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

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

Paper presented at AAEA Annual Meeting

July 29, 2014

Introduction and Motivation

- The **agricultural sector** is more sensitive and vulnerable to climate change than other sectors (IPCC, 2014).
- **The dairy industry** is the 4th largest ag. subsector in the US.
  - **Livestock** is vulnerable to hot weather, especially in combination with high humidity, which can lead to significant losses in productivity and even 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).
- 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.

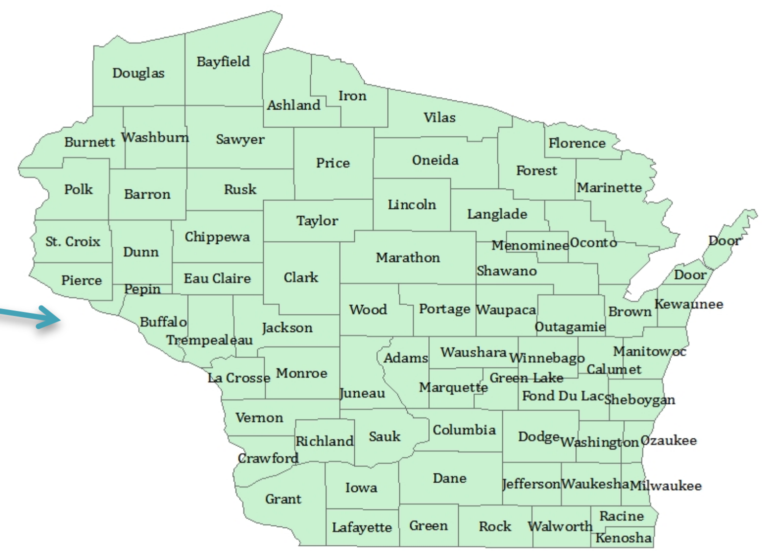
Objective of the Research

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

- **Specific objectives:**
  1. test alternative stochastic frontier panel data models in the analysis of dairy productivity and climatic effects
  2. perform an empirical analysis using panel data for the state of Wisconsin
  3. conduct scenario analysis to predict the expected impact of climate change on output

Contribution

- **Wisconsin** is the 2nd largest dairy producing area in the U.S. Winters can be very cold (-23.28 C°, 2009.01) and snowy, and summers hot (31.46 C°, 2012.07) and humid.
- **Wisconsin** *is an ideal location to examine the effects of extreme climatic factors on dairy production.*
- Our model makes it possible to calculate a total climatic effect, and partial effects for temperature, precipitation and seasons.
- This study estimates dairy output changes for four alternative IPCC climatic scenarios.



State of Wisconsin

Literature

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

- St-Pierre, Cobanov and Schnitkey (2003) calculated the overall economic effects of heat stress on the U.S. dairy industry at $900 million/yr ($100/cow per year) with heat abatement. The loss would be $1.5 billion/yr ($167/cow per year) without abatement.

- 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.

- Key and Sneeringer (2014) examined the effect of local thermal environments on the technical efficiency of dairies across the US.

- Alternative *temperature and precipitation variables* have been used to incorporate climatic effects in crop and livestock models (e.g., Mendelsohn, Nordhaus and Shaw, 1994; Schlenker, Hanemann and Fisher 2006; Deschenes and Greenstone, 2007).

- **Here we define seasonal averages for temperature and precipitation to capture the climatic effect.**

Methodology: General model

$$MILK = f(COW, LAB, FEED, CAP, ANEX, CREX, SPRT, ..., WINP, T, T^2)$$

Dependent variable:

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

Input variables:

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.
T	Time trend.

Methodology: General model

MILK = f (COW, LAB, FEED, CAP, ANEX, CREX, SPRT, ..., WINP, T, T^2)

Climatic variables:

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.

Methodology: Empirical Models

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;

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

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

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

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

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

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:**

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

- **Partial CEI Expressions**:
  - CEI for temperature: $CEI\_T_{it} = \exp\,(\sum_{s=1}^{4} \hat{\gamma}_s Z_{sit})$
  - CEI for precipitation: $CEI\_P_{it} = \exp\,(\sum_{s=5}^{8} \hat{\gamma}_s Z_{sit})$
  - CEI for spring: $CEI\_SPR_{it} = \exp\,(\hat{\gamma}_1 Z_{1it} + \hat{\gamma}_5 Z_{5it})$
  - CEI for summer: $CEI\_SUM_{it} = \exp\,(\hat{\gamma}_2 Z_{2it} + \hat{\gamma}_6 Z_{6it})$
  - CEI for autumn: $CEI\_AUT_{it} = \exp\,(\hat{\gamma}_3 Z_{3it} + \hat{\gamma}_7 Z_{7it})$
  - CEI for winter: $CEI\_WIN_{it} = \exp\,(\hat{\gamma}_4 Z_{4it} + \hat{\gamma}_8 Z_{8it})$

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 54 farms with information for the full 17-year period , which yields a total of 918 observations (balanced panel) in 10 counties.

- **Climate data:** Parameter-elevation Regressions on Independent Slopes Model (PRISM) maps.

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

Summary of Results

Table 2. Parameter Estimates for Four SPF 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***
lnLAB	0.1165***	0.1252***	0.0418**	0.0449**
lnFEED	0.1131***	0.1275***	0.1246***	0.1252***
lnDEP	0.0642***	0.0727***	0.0487***	0.0493***
lnANEX	0.0754***	0.0682***	0.0154	0.0265***
lnCREX	0.1622***	0.1636***	0.1105***	0.1177***
T	0.0289***	0.0433***	0.0524***	0.0504***
T2	-0.0006**	-0.0012***	-0.0017***	-0.0016***
SPRT		-0.0025	0.0094**	0.0080*
SUMT		**-0.0226*** **	**-0.0475*** **	**-0.0452*** **
AUTT		-0.0154***	-0.0321***	-0.0304***
WINT		**0.0217*** **	**0.0173*** **	**0.0178*** **
SPRR		-0.0039	-0.0065***	-0.0062***
SUMR		-0.0019	-0.0026	-0.0024
AUTR		0.0043	0.0025	0.0026
WINR		-0.0146***	-0.0160***	-0.0155***
Constant	2.8698***	3.4786***		5.1047***

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

Climatic Effect Index

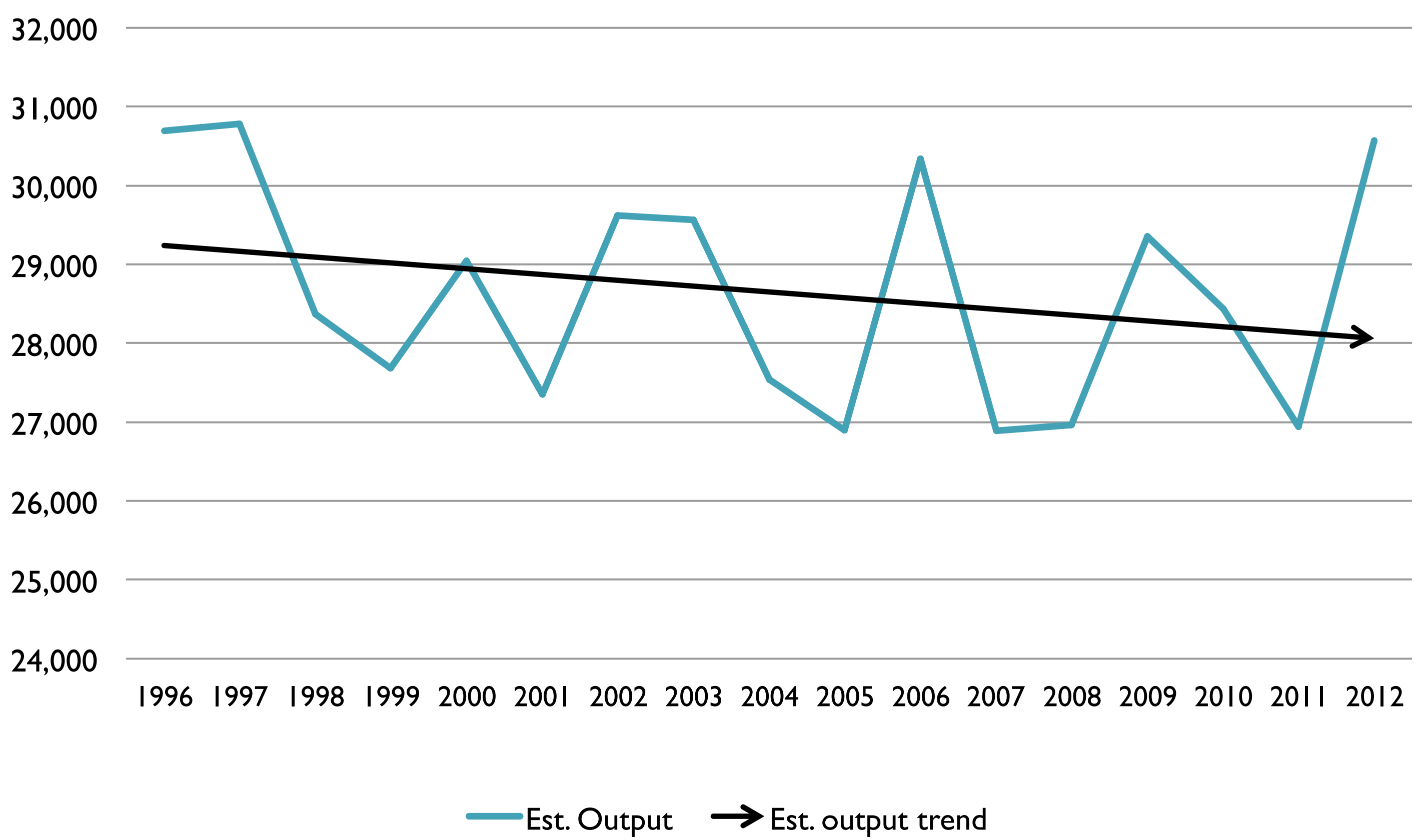
Table 3. Average Annual CEI Values Based on the TRE Model

Year	CEI	CEI_T	CEI_R	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**

CEI and Output Change

Figure 4 reflects the estimated output over time with respect the annual total CEI for the past 17-year period under study.

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



Scenario Design

Table 4. IPCC Emission Scenarios

	Population Growth	GDP Growth	Energy Use	Land Use Changes	Resource Availablility	Technological change
Commitment Scenario	Assumes concentrations in the atmosphere are held fixed at year 2000 levels					
Low B1 Scenario	Low	High	Low	High	Low	Medium Pace
Medium A1B Scenario	Low	Very High	Very High	Low-medium	Medium	Rapid Pace
High A2 Scenario	High	Medium	High	Medium-high	Low	Slow Pace

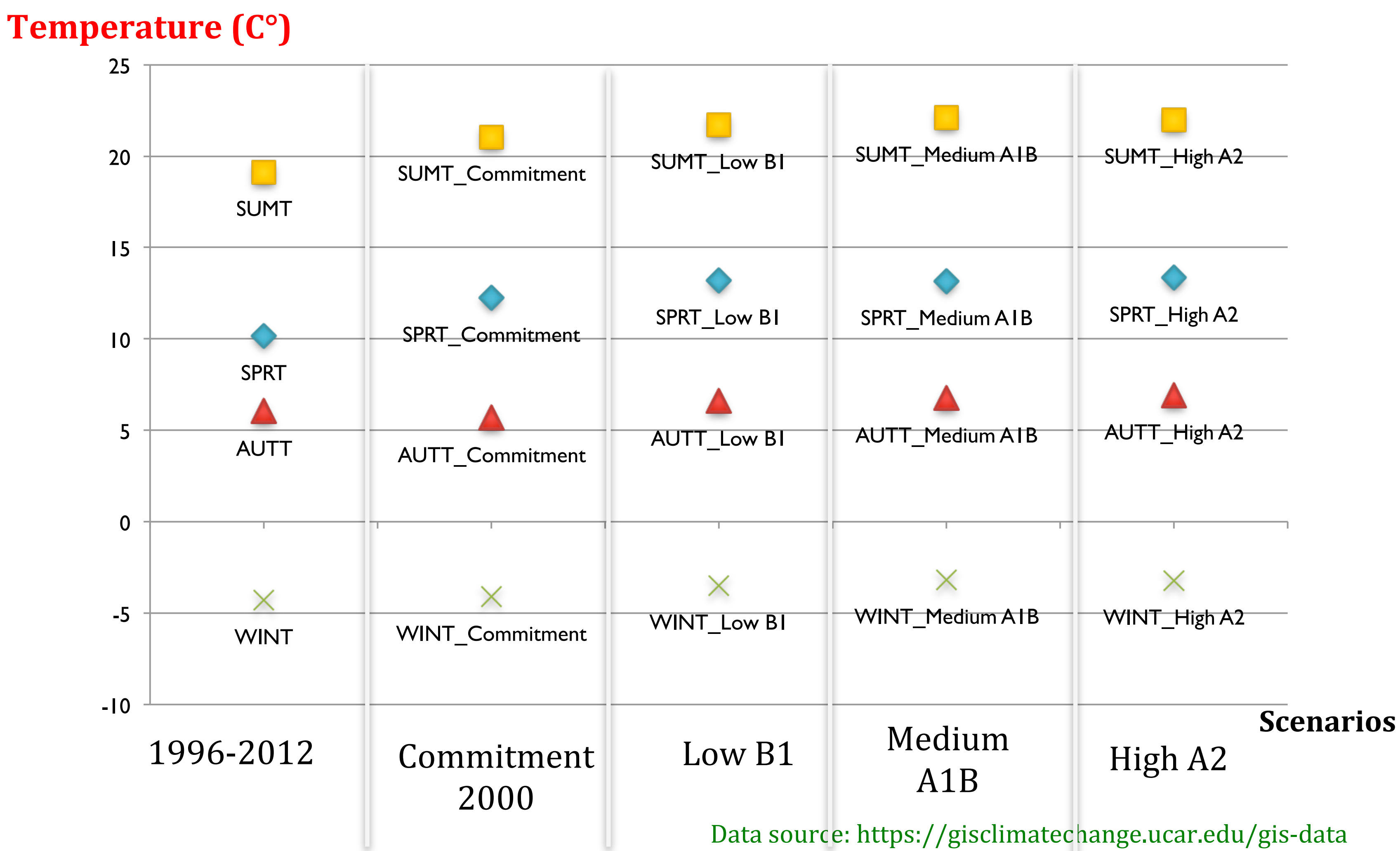
Source: http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf

For each scenario, we obtained the long term (2020-2039) average temperature and precipitation for each month. Then, we calculated the seasonal values.

These climate change projections were generated by the NCAR Community Climate System Model, or CCSM, for the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007).

CEI and Output Change

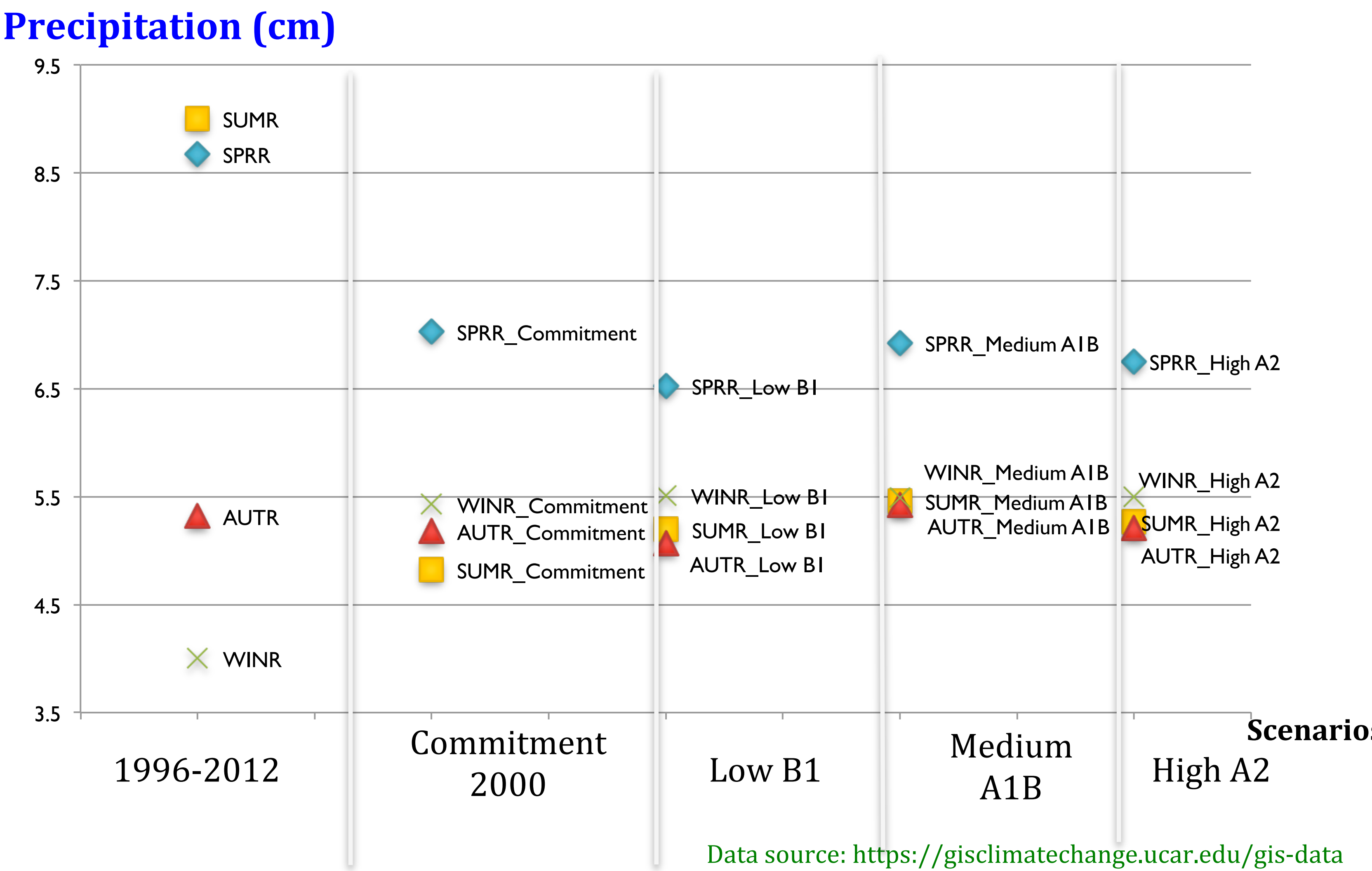
Figure 6. Seasonal Average Temperature (C°) for 1997-2012 and Average for Four IPCC Scenarios (Near term: 2020-2039)



Data source: https://gisclimatechange.ucar.edu/gis-data

CEI and Output Change

Figure 7. Seasonal Avg. (cm) for 1997-2012 and Projected Precipitation for Four IPCC Scenarios (Near term: 2020-2039)



Data source: https://gisclimatechange.ucar.edu/gis-data

Scenario Analysis

Table 5. Average Output changes under IPCC Projection Scenarios

Scenario	CEI	Output per farm (cwt)	Output Change (%)
Baseline (1996-2012)	0.311	28615	--
Commitment Scenario	0.294	26987	-5.69%
Low B1 Scenario	0.283	25997	-9.15%
Medium A1B Scenario	0.277	25486	-10.93%
High A2 Scenario	0.278	25517	-10.83%

CEI: calculated by using the climatic variables of each scenario

$$\widehat{CEI}_{Scenario} = exp\left(\sum_{s=1}^{8} \hat{\gamma}_s Z_{Scenario}\right)$$

Output per farm: Average output per farm of different climatic scenario holding inputs constant.

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

Concluding Remarks

- This paper uses alternative panel data SPF models and derives overall and specific measures of the climatic effect on Wisconsin dairy production.
- Higher summer and autumn temperatures are harmful for dairy production, while a warmer winter and spring is beneficial. Higher precipitation has a consistent negative effect.
- The analysis shows that IPCC scenarios lead to a 5% (1 case) and 10% (3 cases) reduction on average dairy farm output over the 20-year period from 2020-2040 compared to 1996-2012.
- Future work will focus on total factor productivity analysis. And, alternative procedures for undertaking the scenario analysis will be investigated and applied.

Thanks!

UNIVERSIDAD DE TALCA

UNIVERSITY OF CONNECTICUT 1881

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

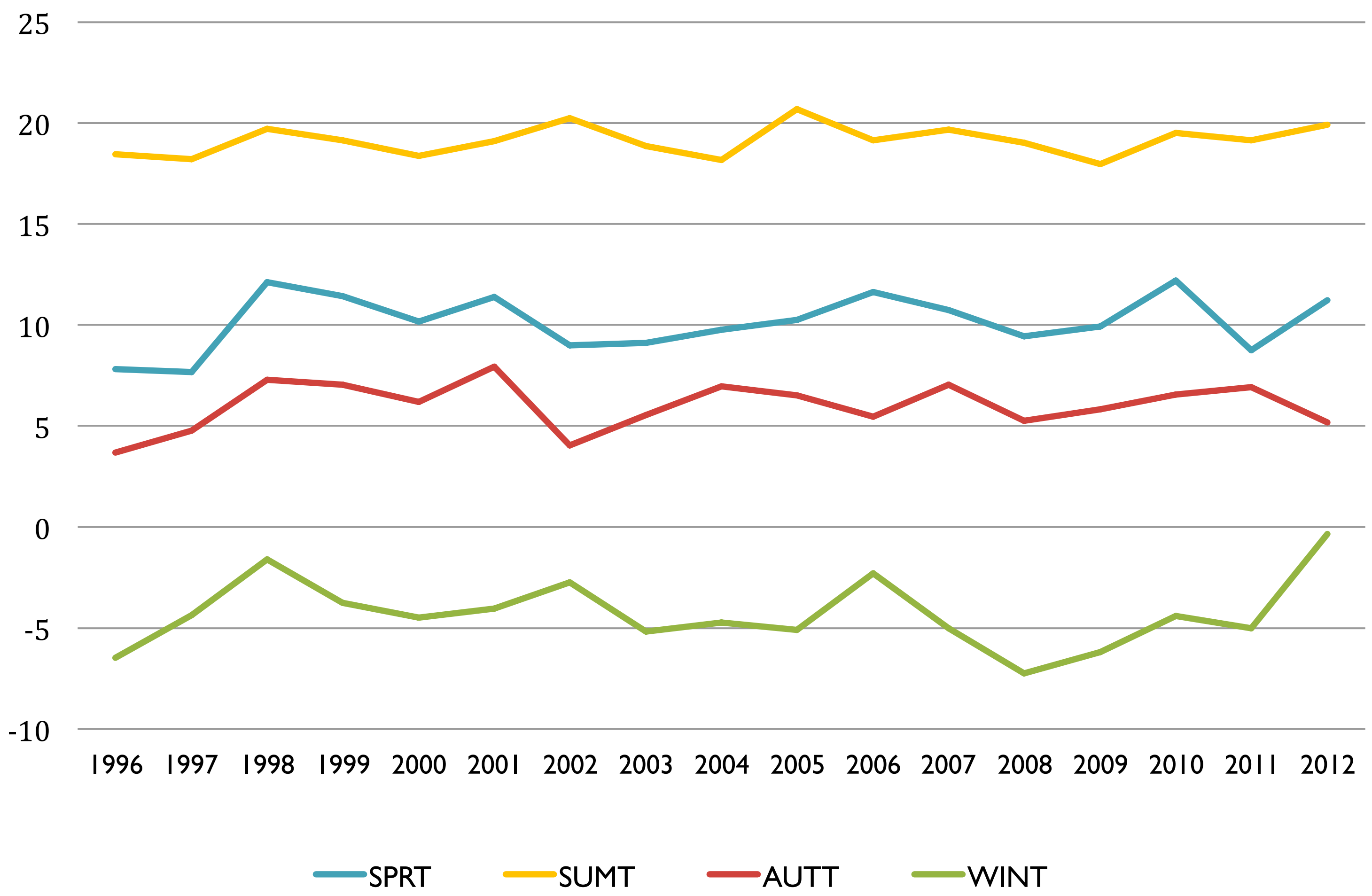
Data: Descriptive Statistics

Table 1. Descriptive Statistics for Wisconsin 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

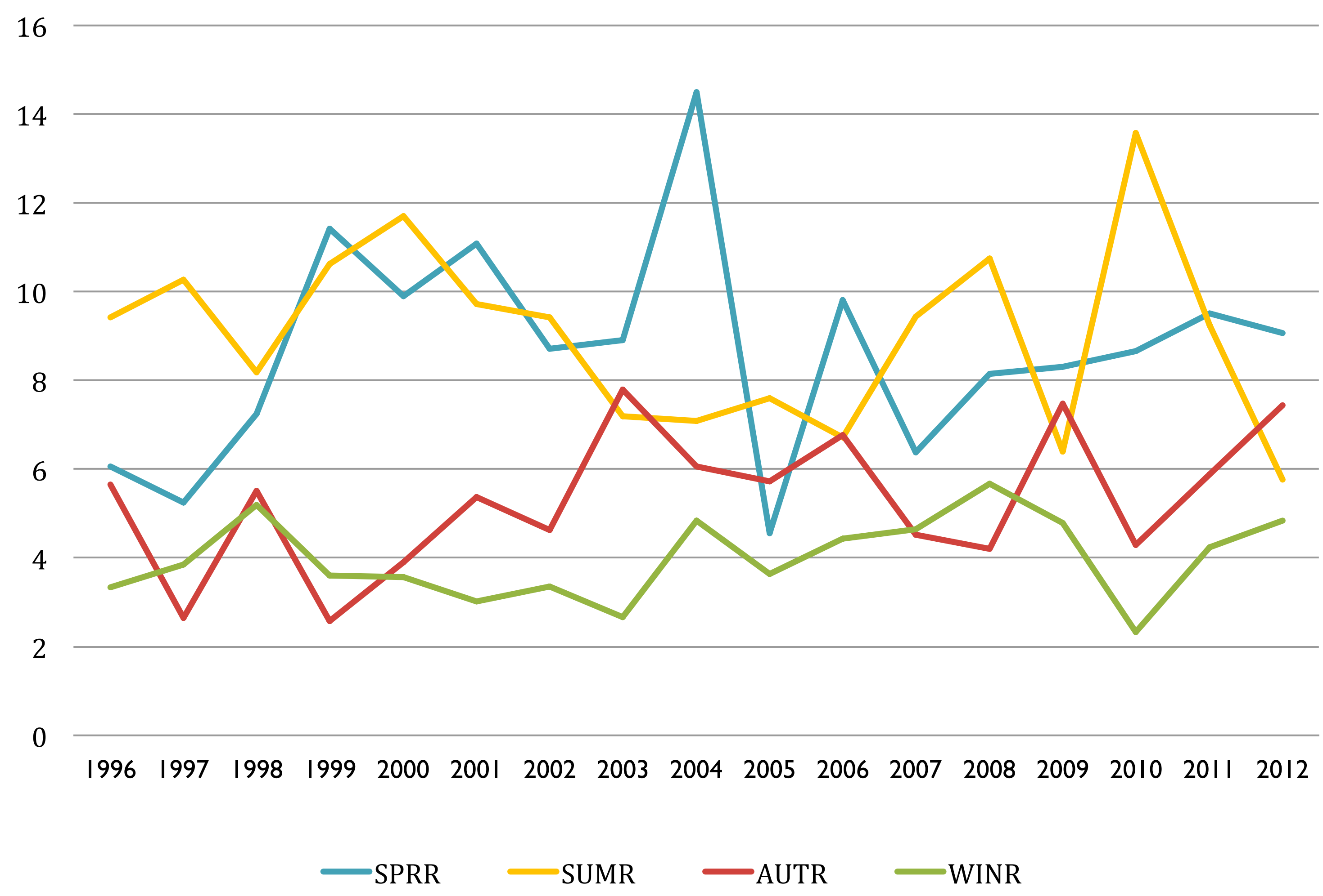
Climatic Conditions

Figure 2. **Seasonal Average Temperature (C°) for Wisconsin**



Climatic Conditions (2)

Figure 3. Seasonal Average Precipitation (cm) for Wisconsin



Summary of Results

- Estimated coefficients of all conventional inputs are significant with the expected positive sign and values (i.e., between 0 and 1).
- Model 4 is chosen based on Likelihood ratio and Hausman tests
- The four models exhibit decreasing returns to scale ranging from 0.998 (Model 1) to 0.928 (Model 3).
- 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.**

Climatic Effect

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

- According to **Model 4**, 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.

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.

- Hausman tests for model 4 reject the null hypothesis that unobserved heterogeneity is independent of the other explanatory variables.

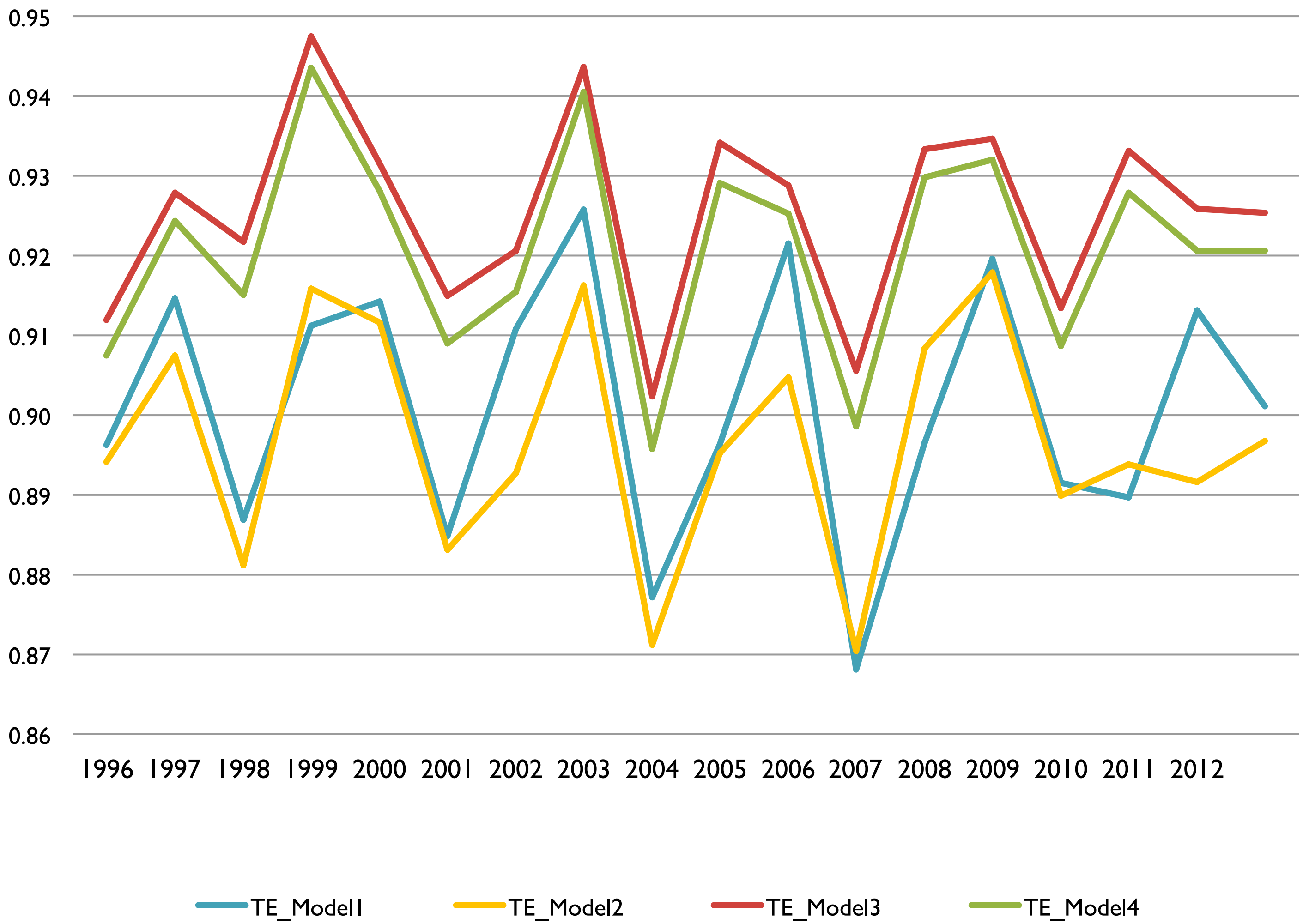
Summary of Results (2)

- 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.

- Hausman tests for model 4 reject the null hypothesis that unobserved heterogeneity is independent of the other explanatory variables.

Technical Efficiency (TE)

Figure 2. **Average Annual Technical Efficiency for Four Alternative Models: Wisconsin Dairy Farms 1996-2012**



Scenario Analysis

Table 5. Worst/Best Case and IPCC Projection Scenarios

Scenario--Average	CEI	Output (cwt)	Output Change (%)
Baseline/Current	0.311	28615	--
Commitment2000	0.294	26987	-5.69%
Low Scenario	0.283	25997	-9.15%
Medium Scenario	0.277	25486	-10.93%
High Scenario	0.278	25517	-10.83%

Scenario--Best	CEI	Output (cwt)	Output Change (%)
Current	0.391	35944	25.61%
Commitment2000	0.350	32188	12.48%
Low Scenario	0.337	30924	8.07%
Medium Scenario	0.330	30342	6.03%
High Scenario	0.331	30407	6.26%

Scenario--Worst	CEI	Output (cwt)	Output Change (%)
Current	0.279	25637	-10.41%
Commitment2000	0.259	23785	-16.88%
Low Scenario	0.249	22860	-20.11%
Medium Scenario	0.244	22444	-21.57%
High Scenario	0.244	22410	-21.69%