FROM COLD TO HOT: A PRELIMINARY ANALYSIS OF CLIMATIC EFFECTS ON THE PRODUCTIVITY OF WISCONSIN DAIRY FARMS

Lingqiao Qi
Department of Agricultural and Resource Economics, University of Connecticut
lingqiao.qi@uconn.edu

Boris E. Bravo-Ureta
Department of Agricultural and Resource Economics, Department of Economics, University of Connecticut
Department of Agricultural Economics, University of Talca, Chile.
boris.bravoureta@uconn.edu

Victor E. Cabrera
Department of Dairy Science, University of Wisconsin-Madison.
victor.cabrera@ces.uwex.edu

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Abstract: This study examines the effect of climatic variables on dairy farm productivity using panel data for the state of Wisconsin along with alternative stochastic frontier models. A noteworthy feature of this analysis is that Wisconsin is a major dairy producing area where winters are typically very cold and snowy, and summers hot and humid. Thus, it is an ideal geographical region for examining the effects of a range of climatic factors on dairy production. This paper presents a preliminary analysis of the climatic effect on the productivity of Wisconsin farms. We identify the effect of temperature and precipitation, both jointly and separately, on milk output. The analysis shows that increasing temperature in summer or in autumn is harmful for dairy production, while warmer winters and warmer springs are beneficial. By contrast, more precipitation has a consistent adverse effect on dairy productivity. Overall, in the past 17 years, climatic conditions have had a negative impact on the dairy farms in Wisconsin and the data reveals a mild negative trend.

Key words: climatic effect, dairy production, stochastic production frontiers, Wisconsin

JEL classification: Q12, D24

1. INTRODUCTION

There is an increasing concern about the impact of climate change on food security and agricultural sustainability among policy makers and public interest groups. The U.S. Environmental Protection Agency (EPA, 2013) reports that global surface air temperature over land and oceans has risen steadily over the last 100 years, while extreme weather events have become routine. Climatic factors, such as temperature and rainfall, have a strong impact on agricultural output (IPCC, 2014), which induces adaptation strategies that can lead to structural changes in farming (Mendelsohn, Nordhaus and Shaw, 1994).

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). Comprehensive analyses of the connection between climatic effects and agricultural productivity of dairy farms are of increasing importance.

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 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 paper 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. These extremes are ideal to explore 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 5 C° and 25 C°, 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 -1.11 C° and 15.56 C° while for Indian cattle this zone was found to be between 10 C° and 26.67 C°. A temperature outside of thermoneutral zone has adverse effects on livestock productivity (Brody, 1956).

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 (22.2 C° with 45% RH to 26.7 C° with 0% RH) are currently accepted as the lower thresholds of heat stress (Zimbelman et al., 2009).

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. 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 40 C° (NRC, 2001).

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.

Climatic conditions have a strong impact on livestock productivity and on dairy sector. 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. St-Pierre, Cobanov and Schnitkey (2003) documented that heat stress affects livestock in all U.S. continental states, although with considerable spatial variation. They 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. Another study conducted by Seo and Mendelsohn (2008) used a discrete choice model and showed that farmers change choices of livestock species and numbers to adapt to climatic change.

Dairy production is influenced by temperature and precipitation, and even one of these variables can have a different effect in different seasons. 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). These studies usually use temperature, precipitation, and even heat degree-day to reflect climatic effect on crop production.

This analysis adopts the seasonal averages for temperature and average precipitation to capture the climatic effects. 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. What is more, this study redefines the length of each season according to the monthly average temperature in the State of Wisconsin.

3. DATA AND EMPIRICAL MODEL

Wisconsin is one of the largest dairy producing areas in the U.S. According to the National Agricultural Statistics Service (NASS), total milk production in Wisconsin was 27,572 million pounds in 2013, accounting for nearly 14% of U.S. total milk production. The total number of milk cows was 1.271 million in 2013, which is 32% lower than what it was in 1991. The total number of dairy farms was 30,000 in 1993 dropping to 14,200 in 2007, and only 2,100 of these farms had less than 30 cows compared to 6,700 in 1993. In contrast, 280 farms had more than 500 cows in 2007, a number that was five times larger than ten years earlier. These figures reveal a major and rapid structural change in the Wisconsin dairy sector.

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. The temperature and precipitation data are obtained from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) maps[1]. We use Geographic Information System (GIS) techniques to generate monthly mean temperature and precipitation for each county and year. The two data sets (input-output and climate) are merged based on county and year identifiers.

This study divides the year into four seasons: summer June to September; winter includes December, January, February and March; spring is from April to May; and autumn includes October and November. Based on this definition, the average temperature in winter is around -5 C°, and the average temperature in summer is around 19 C° (Figure 1). Average precipitation in spring and in summer is larger than in autumn and in winter. The highest average precipitation was 14.5 cm in spring of 2004 (Figure 2).

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

For this analysis, we include a total of 54 farms that have data for the full 17-year period. Thus, it derives a balanced panel data with 918 observations. Descriptive statistics for output, inputs and climatic variables are presented in Table 2.

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

$$\text{MILK} = f(\text{COW, LAB, CFEED, DEP, ANEX, CREX, SPRT, SUMT, AUTT, WINT, SPRP, SUMP, AUTP, WINP}, T, T^2) \quad (1)$$

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;

CFEED = 16% protein dairy concentrate feed in metric tons;

DEP = value of breeding livestock depreciation, machinery and equipment depreciation, and buildings depreciation, 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;

SPRT = average temperature (C°) in spring (April and May);

SUMT = average temperature (C°) in summer (June, July, August and September);

AUTT = average temperature (C°) in autumn (October and November);

WINT = average temperature (C°) in winter (December, January, February and March);

SPRP = average precipitation (cm) in spring;

SUMP = average precipitation (cm) in summer;

AUTP = average precipitation (cm) in autumn;

$WINP$ = average precipitation (cm) in winter.

T = time trend.

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).

In order to select the most robust model the following four 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. 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:

$$\ln Y_{it} = \alpha + \sum_{k=1}^{6} \beta_k \ln X_{kit} + \sum_{s=1}^{8} \gamma_s Z_{sit} + \theta_1 T + \theta_2 T^2 + v_{it} - u_{it} \tag{2}$$

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 (*SPRT* thru *WINR*) 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 $v_{it} \sim \text{iid } N(0, \sigma_v^2)$; and u_{it} follows a half-normal 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 four alternative model specifications considered (Model 1-4) 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:

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

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

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

Thus, Models 1 and 2 make it possible to test the null hypothesis that climatic effect are not relevant; i.e., H_0: $\gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = \gamma_5 = \gamma_6 = \gamma_7 = \gamma_8 = 0$.

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:

$$\ln Y_{it} = \alpha_i + \sum_{k=1}^{6} \beta_k \ln X_{kit} + \sum_{s=1}^{8} \gamma_s Z_{sit} + \theta_1 T + \theta_2 T^2 + v_{it} - u_{it} \tag{5}$$

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:

$$\ln Y_{it} = \alpha + w_i + \sum_{k=1}^{6} \beta_k \ln X_{kit} + \sum_{s=1}^{8} \gamma_s Z_{sit} + \theta_1 T + \theta_2 T^2 + v_{it} - u_{it} \tag{6}$$

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.

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:

$$CEI_{it} = exp\ (\textstyle\sum_{s=1}^{8} \hat{\gamma}_s Z_{sit}) \tag{7}$$

Given the way we have incorporated the climatic variables, in addition to the total *CEI* in equation (7), it is possible to generate the following six partial *CEI* expressions: *CEI* for temperature; *CEI* for precipitation; *CEI* for spring; and *CEI* for summer; *CEI* for autumn; and *CEI* for winter. These partial *CEI*s can be expressed as follows:

$$CEI\_T_{it} = \exp\ (\textstyle\sum_{s=1}^{4} \hat{\gamma}_s Z_{sit}) \tag{8}$$

$$CEI\_P_{it} = \exp\,(\textstyle\sum_{s=5}^{8} \hat{\gamma}_s Z_{sit}) \tag{9}$$

$$CEI\_SPR_{it} = \exp\,(\hat{\gamma}_1 Z_{1it} + \hat{\gamma}_5 Z_{5it}) \tag{10}$$

$$CEI\_SUM_{it} = \exp\,(\hat{\gamma}_2 Z_{2it} + \hat{\gamma}_6 Z_{6it}) \tag{11}$$

$$CEI\_AUT_{it} = \exp\,(\hat{\gamma}_3 Z_{3it} + \hat{\gamma}_7 Z_{7it}) \tag{12}$$

$$CEI\_WIN_{it} = \exp\,(\hat{\gamma}_4 Z_{4it} + \hat{\gamma}_8 Z_{8it}) \tag{13}$$

These six *CEI* terms provide a rich perspective for examining the climatic effects in 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 4 are presented in Table 3. 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 are around 0.125). In contrast, when heterogeneity is ignored, expenditure on crops is the second most important input (elasticities are around 0.16). This difference suggests that the exclusion or the inclusion of heterogeneity in the production frontier deserves attention. The elasticity of labor in the pooled models is three times larger than the others. Similarly, the coefficients for animal expenditures and capital depreciation are greater in the pooled models compared to the other two. The four models exhibit decreasing returns to scale ranging from 0.998 (Model 1) to 0.928 (Model 3).

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 and 4, which include unobserved heterogeneity and climatic variables, a Hausman test of the TFE (Model 3) vs. the TRE (Model 4) is conducted, which is a test of the null hypothesis that unobserved heterogeneity is independent of the other explanatory variables. The results of this test cannot reject the null hypothesis[2], which supports the TRE (Model 4) indicating that unobserved heterogeneity is uncorrelated with the other regressors. Therefore, the discussion that follows is based on Model 4.

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[2] Hausman test: Prob>chi2 =0.591.

The results show that the parameters for the climatic variables are consistent across models 3 and 4. Specifically, in both models an increase in temperature has a positive effect on output in spring and in winter while the opposite is noted in summer and in autumn. A higher value of precipitation has a significantly negative effect on output in both spring and winter.

The analysis of the climatic effect is key in this paper so we now turn to this issue. According to Model 4, high temperatures in summer have the largest negative effect compared to other seasons. A one-unit increase in temperature (1 C°) leads to a 4.52% reduction in output in summer and to a 3.04% reduction in autumn. It is interesting to note that a "warmer" spring and a "warmer" winter have a positive effect on output, and in this case a 1 C° increase leads to 0.8% rise in output in spring and 1.8% rise in winter. Precipitation in summer and in autumn does not have a significant effect on dairy output. However, a 1 cm increase in precipitation in spring leads to a 0.062% reduction in output. Precipitation in winter is also harmful and a 1 cm increase leads to a 1.6% reduction in output.

Table 4 shows the average annual technical efficiency (TE) estimated by each model, and these numbers are also graphed in Figure 3. The overall Average TE is high at 92% compared to the results summarized in the meta-analysis by Bravo-Ureta et al. (2007). The average TE from Model 4 (92.1%) is higher than from Model 1 (90.1%). The annual TE of Model 3 and 4 is higher than Model 1 and 2, which is consistent with the fact that Model 3 and 4 separate farm heterogeneity from the TE term.

Table 5 presents the annual average CEIs based on equations 7 through 13. We first compute the CEI terms for each farm i at time t and then we aggregate these values to obtain average annual CEIs. A higher CEI value implies a better climatic condition for dairy production. What is more, a CEI greater than one means that climatic conditions are favorable while a CEI less than one denotes unfavorable conditions. The table indicates that temperature has a larger negative impact than precipitation. Climatic conditions have a negative effect on production in summer while the effect in spring is positive. The CEIs in autumn and in winter are around 0.85, which means that the climatic effect is a slightly negative for dairy production in these two seasons.

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 7 and 2, and ignoring inefficiency, the production frontier can be rewritten as:

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

Figure 4 reflects the estimated output change over time with respect the CEI for the past 17-year period under study. The output is calculated by estimated parameters of Model 4, the average value of inputs, and the annual average value of climatic variables. The estimated output 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, $\mathrm{CEI}_{\mathrm{best}}$, corresponds to the maximum individual farm CEI calculated over the 17-year period across all farms. In contrast, the worse case scenario, $\mathrm{CEI}_{\mathrm{worst}}$ is defined as minimum CEI value.

To compare the results of the best and worst-case scenarios we define a baseline using equation 14. The $\mathrm{CEI}_{\mathrm{base}}$ is equal to the mean for all CEI values. This average CEI value is 0.312 as depicted in Table 6. As shown in that same Table, the total CEI for the best and worst case scenarios are 0.391 and 0.279, respectively. The baseline output value is equal to 28,685 cwt. per farm. By comparison, under the best case scenario output increases to 35,944 cwt., which represents a 25.3% rise. The worst-case scenario reveals a level output equal to 25,637 cwt. or a -10.6% drop relative to the baseline. Thus, the range between the worst and best case scenario is a total of 10,308 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 eight 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 Monthly Mean Temperature in Wisconsin

	Variable	Mean	Std. Dev.	Min	Max
WINT	JANT	-7.57	3.13	-16.43	0.17
	FEBT	-5.31	3.08	-13.38	1.21
	MART	0.30	2.88	-7.52	8.26
SPRT	APRT	7.25	1.55	1.14	10.49
	MAYT	13.06	1.86	7.71	16.66
SUMT	JUNT	18.66	1.19	15.17	21.99
	JULT	21.44	1.65	15.87	24.88
	AUGT	20.33	1.36	15.01	22.29
	SEPT	16.11	1.44	11.33	19.17
AUTT	OCTT	9.32	1.72	3.44	13.22
	NOVT	2.70	2.30	-4.88	7.88
WINT	DECT	-4.60	3.17	-14.66	0.14

Table 2. Descriptive Statistics for WI Dairy Farms: 1997-2012 (918 Observations)

Variable		Mean	Std. Dev.	Min	Max
MILK	(cwt.=45.4 kg)	26,931	32,851	3,130	408,809
COW	(head)	98	98	21	1,162
LAB	(hour)	6,320	6,391	1,298	69,686
CFEED	(metric ton)	610	900	11	8,695
DEP	(2012 $)	80,513	99,355	465	1,196,189
ANEX	(2012 $)	34,918	52,940	283	642,433
CREX	(2012 $)	86,907	76,434	2,666	979,827
T		9	5	1	17
SPRT	(C°)	10.15	1.47	5.37	12.71
SUMT	(C°)	19.14	0.94	15.70	21.02
AUTT	(C°)	6.01	1.46	0.36	8.83
WINT	(C°)	-4.29	2.08	-10.87	0.73
SPRR	(cm)	8.67	2.61	3.89	16.11
SUMR	(cm)	9.00	2.30	4.87	18.69
AUTR	(cm)	5.32	1.74	2.09	9.81
WINR	(cm)	4.00	1.09	1.93	6.90

Table 3. Parameter Estimates for Four Stochastic Production Frontier Models

Variable	Model 1 W/o Climate	Model 2 With Climate	Model 3 (TFE)	Model 4 (TRE)
lnCOW	0.4674***	0.4381***	0.5865***	0.5823***
	(0.029)	(0.029)	(0.032)	(0.033)
lnLAB	0.1165***	0.1252***	0.0418**	0.0449**
	(0.023)	(0.023)	(0.021)	(0.021)
lnCFEED	0.1131***	0.1275***	0.1246***	0.1252***
	(0.012)	(0.012)	(0.013)	(0.013)
lnDEP	0.0642***	0.0727***	0.0487***	0.0493***
	(0.007)	(0.007)	(0.007)	(0.007)
lnANEX	0.0754***	0.0682***	0.0154	0.0265***
	(0.009)	(0.009)	(0.011)	(0.010)
lnCREX	0.1622***	0.1636***	0.1105***	0.1177***
	(0.012)	(0.012)	(0.013)	(0.013)
T	0.0289***	0.0433***	0.0524***	0.0504***
	(0.004)	(0.005)	(0.004)	(0.004)
T2	-0.0006**	-0.0012***	-0.0017***	-0.0016***
	(0.000)	(0.000)	(0.000)	(0.000)
SPRT		-0.0025	0.0094**	0.0080*
		(0.005)	(0.004)	(0.004)
SUMT		-0.0226***	-0.0475***	-0.0452***
		(0.009)	(0.007)	(0.007)
AUTT		-0.0154***	-0.0321***	-0.0304***
		(0.005)	(0.004)	(0.004)
WINT		0.0217***	0.0173***	0.0178***
		(0.004)	(0.003)	(0.003)
SPRR		-0.0039	-0.0065***	-0.0062***
		(0.003)	(0.002)	(0.002)
SUMR		-0.0019	-0.0026	-0.0024
		(0.003)	(0.002)	(0.002)
AUTR		0.0043	0.0025	0.0026
		(0.004)	(0.003)	(0.003)
WINR		-0.0146***	-0.0160***	-0.0155***
		(0.005)	(0.004)	(0.004)
Constant	2.8698***	3.4786***	________	5.1047***
	(0.128)	(0.220)		(0.214)

Level of Significance: ***1%, **5%, *10%

Table 4. Average Annual Technical Efficiency for Wisconsin Dairy Farms: 1996-2012

Year	TE_Model1	TE_Model2	TE_Model3	TE_Model4
1996	0.896	0.894	0.912	0.907
1997	0.915	0.907	0.928	0.924
1998	0.887	0.881	0.922	0.915
1999	0.911	0.916	0.947	0.944
2000	0.914	0.912	0.932	0.928
2001	0.885	0.883	0.915	0.909
2002	0.911	0.893	0.921	0.915
2003	0.926	0.916	0.944	0.941
2004	0.877	0.871	0.902	0.896
2005	0.896	0.895	0.934	0.929
2006	0.922	0.905	0.929	0.925
2007	0.868	0.870	0.906	0.899
2008	0.897	0.908	0.933	0.930
2009	0.920	0.918	0.935	0.932
2010	0.892	0.890	0.913	0.909
2011	0.890	0.894	0.933	0.928
2012	0.913	0.892	0.926	0.921
Average	0.901	0.897	0.925	0.921

Table 5. Average Annual CEI Values Based on the TRE Model

Year	CEI	CEI_T	CEI_P	CEI_SPR	CEI_SUM	CEI_AUT	CEI_WIN
1996	0.334	0.368	0.908	1.026	0.425	0.908	0.847
1997	0.335	0.374	0.896	1.029	0.429	0.871	0.872
1998	0.309	0.352	0.878	1.054	0.402	0.813	0.897
1999	0.302	0.349	0.865	1.021	0.411	0.813	0.885
2000	0.316	0.362	0.875	1.021	0.424	0.837	0.874
2001	0.298	0.337	0.883	1.023	0.412	0.797	0.888
2002	0.323	0.363	0.890	1.018	0.392	0.895	0.904
2003	0.322	0.354	0.911	1.018	0.419	0.862	0.875
2004	0.300	0.354	0.848	0.989	0.433	0.822	0.853
2005	0.293	0.320	0.916	1.055	0.386	0.833	0.863
2006	0.331	0.376	0.880	1.033	0.414	0.863	0.896
2007	0.293	0.331	0.885	1.048	0.402	0.817	0.851
2008	0.294	0.342	0.859	1.025	0.413	0.862	0.805
2009	0.320	0.361	0.886	1.029	0.438	0.854	0.832
2010	0.310	0.346	0.895	1.045	0.401	0.829	0.892
2011	0.294	0.335	0.877	1.012	0.412	0.822	0.857
2012	0.333	0.378	0.882	1.034	0.401	0.871	0.922
Average	0.312	0.353	0.884	1.028	0.413	0.845	0.871

Table 6. Scenario Analysis

	CEI	Output (cwt)	Output Change (%)
Baseline	0.312	28,685	0
Best Case Scenario	0.279	25,637	-10.63%
Worst Case Scenario	0.391	35,944	25.31%

Figure 1. Annual Seasonal Average Temperature (C°) for Wisconsin

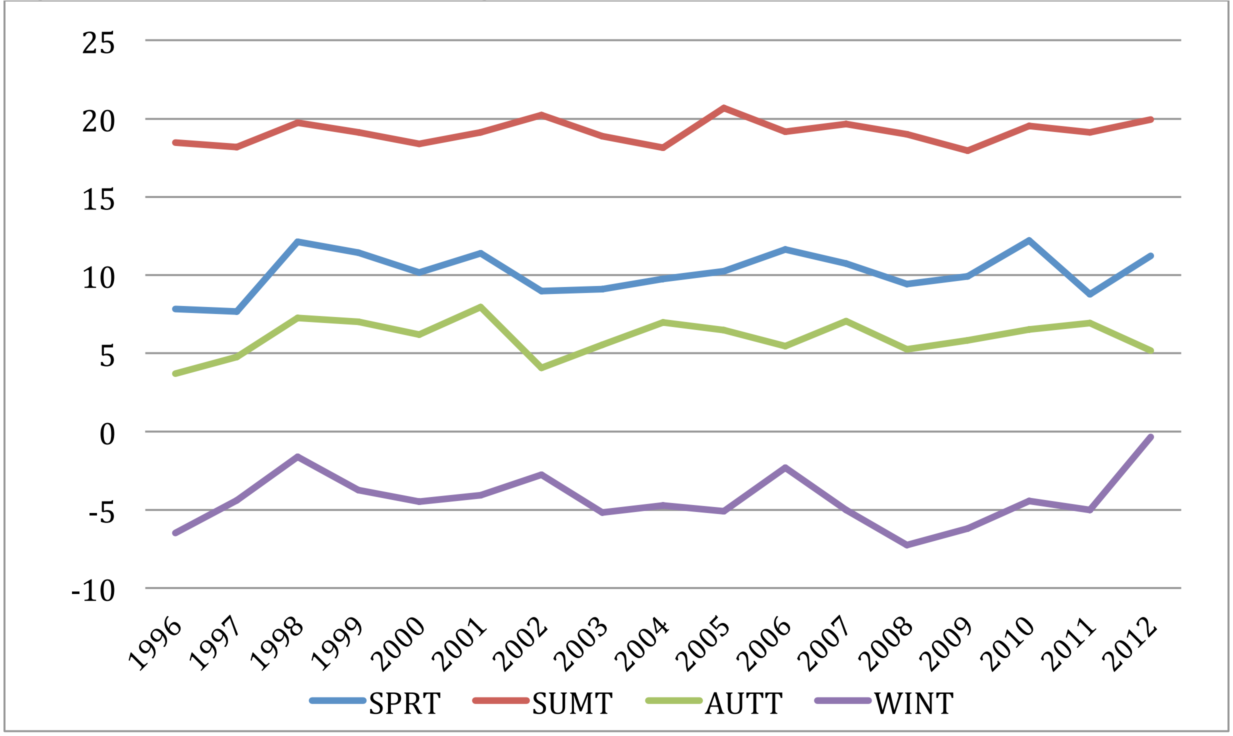


Figure 2. Annual Seasonal Average Precipitation (cm) for Wisconsin

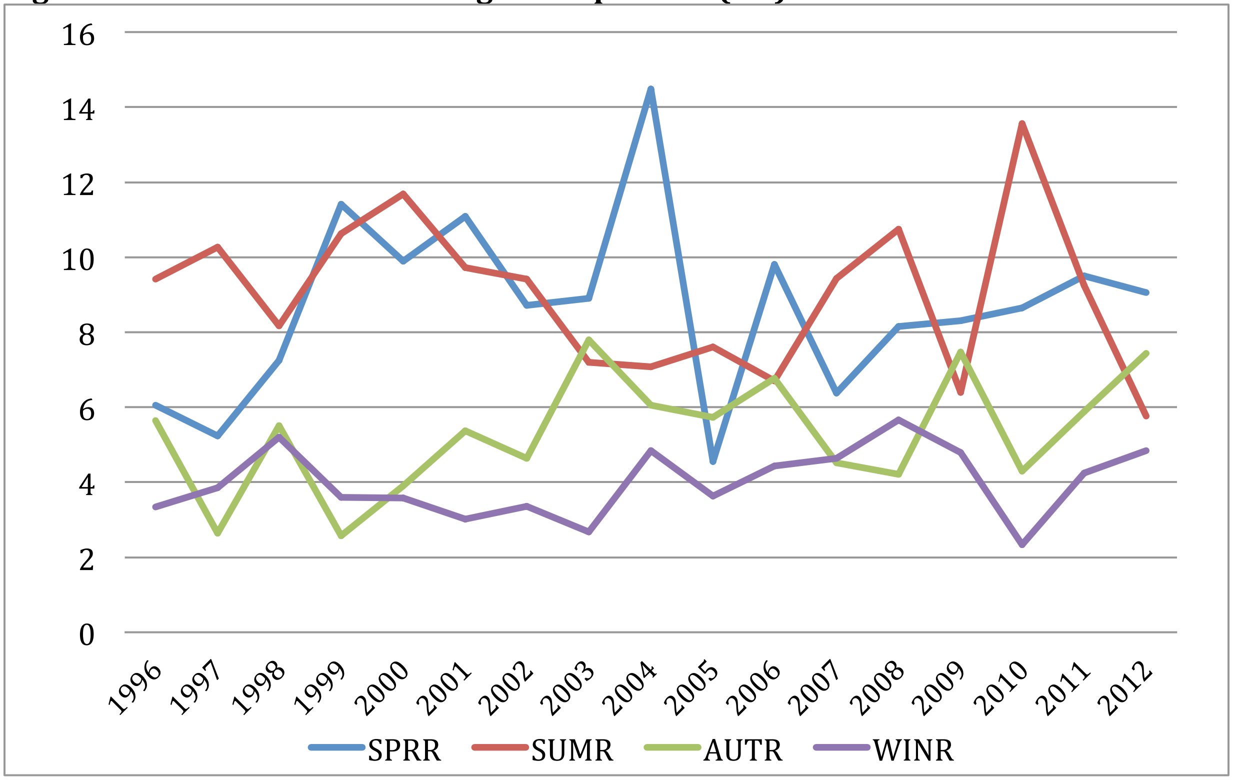


Figure 3. Average Annual Technical Efficiency for Wisconsin Dairy Farms

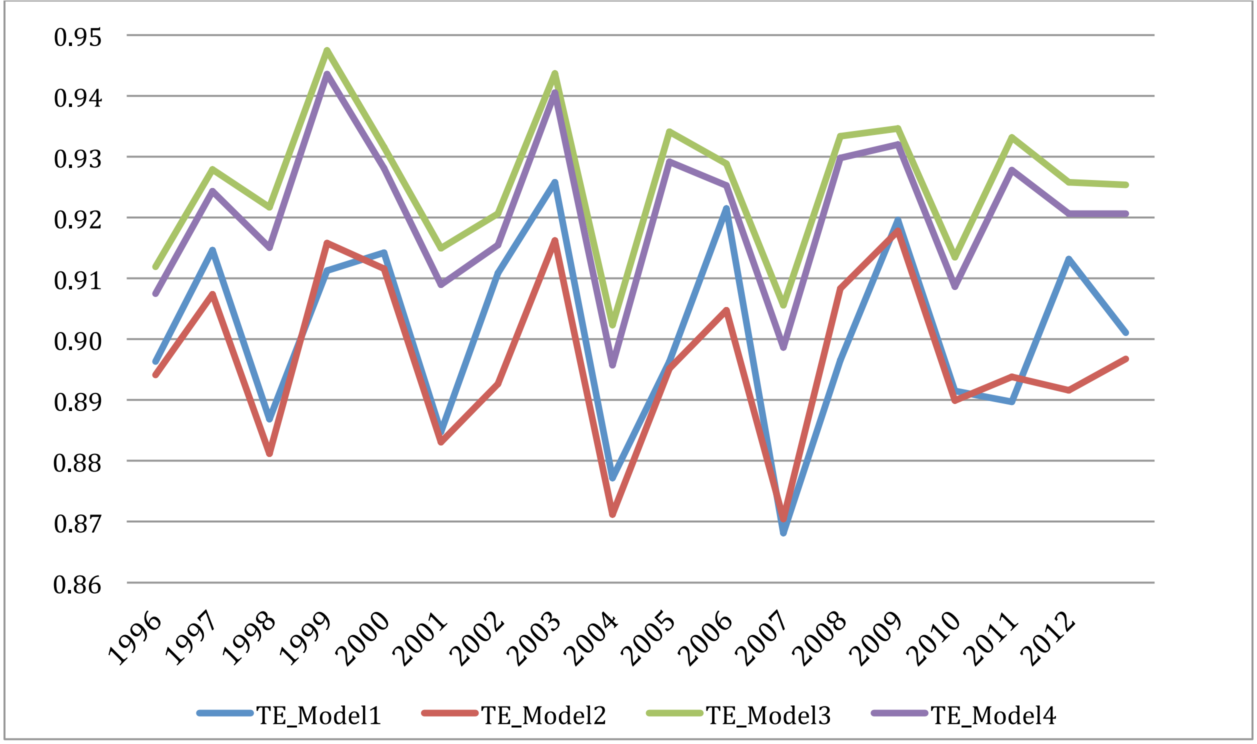
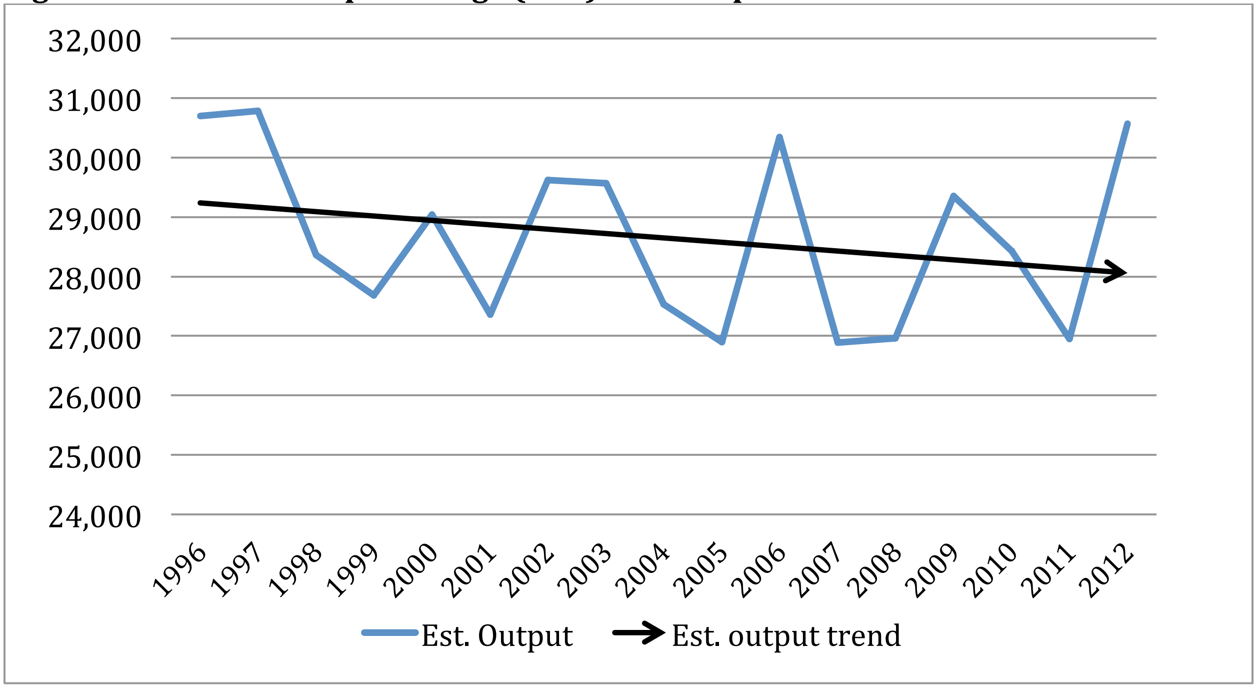


Figure 4. Estimated output change (cwt.) with respect the annual CEI



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