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

Lingqiao Qi

Graduate Research Assistant, Agric. & Resource Economics (ARE), U of Connecticut (UCONN), USA

Boris E. Bravo-Ureta

Professor, ARE-UCONN and Adjunct Professor, Ag. Econ., U of Talca, Chile

Victor E. Cabrera

Associate Professor & Extension Specialist in Dairy Management, and Alfred Toepfer Faculty Fellow, Dairy Science, U of Wisconsin-Madison

MAY 26, 2014

UNIVERSIDAD DE TALCA

UNIVERSITY OF CONNECTICUT 1881

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

Objective of the Research

- **General objective:** to contribute to the understanding of the effect of climatic variables on dairy farm productivity.

- **Specific objectives:**
  1. explore alternate definitions and measures of climatic effects;
  2. test alternative stochastic frontier panel data models in the analysis of dairy productivity and climatic effects;
  3. perform an empirical analysis using panel data for the state of Wisconsin.

Introduction and Motivation

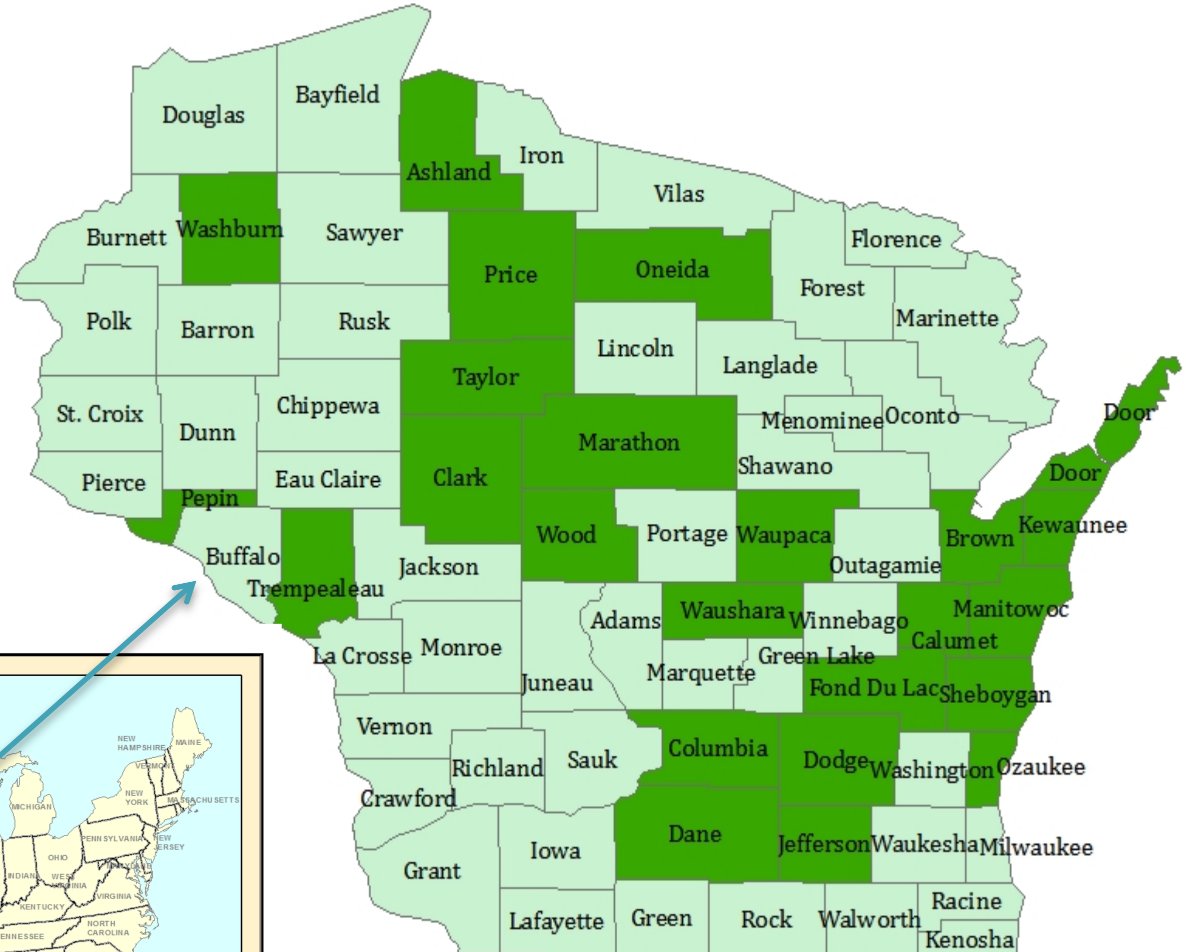
- The **agricultural sector**, which remains important to the U.S. economy (USGCRP, 2009), is more sensitive and vulnerable to climate change than other sectors (IPCC, 2014).
- The **livestock sector** is particularly vulnerable to hot weather, especially in combination with high humidity, which can lead to significant losses in productivity and, in extreme cases, to animal death (Boyles, 2008; Mader, 2003).
- Climatic conditions also affect feed supplies by influencing the growth of silage and forage crops (Hill et al., 2004).

Introduction and Motivation

- **Dairy industry** is the fourth largest agricultural subsector in the United States.
- There is a significant body of animal and dairy science literature, which 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.

Research Area



State of Wisconsin (Research area: 24/72 counties)

Contribution

- **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,* ***Wisconsin*** *is an ideal location to examine the effects of extreme climatic factors on dairy production.*

The specification of our model makes it possible to calculate a total climatic effect as well as partial effects for temperature, precipitation and seasons.

- *This analysis is a novel contribution to the dairy productivity literature.*

Background: Heat Stress and Cold Stress

- Heat and cold stress requires cows to increase the amount of energy used to maintain body temperature and less energy is available for milk production (Collier et al., 2011).

- **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).

- **Cold stress** causes animals to consume more feed but to produce less milk, and it also increases milk fat content (Young, 1981).

Background: Economic Effect

- St-Pierre, Cobanov and Schnitkey (2003) calculated the overall effects of **heat stress on the U.S. dairy** industry at $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.

- Mukherjee, Bravo-Ureta and de Vries (2013) incorporated an annual average Temperature Heat Index (THI) in a production frontier model and found a significant negative effect on output and document cost-effective adaptation.

- Seo and Mendelsohn (2008) used a discrete choice model to examine how farmers change livestock species and numbers to adapt to climatic change.

Background: Measures of Climatic Effects

- **Alternative measures** based on *temperature and precipitation* have been used to incorporate climatic effects in crop and livestock models (e.g., Mendelsohn, Nordhaus and Shaw, 1994; Kelly, Kolstad and Mitchell, 2005; Arriagada, 2005; Schlenker, Hanemann and Fisher 2006; Deschenes and Greenstone, 2007).

- **THI** has been developed and widely used (Kadzere et al., 2002) to measure heat stress suffered by dairy cattle.

- Here we define winter and summer averages for temperature and precipitation to capture the climatic effect. **Much more to do!!!!**

- 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.

Methodology: General model

$$MILK = f(COW, LAB, FEED, CAP, ANEX, CREX, HOTT, COLT, HOTR, COLR, T, T^2)$$

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
T2	time trend square

Methodology: Empirical Model

Model 1. Pooled SPF model without climatic variables;

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

Model 2. Pooled SPF model with climatic variables;

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

Model 3. "True" fixed effects (TFE) model with climatic variables;

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

Model 4. "True" random effects (TRE) model with climatic variables;

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

Model 5. "True" random effects model with the Mundlak specification (TRE-M) and climatic variables.

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

Methodology: Climatic Effects

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 (Hughes et al. 2011)

- **Total CEI:**

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

- **Partial CEI Expressions**:
  - CEI for temperature: $CEI\_temp_{it} = \exp(\hat{\gamma}_1 Z_{1it} + \hat{\gamma}_2 Z_{2it})$
  - CEI for precipitation: $CEI\_prep_{it} = \exp(\hat{\gamma}_3 Z_{3it} + \hat{\gamma}_4 Z_{4it})$
  - CEI for summer: $CEI\_summer_{it} = \exp(\hat{\gamma}_1 Z_{1it} + \hat{\gamma}_3 Z_{3it})$
  - CEI for winter: $CEI\_winter_{it} = \exp(\hat{\gamma}_2 Z_{2it} + \hat{\gamma}_4 Z_{4it})$

Data

- **Input-output data:** Ag. Financial Advisor (AgFA)

  958 dairy farms; 52 Wisconsin counties; 17-year period (1996–2012); a total of 9,437 observations.

  We include 221 farms with 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.

- **Climate data**

  Parameter-elevation Regressions on Independent Slopes Model (PRISM) maps.

  Geographic Information System (GIS) techniques are used to calculate monthly mean temperature and precipitation for each county and year.

Data: Descriptive Statistics

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

Variable		Mean	Std. Dev.	Min	Max
MILK	(cwt=45.4kg)	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	17
HOTT	(F)	68	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

Summary of Results (1)

- Estimated coefficients of all conventional inputs are significant with the expected positive sign and values (i.e., between 0 and 1).
- Dairy herd size is the main input in production.
- Concentrate feed is the second most important input when unobserved heterogeneity is accounted for. But, expenditure on crops is the second most important input when heterogeneity is ignored.
- This difference suggests that the **treatment of heterogeneity in the production frontier deserves attention.**
- The five models exhibit decreasing returns to scale ranging from 0.91 (Model 3) to 0.97 (Model 1).

Summary of Results (2)

- Likelihood ratio tests show that climatic variables should be included in the specification of the production frontier model. The impact of the climatic variables is consistent:

  * Higher temperature in the summer has a negative effect on output while the opposite is noted in winter;

  * Higher precipitation has an adverse effect in both summer and winter.

- Hausman tests for model 4 shows that **unobserved heterogeneity** is found to be **random and correlated** with the other regressors.
- **Model 5** which is a **TRE with the Mundlak Correction is better.**

Summary of Results (3)

Table 2. Parameter Estimates for Five SPF 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)
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%

Technical Efficiency (TE)

Average TE very similar across models and higher than the results in the meta-analysis by Bravo-Ureta et al. (2007).

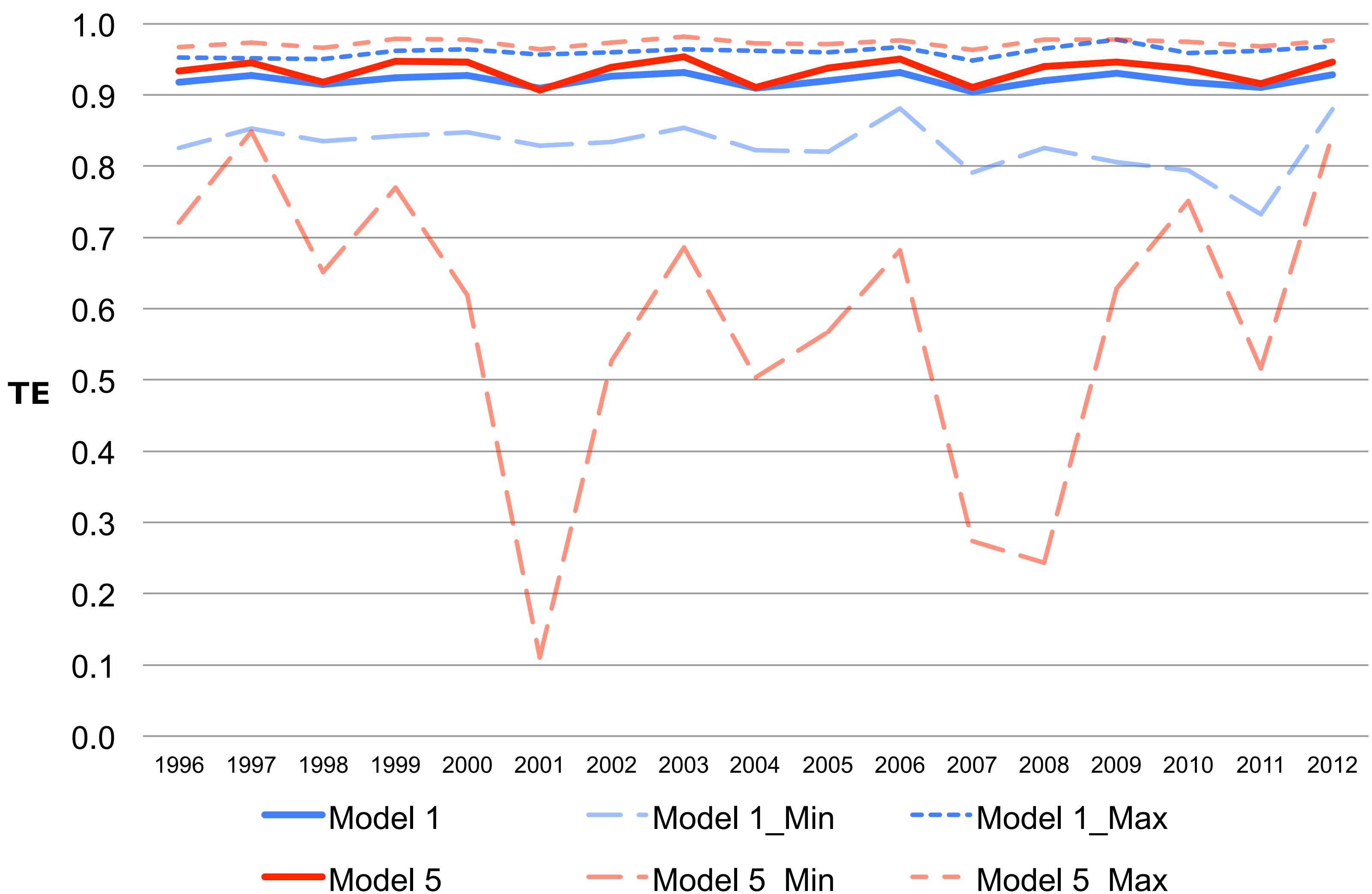
However, the **range of TE values varies** considerably.

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

Year	Model 1 W/o Climate	Model 2 With Climate	Model 3 (TFE)	Model 4 (TRE)	Model 5 (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**

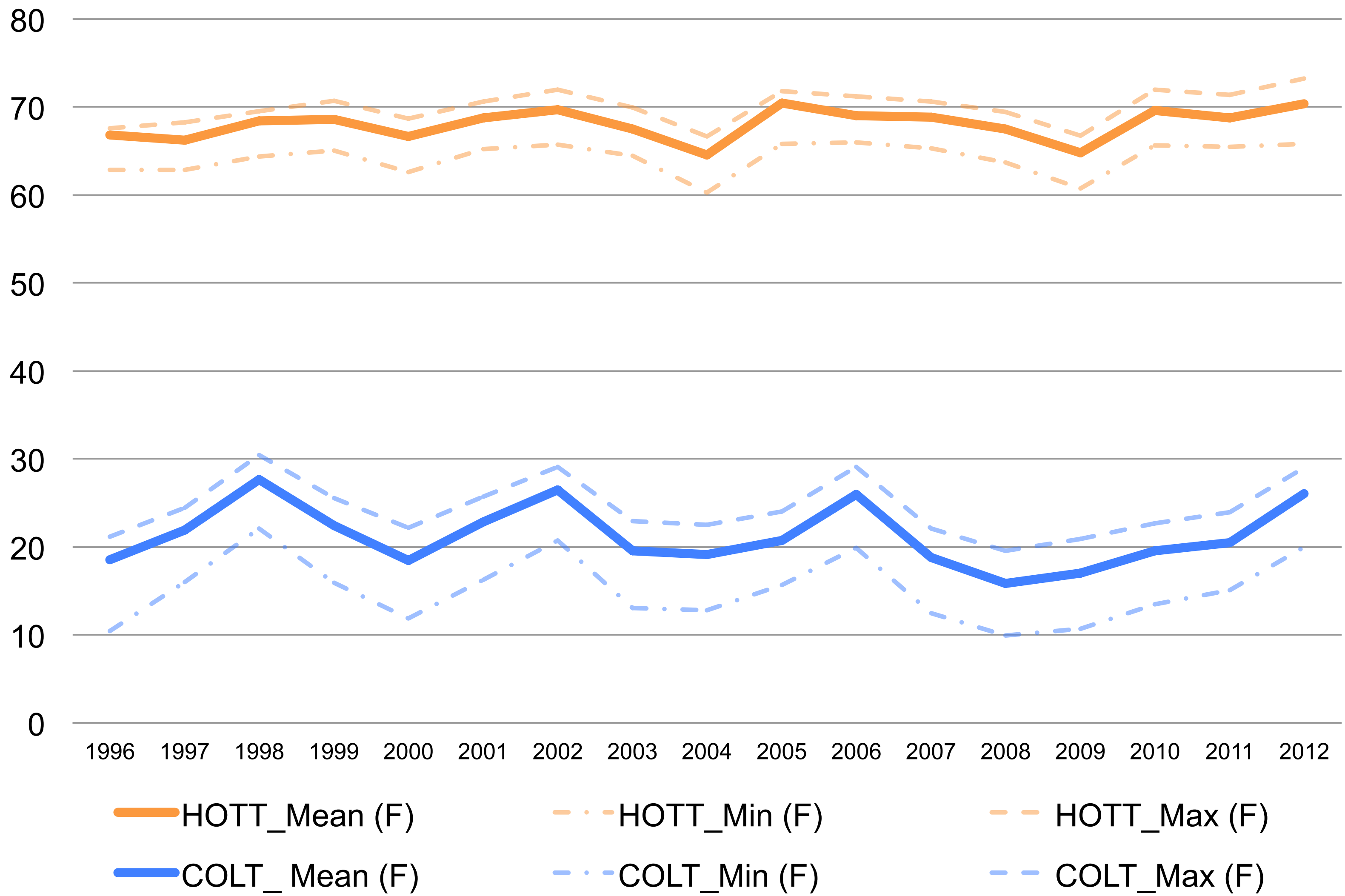
Technical Efficiency (2)

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



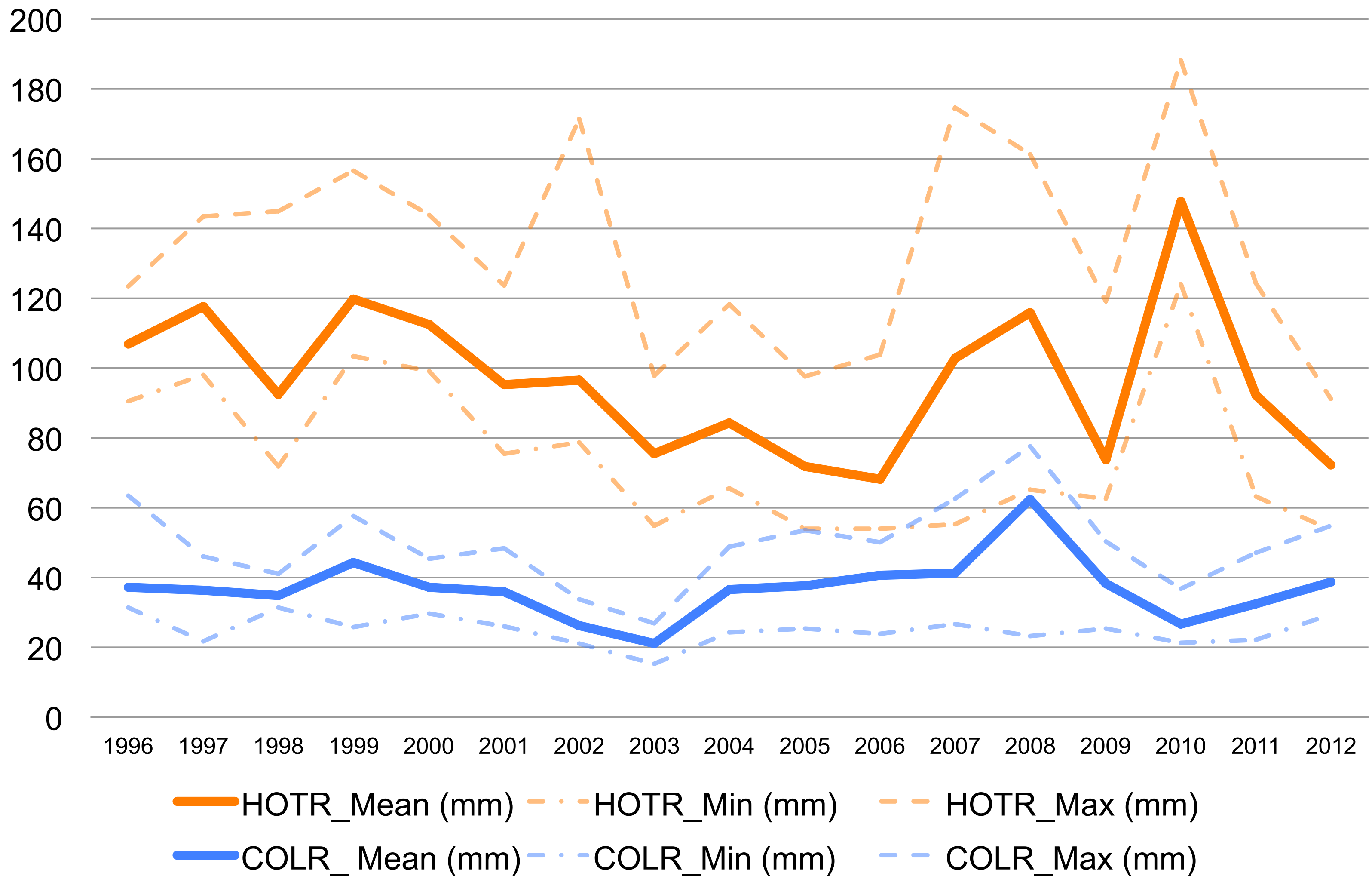
Climatic Conditions (1)

Figure 2. **Average, Maximum and Minimum Values of Winter and Summer Temperature in Wisconsin: 1996-2013**



Climatic Conditions (2)

Figure 3. Average, Maximum and Minimum Values of Winter and Summer Precipitation in Wisconsin: 1996-2013



Climatic Effect

The analysis of the climatic effect is key in this paper.

- 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.
- 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 0.48% rise in output.

Climatic Effect Index

Temperature has a larger negative impact than precipitation, and 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.

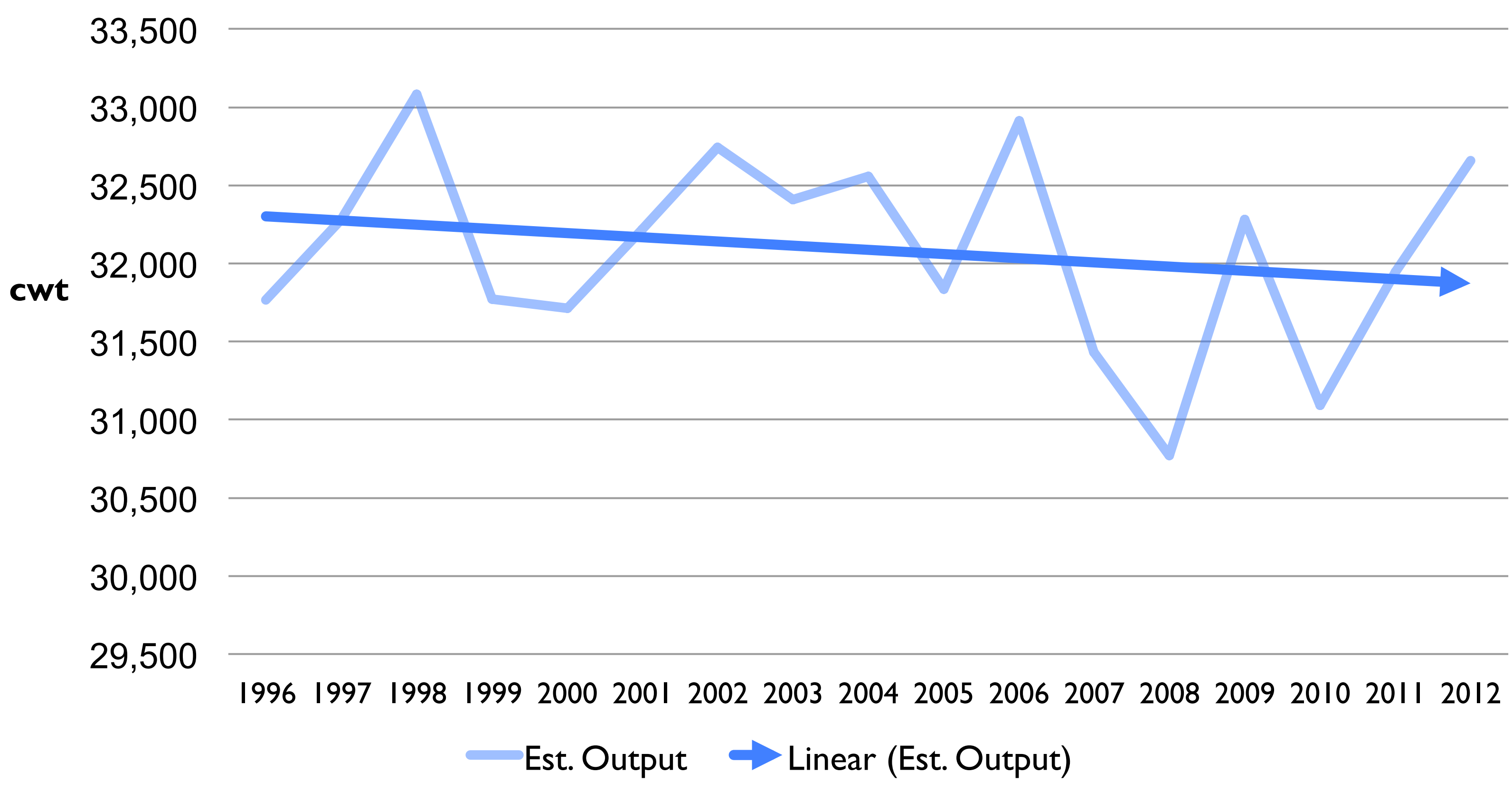
Table 4. Average Annual CEI Values Based on the TRE-M Model

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

CEI and Output Change

The data shows **wide variability** in output with respect the total CEI for the past 17-year period under study AND a **slight negative trend** indicating that the climate effect has gradually led to declines in output holding all else constant.

Figure 4. Annual Output and Total Climatic Effect (CEI) using the RFE- M Model



Scenario Analysis

- In the **best case scenario**, CEI is defined as:
  - ✓ The lowest average summer precipitation (53.6 mm);
  - ✓ the lowest average precipitation in winter (15.2 mm);
  - ✓ the lowest average temperature in summer (60.3 F°);
  - ✓ the highest average temperature in winter (30.5 F°).
- In the **worst case scenario**, CEI is defined as:
  - ✓ The highest precipitation in summer (188.3 mm);
  - ✓ the highest precipitation in winter (77.5 mm);
  - ✓ the highest temperature in summer (73.2 F°);
  - ✓ the lowest temperature in winter (9.9 F°).
- A **baseline** using the CEI value calculated from 17-year mean for each of the four climatic variables introduced in the model.

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%

Range between the worst and best case scenario is **8,008 cwt**.

Concluding Remarks

- This paper **introduces four climatic variables** into alternative SPF models and derives overall and specific measures of the climate effect.
- Climatic effects are significant on dairy farming. In particular, **higher summer** month temperatures are **harmful** for dairy production, while a **warmer winter** is **beneficial**.
- **Higher precipitation** has a negative effect on dairy production in Wisconsin in both seasons.
- The results also suggest that, *ceteris paribus*, there is **a mild negative association** between the climatic effect and dairy farm output over the past 17 years in Wisconsin.
- Thus, if climate change continues, research and extension efforts will be needed to **promote adaptation strategies**.
- *FUTURE/ON-GOING WORK (data, Climatic definitions, TFP)*

Thanks!

Gracias

Lingqiao Qi

U. of Connecticut (UCONN), USA

Boris E. Bravo-Ureta

UCONN and Adjunct Professor, U. of Talca, Chile

Victor E. Cabrera

U. of Wisconsin-Madison

UNIVERSIDAD DE TALCA

UNIVERSITY OF CONNECTICUT 1881

WISCONSIN

UNIVERSITY OF WISCONSIN–MADISON