F° with 0% RH) are currently accepted as the lower thresholds of heat stress (Zimbelman et al., 2009). Heat stress will occur above these thresholds and its severity will increase as the THI increases.

Heat stress affects feed intake, feed efficiency, milk yield, reproductive efficiency, cow behavior, and disease incidence (Cook et al., 2007; Tucker, Rogers and Shutz, 2007; Rhoads et al., 2009). It is estimated that dry matter intake (DMI) decreases by up to 40% when ambient temperature is 104 F° (NRC, 2001). It is also well established that there is a significant negative correlation between THI and DMI (Holter et al., 1996) and, consequently, a negative correlation between THI and milk yield. Milk yield losses (kg/d per cow) were estimated to be between 0.32 (Ingraham, Stanley and Wagner, 1979) and 0.20 (Ravagnolo, Misztal and Hoogenboom, 2000) per unit increase in THI for THI values above 72. Mukherjee, Bravo-Ureta and Vries (2013) incorporated an annual average THI in a production frontier model and found a significant negative effect on output. Another study conducted by Seo and Mendelsohn (2008) used a discrete choice model and examined how farmers change choices of livestock species and numbers to adapt to climatic change.

St-Pierre, Cobanov and Schnitkey (2003) documented that heat stress affects livestock in all U.S. continental states, although with considerable spatial variation. They calculated the overall U.S. dairy industry effects due to heat stress by aggregating its effects on DMI, milk yield, reproduction, culling, and death, and estimated that total losses would add up to about $900 million/yr ($100/cow per year) even when heat abatement systems were in place. The loss would be as high as $1.5 billion/yr ($167/cow per year) without abatement systems.

Cold stress is another climatic element that reduces output in some areas. At low temperatures, more dietary energy is needed for cows to maintain body temperature. Cold stress causes animals to consume more feed but to produce less milk, and it also increases milk fat content (Young, 1981). In comparison to heat stress, cold stress is a regional problem that arises in the northern U.S. during winter months.

The literature reveals a variety of methods to measure and incorporate climatic effects in crop and livestock farming (e.g., Mendelsohn, Nordhaus and Shaw, 1994; Kelly, Kolstad and Mitchell, 2005; Arriagada, 2005; Schlenker, Hanemann and Fisher 2006; Deschenes and Greenstone, 2007). In this analysis, we define winter and summer averages for temperature and precipitation to capture the climatic effect. Using temperature and precipitation directly, instead of an index such as THI, allows for a clear interpretation of the climate effect on the dependent variable of interest.

3. DATA AND EMPIRICAL MODEL

The data used for empirical estimation is derived from two sources. The input-output data contains a total of 9437 observations for 958 dairy farms scattered around 52 Wisconsin counties over the 17-year period going from 1996 to 2012. This data comes from the Agricultural Financial Advisor (AgFA; http://cdp.wisc.edu/agfa.htm) program. For this study we include 221 farms that have information for 10 or more consecutive years, which yields a total of 3,070 observations in 24 counties. A total of 54 farms have data for the full 17-year period.

The temperature and precipitation data are obtained from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) maps[2]. We use Geographic Information System (GIS) techniques to generate monthly mean temperature and precipitation for each county and year. Finally, the two data sets (input-output and climate) are merged based on county and year identifiers.

The general model specified in this study can be expressed in general terms as:

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[2] Data is available at: http://www.prism.oregonstate.edu/recent/

$$\text{MILK} = f\,(\text{COW, LAB, FEED, CAP, ANEX, CREX, HOTT, COLT, HOTR, COLR, T, T}^2) \tag{1}$$

where:

$MILK$ = total milk equivalent production in cwt (which is equal to 45.4 kg) of dairy farms per year;

COW = number of adult cows in dairy farm;

LAB = total hours of labor including family paid and unpaid labor and management, and hired labor;

$FEED$ = 16% protein-mixed dairy feed equivalent in metric tons;

CAP = book value of breeding livestock, machinery and equipment, and buildings, measured in constant 2012 dollars;

$ANEX$ = animal expenses including veterinary and medicine, breeding fees, and other livestock expense, measured in constant 2012 dollars;

$CREX$ = crop expenses including chemical, fertilizer, seeds and plants, gas and fuel, rented machinery, and other crop expense, measured in dollars constant 2012 dollars.

$HOTT$ = average temperature (F°) in summer (i.e., June, July and August);

$COLT$ = average temperature (F°) in winter (i.e., December, January and February);

$HOTR$ = average precipitation (mm) in summer;

$COLR$ = average precipitation (mm) in winter.

T = time trend;

T^2 = time trend square.

Descriptive statistics for output, inputs and climatic variables are presented in Table 1.

4. METHOLOGY

4.1 Models

Equation (1) is specified as a stochastic production frontier (SPF) model and alternative panel data formulations are explored. Greene (2005 a, b) proposed the "true" fixed and random effects models to capture time invariant heterogeneity along with time-variant technical efficiency. The "true" fixed effects model allows for correlation between the regressors and the heterogeneity term, while the "true" random effects model assumes no correlation (Greene, 2005b). A variant of the "true" random effects model, which relies on Mundlak's specification (1978) to account for possible correlation between regressors and unobserved factors, is also considered below (Abdulai and Tietje, 2007).

In order to select the most robust model the following five alternatives are compared: 1) pooled frontier model without climatic variables; 2) pooled frontier model with climatic variables; 3) "true" fixed effect model with climatic variables; 4) "true" random effect model with climatic variables; and 5) "true" random effect model with Mundlak's specification and climatic variables. A battery of statistical tests is performed to arrive at the most robust model, which is then used to undertake a comprehensive efficiency and productivity analysis with special focus on climatic effects.

The basic SPF model adopted in this analysis is a Cobb-Douglas stochastic production frontier, which is written as:

$$\ln Y_{it} = \alpha + \sum_{k=1}^{6} \beta_k \ln X_{kit} + \sum_{s=1}^{4} \gamma_s Z_{sit} + \theta_1 T + \theta_2 T^2 + v_{it} - u_{it} \qquad (2)$$

where: Y_{it} is output (*MILK*) for the ith farm in period t; X_{kit} is the kth input as defined above (*COW* thru *CREX*); Z_{sit} is the sth climatic variable (*HOTT* thru *COLR*) as defined above, and T denotes the time trend. $\boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma},$ and $\boldsymbol{\theta}$ are vectors of parameters to be estimated. The component v_{it} has a symmetric normal distribution where $\mathrm{v}_{\mathrm{it}} \sim \mathrm{iid}\ \mathrm{N}(0, \sigma_{\mathrm{v}}^2)$; and u_{it} follows an exponential distribution. These two terms are assumed to be independent of each other. Thus, v_{it} denotes the variation from the frontier resulting from external events such as luck or machine performance, and u_{it} captures technical inefficiency reflecting managerial ability.

Based on equation (2) the key features of the five alternative model specifications considered (Model 1-5) are briefly presented below.

Model 1. Pooled SPF model without climatic variables: In this model, all of the observations are pooled together as if the data was cross-sectional. This model, which provides a benchmark specification, can be written as:

$$\ln Y_{it} = \alpha + \sum_{k=1}^{6} \beta_k \ln X_{kit} + \theta_1 T + \theta_2 T^2 + v_{it} - u_{it} \qquad (3)$$

Model 2. Pooled SPF model with climatic variables: Model 2 incorporates climatic variables to equation (3), which becomes:

$$\ln Y_{it} = \alpha + \sum_{k=1}^{6} \beta_k \ln X_{kit} + \sum_{s=1}^{4} \gamma_s Z_{sit} + \theta_1 T + \theta_2 T^2 + v_{it} - u_{it} \qquad (4)$$

Thus, Models 1 and 2 make it possible to test the null hypothesis that climatic effect are not relevant; i.e., H_0: $\gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = 0$.

Model 3. "True" fixed effects (TFE) model with climatic variables: Models 1 and 2 ignore possible unobserved heterogeneity, which can lead to biased estimates. Model 3 incorporates the term α_i to capture a farm-specific fixed effect and is written as:

$$\ln Y_{it} = \alpha_i + \sum_{k=1}^{6} \beta_k \ln X_{kit} + \sum_{s=1}^{4} \gamma_s Z_{sit} + \theta_1 T + \theta_2 T^2 + v_{it} - u_{it} \tag{5}$$

This model can be estimated by maximizing the unconditional log likelihood function directly (Greene, 2005b).

Model 4. "True" random effects (TRE) model with climatic variables: This model incorporates a heterogeneity term $w_i \sim \text{iid N}(0, \sigma_w^2)$ which is randomly distributed and is assumed to be uncorrelated with all other regressors. It is specified as:

$$\ln Y_{it} = \alpha + w_i + \sum_{k=1}^{6} \beta_k \ln X_{kit} + \sum_{s=1}^{4} \gamma_s Z_{sit} + \theta_1 T + \theta_2 T^2 + v_{it} - u_{it} \tag{6}$$

Equation (6) can be estimated as a standard SFP model with random coefficients. Further, the Hausman test (Hausman, 1978; Greene, 2008) is used to evaluate the hypothesis of independence of farm-specific heterogeneity and other variables.

Model 5. "True" random effects model with the Mundlak specification (TRE-M) and climatic variables. A shortcoming of the TRE model is ignoring the possible correlation between the heterogeneity effects and other regressors. To address this shortcoming, Abdulai and Tietje (2007) based on Mundlak (1978) redefine the heterogeneity term w_i by expressing it as a function of the group means of regressors:

$$w_i = \sum_{k=1}^{6} \delta \overline{\ln X}_{ki} + \overline{m}_i \tag{7}$$

where $\overline{\ln X}_{ki}$ represents the average value for the k^th regressor over time for farm i, and $\overline{m}_i \sim \text{iid N}(0, \sigma_{\overline{m}}^2)$ is uncorrelated with all other regressors. Thus, the model can be written as:

$$\ln Y_{it} = \alpha + \overline{m}_i + \sum_{k=1}^{6} \beta_k \ln X_{kit} + \sum_{s=1}^{4} \gamma_s Z_{sit} + \sum_{k=1}^{6} \delta \overline{\ln X}_{ki} + \theta_1 T + \theta_2 T^2 + v_{it} - u_{it} \tag{8}$$

Equations (6) and (8) can be estimated using a Maximum Simulated Likelihood approach.

4.2 Climatic Effects

According to Hughes et al. (2011), the Climatic Effect Index (*CEI*) is the joint effect of all climatic variables included in the production frontier on output, holding conventional inputs and other variables constant. Thus, given the models above, the estimated climatic parameters are $\hat{\boldsymbol{\gamma}}$, so the total CEI for farm i at time t, holding all else constant, can be written as:

$$CEI_{it} = exp\ (\sum_{s=1}^{4} \hat{\gamma}_s Z_{sit}) \tag{9}$$

Given the way we have incorporated the climatic variables, in addition to the total *CEI* in equation (9), it is possible to generate the following four partial *CEI* expressions: *CEI* for temperature; *CEI* for precipitation; *CEI* for winter; and *CEI* for summer. Thus, these partial *CEI*s are the following:

$$CEI\_temp_{it} = \exp\ (\hat{\gamma}_1 Z_{1it} + \hat{\gamma}_2 Z_{2it}) \tag{10}$$

$$CEI\_prep_{it} = \exp\ (\hat{\gamma}_3 Z_{3it} + \hat{\gamma}_4 Z_{4it}) \tag{11}$$

$$CEI\_summer_{it} = \exp\ (\hat{\gamma}_1 Z_{1it} + \hat{\gamma}_3 Z_{3it}) \tag{12}$$

$$CEI\_winter_{it} = \exp\ (\hat{\gamma}_2 Z_{2it} + \hat{\gamma}_4 Z_{4it}) \tag{13}$$

These four *CEI* terms provide a rich perspective for examining the climatic effects on dairy farming. We note that this analysis is a novel contribution of this paper to the dairy productivity literature.

5. RESULTS

The estimated results for Models 1 through 5 are presented in Table 2. The null hypothesis that all coefficients are zero is rejected for all models. Furthermore, the estimated coefficients of the six conventional inputs are all significant with the expected positive sign and values (i.e., between 0 and 1). Dairy herd size is the main input influencing production, a finding consistent with several other papers that have a similar specification (e.g., Mukherjee, Bravo-Ureta and Vries, 2013; Key and Sneeringer, 2014). Concentrate feed is the second most important input when unobserved heterogeneity is included (elasticities ranging from 0.089 to 0.096). In contrast, when heterogeneity is ignored, expenditure on crops is the second most important input. This difference suggests that the exclusion or the inclusion of heterogeneity in the production frontier deserves attention. The coefficients for the labor input are very close across all five models while the coefficients for animal expenditures and capital are larger in the pooled models compared to the other three. The five models exhibit decreasing returns to scale ranging from 0.91 (Model 3) to 0.97 (Model 1).

The impact of the climatic variables is also consistent for models 2 through 5: an increase in temperature in the summer has a negative effect on output while the opposite is noted in winter; and higher precipitation has an adverse effect in both summer and winter.

We conducted a likelihood ratio test between Model 1 and Model 2, and the results lead to the rejection of the hypothesis that the coefficients of the climatic variables are jointly zero. Thus, climatic variables should be included in the specification of the production frontier model.

Turning to Models 3, 4 and 5, which include unobserved heterogeneity and climatic variables, we first test the TFE vs. the TRE, which is a test of the null hypothesis that unobserved heterogeneity is independent of the other explanatory variables. The results of the Hausman test reject this hypothesis, which means that the TFE model (Model 3) dominates the TRE (Model 4). The final step in the model selection is to evaluate Model 5, the TRE-M specification, which entails a test of the null hypothesis that the parameters of the mean value of the conventional inputs are jointly zero. In this case we use a likelihood ratio test and the results lead to the rejection of the null hypothesis thus lending support to the TRE-M model. In sum, these tests indicate that unobserved heterogeneity is better represented by a random specification while accommodating correlation with the regressors. Therefore, the discussion that follows is based on the estimates for Model 5.

The analysis of the climatic effect is key in this paper so we now turn to this issue. According to Model 5, a one-unit increase in temperature (1 F°) in summer leads to a 0.58% reduction in output. In addition, a 1 cm increase in precipitation in summer, leads to a 0.37% reduction in output because it can increase humidity, which reduces the capability of cows to dissipate heat. Precipitation in winter is also harmful and a 1 cm increase leads to a 0.47% reduction in output. It is interesting to note that a "warmer" winter has a positive effect and in this case a one-unit increase in temperature leads to a 0.048% rise in output.

Table 3 shows the average annual technical efficiency (TE) estimated by each model, and Figure 1 represents the evolution of average technical efficiency over time based on Models 1, the benchmark, and 5, the preferred specification. The overall Average TE is high at 93.4% compared to the results summarized in the meta-analysis by Bravo-Ureta et al. (2007). The average TE from Model 5 (93.4%) is higher than Model 1 (92.1%), which is consistent with the fact that Model 5 separates farm heterogeneity from the TE term. However, average TE is considerably more variable for Model 5 compared to Model 1.

Figure 2 summarizes the average annual values of the four climatic variables considered. Table 3 presents the annual average CEIs based on equations 9 through 13. We first compute the annual mean for each of the four climatic variables and insert these mean values in the corresponding equation to get the annual value of each partial CEI. We should note that higher CEI values imply a positive climatic effect on dairy production whereas lower ones have the opposite effect.

Table 3 shows the average annual total and partial CEI values for each year. The table indicates that temperature has a larger negative impact than precipitation, and that the climate effect has a negative effect on production in summer while the effect in winter is positive. The value of total CEI has a small variation between years, but it reveals a slight downward trend over the years.

Now, we are interested in examining the relationship between milk output and the CEI. To do so, we hold the conventional inputs and the time trend at their mean value, and (total)

CEI at its annual average value. Then, combining equations 9 and 2, and ignoring inefficiency, the production frontier can be rewritten as:

$$\hat{Y}_t = \widehat{CEI}_t \times exp\ (\hat{\alpha} + \sum_{k=1}^{6} \hat{\beta}_k \ln \bar{X}_k + \hat{\theta}_1 \bar{T} + \hat{\theta}_2 \overline{T^2}) \tag{14}$$

Figure 3 reflects the estimated output change over time with respect the total CEI for he past 17-year period under study. The data shows wide variability but a slight negative trend over time indicating that the climate effect has gradually led to declines in output holding all else constant.

An additional point we address concerns the impact of extreme climatic effects on output. To do this, we define a best and a worst case scenario. The best case scenario, $\mathrm{CEI}_{\mathrm{best}}$, is constructed as follows: 1) The lowest yearly average summer precipitation (53.6 mm) lowest average precipitation in winter (15.2 mm); 3) lowest average temperature in summer (60.3 F°); and 4) highest average temperature in winter (30.5 F°). In contrast, the worse case scenario, $\mathrm{CEI}_{\mathrm{worst}}$ is defined as follows: 1) highest annual precipitation in summer (188.3 mm); 2) highest precipitation in winter (77.5 mm); 3) highest temperature in summer (73.2 F°); and 4) lowest temperature in winter (9.9 F°). Figure 4 shows the annul maximum and minimum values for each these climatic variables.

To compare the results of the scenarios we define a baseline using the average CEI value calculated from equation (9) and the 17-year mean for each of the four climatic variables introduced in the model. This average CEI value is 0.780 as depicted in Table 5. As shown in that same Table, the total CEI for the best and worst case scenarios are 0.796 and 0.619, respectively. The baseline output value is equal to 32,087 cwt. per farm. By comparison, under the best case scenario output increases to 35,982 cwt., which represents a 12.4% rise. The worst case scenario reveals a level output equal to 27,972 cwt. or a 12.8% drop relative to the baseline. Thus, the range between the worst and best case scenario is a total of 8,008 cwt.

6. CONCLUDING REMARKS

Understanding the effect of climatic conditions on dairy farm output is critical to the future of the industry as global warming continues. However, little to no economic research has quantified its impact on milk production using data from operating commercial dairy farms. This paper contributes to the literature by introducing four climatic variables into alternative SPF models and deriving measures of the climate effect.

The results reveal that climatic effects are significant on dairy farming. In particular, higher summer month temperatures are harmful for dairy production, while a warmer winter is beneficial. The findings reveal that higher precipitation is consistently deleterious for dairy production in Wisconsin. The results also suggest that, holding all other factors constant, there is a mild negative association between the climatic effect and dairy farm output over the past 17 years in Wisconsin. Thus, if such a trend continues, research and extension efforts will be needed to promote adaptation strategies.

Table 1. Descriptive Statistics for Wisconsin Dairy Farms: 1997-2012 (3,070 Observations)

Variable	Mean	Std. Dev.	Min	Max
MILK (cwt=45.4 kg)	28,981	39,157	2,643	451,541
COW (head)	106	127	21	1,650
LAB (hour)	6,718	7,798	13	75,597
CAP (2012 $)	77,823	97,216	109	1,196,189
FEED (metric ton)	699	1,230	7	15,488
ANEX (2012 $)	45,696	104,990	95	1,188,064
CREX (2012 $)	91,655	95,119	615	1,057,084
T	9.1	4.4	1.0	17.0
T^2	103	83	1	289
HOTT (F)	68.0	2.1	60.3	73.2
COLT (F)	21.1	4.1	9.9	30.5
HOTR (mm)	95.6	25.4	53.6	188.3
COLR (mm)	36.9	11.3	15.2	77.5

Table 2. Parameter Estimates for Five Stochastic Production Frontier Models

	Pooled Models		Models Including Unobserved Heterogeneity		
Variable	Model 1 W/o Climate	Model 2 With Climate	Model 3 (TFE)	Model 4 (TRE)	Model 5 (TRE-M)
lnCOW	0.552 *** (0.016)	0.548 *** (0.016)	0.644 *** (0.020)	0.645 *** (0.019)	0.642 *** (0.020)
lnLAB	0.051 *** (0.011)	0.055 *** (0.011)	0.042 *** (0.010)	0.053 *** (0.011)	0.043 *** (0.010)
lnFEED	0.099 *** (0.006)	0.100 *** (0.006)	0.095 *** (0.008)	0.089 *** (0.008)	0.096 *** (0.008)
lnCAP	0.056 *** (0.004)	0.057 *** (0.004)	0.032 *** (0.004)	0.035 *** (0.004)	0.032 *** (0.004)
lnANEX	0.088 *** (0.005)	0.089 *** (0.005)	0.038 *** (0.007)	0.051 *** (0.007)	0.037 *** (0.007)
lnCREX	0.163 *** (0.006)	0.160 *** (0.006)	0.061 *** (0.007)	0.09261 *** (0.009)	0.062 *** (0.007)
HOTT		-0.003 (0.002)	-0.00684 *** (0.002)	-0.00676 *** (0.002)	-0.00575 *** (0.002)
COLT		0.003 *** (0.001)	0.00530 *** (0.001)	0.00503 *** (0.001)	0.00477 *** (0.001)
HOTR		-0.00032 ** (0.0001)	-0.00037 *** (0.0001)	-0.00037 *** (0.0001)	-0.00037 *** (0.0001)
COLR		-0.00051 * (0.0003)	-0.00043 *** (0.0002)	-0.00040 ** (0.0002)	-0.00047 *** (0.0002)
avglnCOW					-0.182 *** (0.053)
avglnLAB					0.028 (0.033)
avglnFEED					-0.001 (0.021)
avglnCAP					0.074 *** (0.016)
avglnANEX					0.054 *** (0.017)
avglnCREX					0.111 *** (0.015)
T	0.026 *** (0.003)	0.025 *** (0.002)	0.030 *** (0.002)	0.029 *** (0.002)	0.030 *** (0.002)
T^2	-0.0004 *** (0.0002)	-0.0004 ** (0.0001)	-0.001 *** (0.0001)	-0.001 *** (0.0001)	-0.001 *** (0.0001)
Constant	3.072 *** (0.065)	3.229 *** -0.136		4.469 *** (0.144)	2.966 *** (0.173)
Level of Significance: ***1%, **5%, *10%					

Table 3. Average Annual Technical Efficiency for Wisconsin Dairy Farms: 1996-2012

Year	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
	W/o Climate	**With Climate**	**(TFE)**	**(TRE)**	**(TRE-M)**
1996	0.918	0.930	0.932	0.936	0.934
1997	0.927	0.940	0.944	0.947	0.945
1998	0.914	0.921	0.914	0.920	0.918
1999	0.924	0.937	0.947	0.947	0.947
2000	0.927	0.940	0.949	0.944	0.946
2001	0.909	0.917	0.906	0.910	0.907
2002	0.926	0.935	0.940	0.938	0.939
2003	0.932	0.944	0.956	0.951	0.954
2004	0.909	0.916	0.908	0.910	0.911
2005	0.920	0.931	0.940	0.937	0.938
2006	0.932	0.943	0.952	0.948	0.950
2007	0.904	0.913	0.912	0.911	0.910
2008	0.920	0.935	0.944	0.941	0.940
2009	0.931	0.940	0.947	0.944	0.946
2010	0.918	0.930	0.936	0.940	0.936
2011	0.911	0.916	0.913	0.921	0.916
2012	0.928	0.938	0.945	0.948	0.946
Average	**0.921**	**0.931**	**0.934**	**0.935**	**0.934**
Minimum	**0.828**	**0.746**	**0.702**	**0.291**	**0.585**
Maximum	**0.961**	**0.970**	**0.975**	**0.972**	**0.973**

Table 4. Average Annual CEI Values Based on the TRE-M Model

Year	CEI_total	CEI_temp	CEI_prep	CEI_summer	CEI_winter
1996	0.703	0.744	0.944	0.672	1.073
1997	0.714	0.759	0.941	0.674	1.091
1998	0.732	0.770	0.951	0.666	1.122
1999	0.703	0.750	0.937	0.663	1.090
2000	0.701	0.744	0.942	0.672	1.073
2001	0.713	0.751	0.949	0.665	1.096
2002	0.724	0.760	0.953	0.663	1.121
2003	0.717	0.745	0.963	0.673	1.087
2004	0.720	0.756	0.953	0.681	1.077
2005	0.704	0.736	0.957	0.658	1.084
2006	0.728	0.761	0.957	0.662	1.110
2007	0.695	0.736	0.944	0.663	1.073
2008	0.681	0.732	0.930	0.663	1.047
2009	0.714	0.747	0.956	0.679	1.065
2010	0.688	0.736	0.935	0.664	1.084
2011	0.707	0.742	0.952	0.665	1.086
2012	0.722	0.756	0.956	0.658	1.112
Average	0.710	0.748	0.948	0.667	1.088

Note:
CEI_total=CEI_temp* CEI_prep
CEI_total=CEI_summer*CEI_winter

Table 5. Scenario Analysis

	CEI	Output (cwt)	Output Change (%)
Baseline	0.780	32,087	0
Best Case Scenario	0.796	35,982	+12.4%
Worst Case Scenario	0.619	27,974	-12.8%

Figure 1. Average, Maximum and Minimum Technical Efficiency for Wisconsin Dairy Farms (Model 1 and 5): 1996-2012

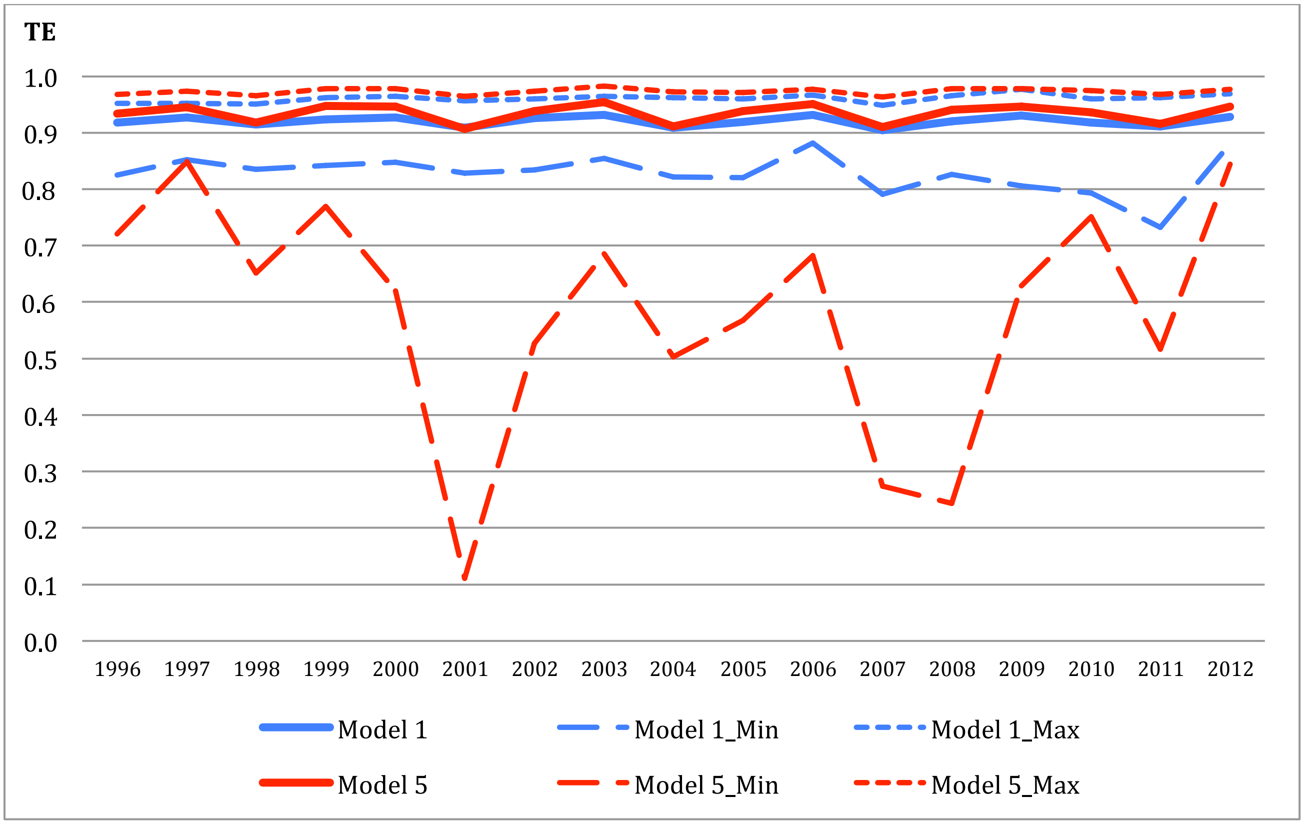


Figure 2. Average Winter and Summer Temperatures and Precipitation in Wisconsin: 1996-2013

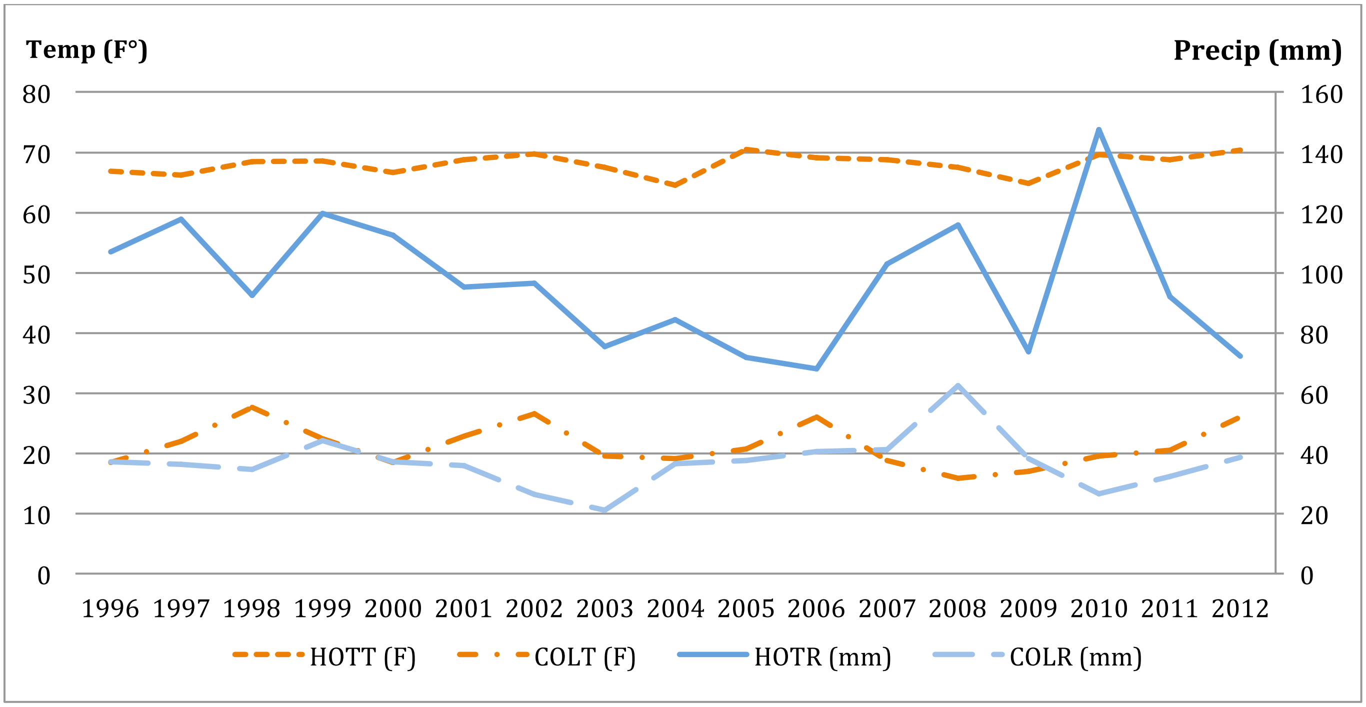


Figure 3. Annual Output and Total Climatic Effect (CEI) using the RFE- M Model

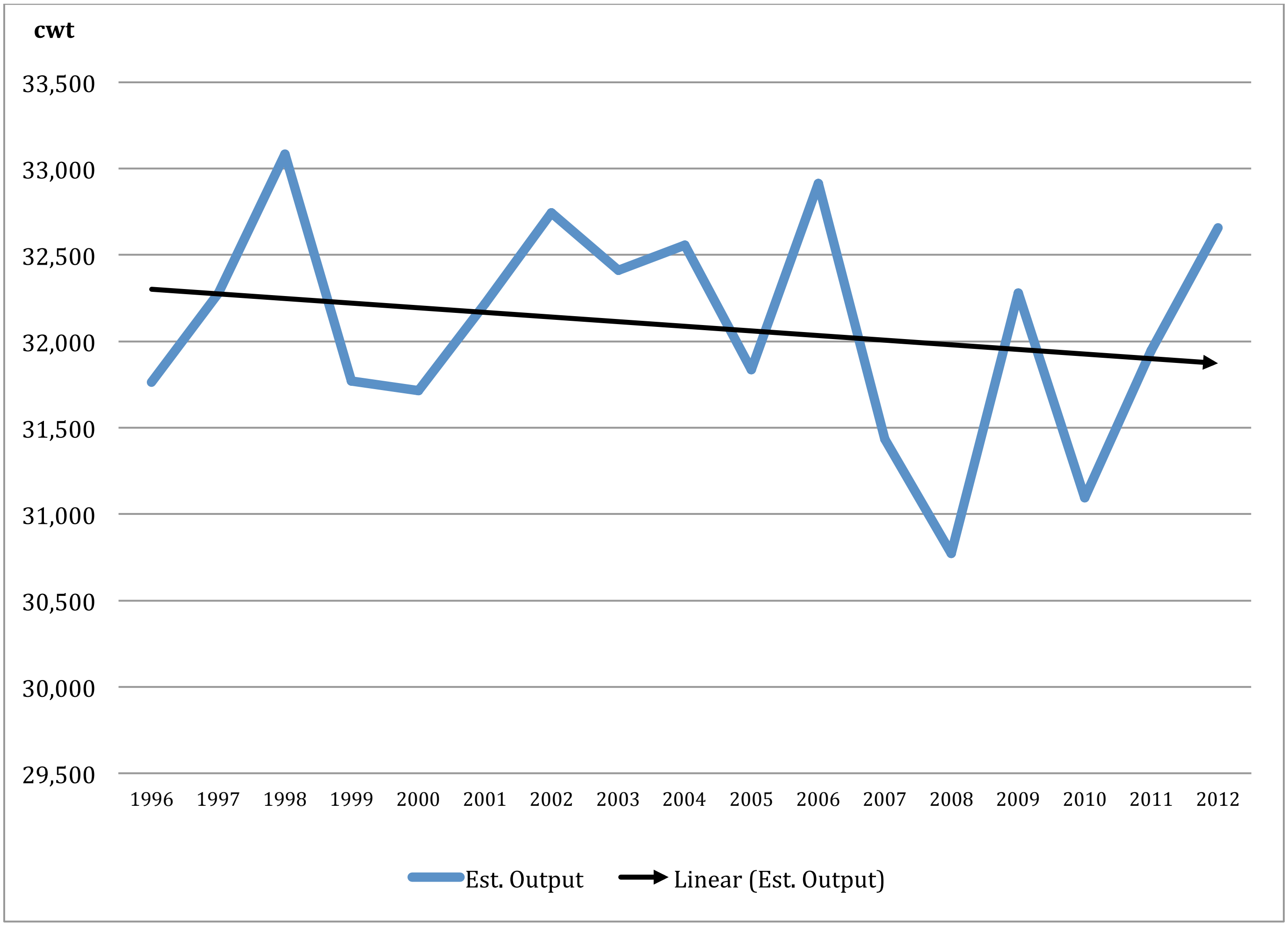
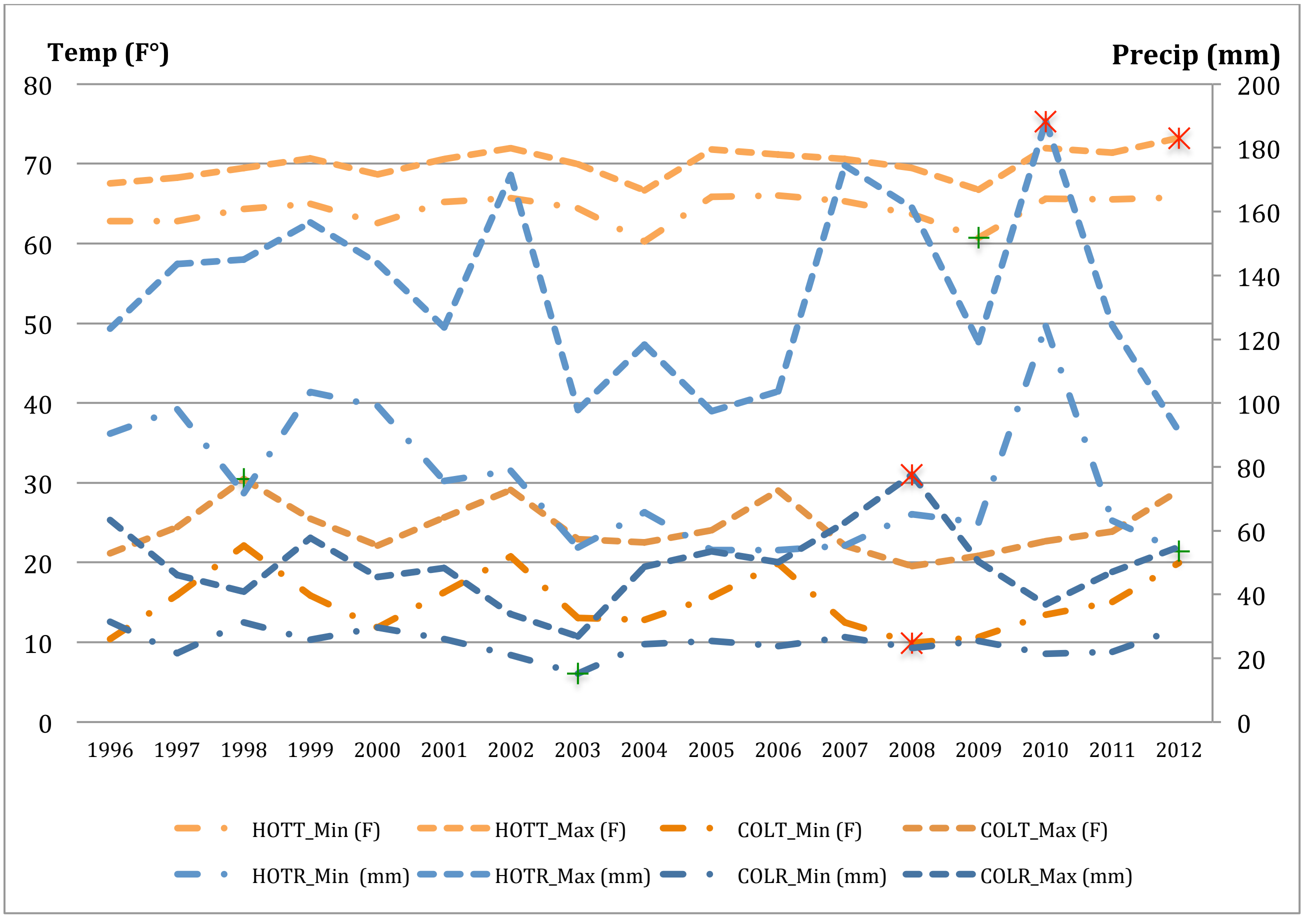


Figure 4. Annual Maximum and Minimum Values of Climatic Variables



Note:
* denotes the value used to calculate CEI for the worst case scenario.
+ denotes the value used to calculate the CEI of the best case scenario.

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