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MODELS FOR UNDERSTANDING ASYMMETRIC SEASONAL CYCLES IN MILK COMPONENT TESTS

PACIFIC NORTHWEST ORDER: 2011-2014

Staff Paper 15-01

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MODELS FOR UNDERSTANDING ASYMMETRIC SEASONAL CYCLES IN MILK COMPONENT TESTS PACIFIC NORTHWEST ORDER: 2011-2014

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Abstract

This study uses Ordinary Least Squares and Generalized Least Squares to model and understand relationships between certain environmental variables and asymmetric seasonal cycles in the butterfat, protein, other solids and water test of milk associated with the Pacific Northwest (FO 124) Federal Milk Marketing Order during 2011-2014. The data represent a balanced panel of 492 producers. Model variables include: regional monthly average daylight hours; regional monthly average temperatures; lagged component tests; dummy variables for region and year; and individual farm fixed effects.

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MODELS FOR UNDERSTANDING ASYMMETRIC SEASONAL CYCLES IN MILK COMPONENT TESTS PACIFIC NORTHWEST ORDER: 2011-2014

John Mykrantz [1]

I. INTRODUCTION

This study uses Ordinary Least Squares (OLS) and Generalized Least Squares (GLS) to model relationships between daylight hours and temperature and asymmetric seasonal cycles in milk component tests. [2] The data represent a balanced panel of 492 producers whose milk was associated milk with the Pacific Northwest (FO 124) Federal Milk Marketing Order during 2011-2014. With an understanding of what general changes in component tests are associated with changes in daylight and temperature, other possible causes of changes might be better understood.

The models include: regional monthly average daylight hours; regional monthly average temperatures; an interaction term of daylight hours and temperature; lagged component tests; dummy variables for region and year; and individual farm fixed effects. Each model is based on different subsets of the data defined by the different parts of the daylight and temperature cycles. The models are estimated using ordinary and generalized least squares regression.

In the Pacific Northwest Order, milk production and butterfat, protein and other solids tests change seasonally. Milk production per cow typically increases to a peak in the spring/early summer and decreases to a low point in the late fall/winter. Butterfat and protein tests also demonstrate a similar but opposite seasonality, decreasing slowly to a low in the early summer and increasing relatively more quickly to a peak in the mid-winter. The slow decrease and relatively quick increase describe an asymmetric cycle. The seasonality of milk production and component tests is a function of breed, genetics, daylight hours, temperature and other atmospheric conditions, feed type/quality/quantity, the biological cycle of cows, and miscellaneous other management practices. Other solids tests are much more consistent throughout the year when compared to the seasonal cycles in butterfat and protein tests but do demonstrate a general, asymmetric seasonality. Other solids, which are primarily lactose, are positively correlated with the portion of milk which is water as lactose is the major osmo-regulator of milk production. [3] [4] Lactose can therefore said to be related to the test (or

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[1] John Mykrantz is an Agricultural Economist with the Market Administrator’s Office, Bothell, Washington. This research is a part of the MA offices mission to provide market information per 1000.25 (c)(8). Special thanks are due Dr. John Newton, University of Illinois, Champaign-Urbana, for his help with R, modeling structure and comments; Dr. Corey Freije, Upper Midwest Market Administrator’s office, Minneapolis, Minnesota, for helpful comments and statistical issues; and Eric Talarico of the Pacific Northwest and Arizona Market Administrator’s office, Bothell, Washington, for his help with R.

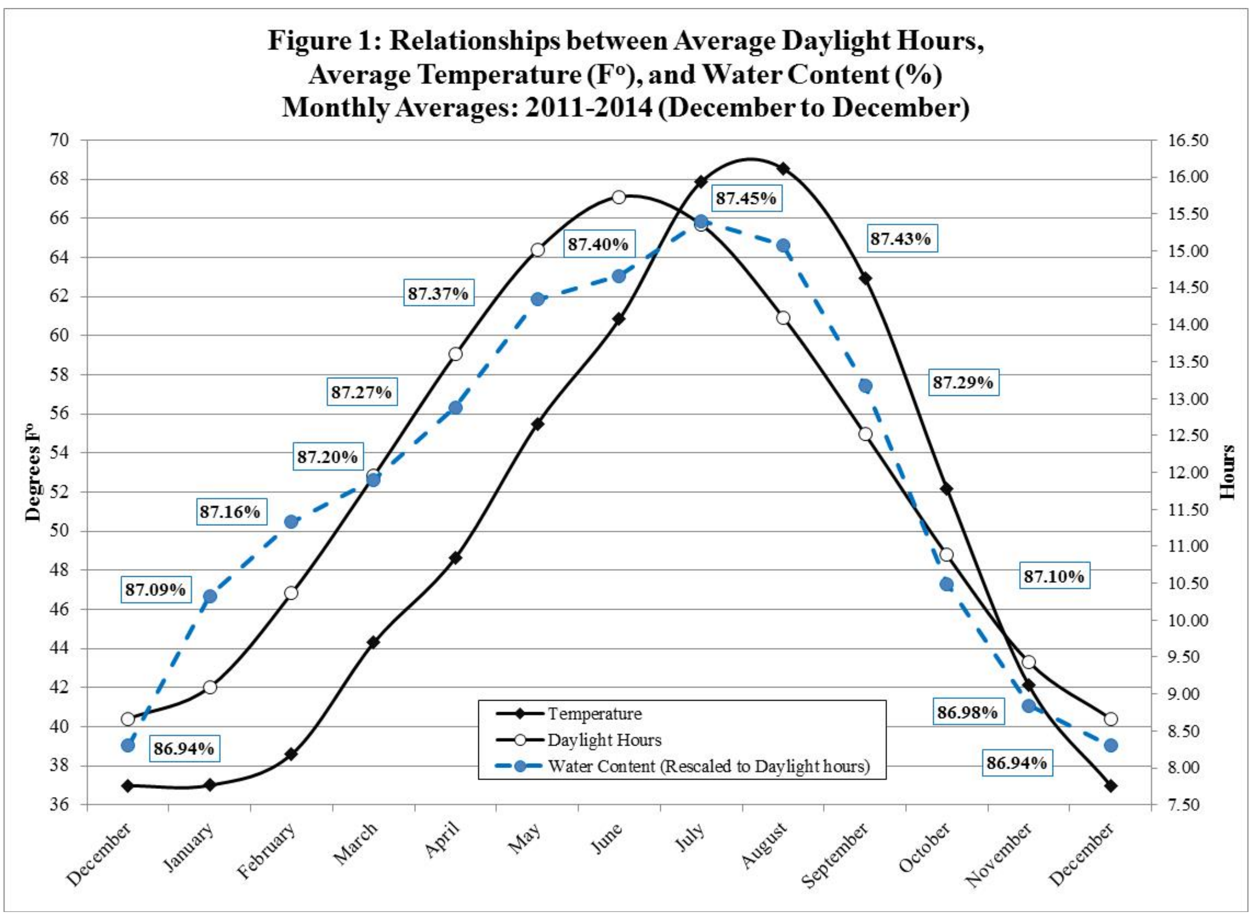
[2] Asymmetry is the lack of symmetry or lack of proportion between the parts of a thing. Merriam-Webster, Incorporated, 2015.

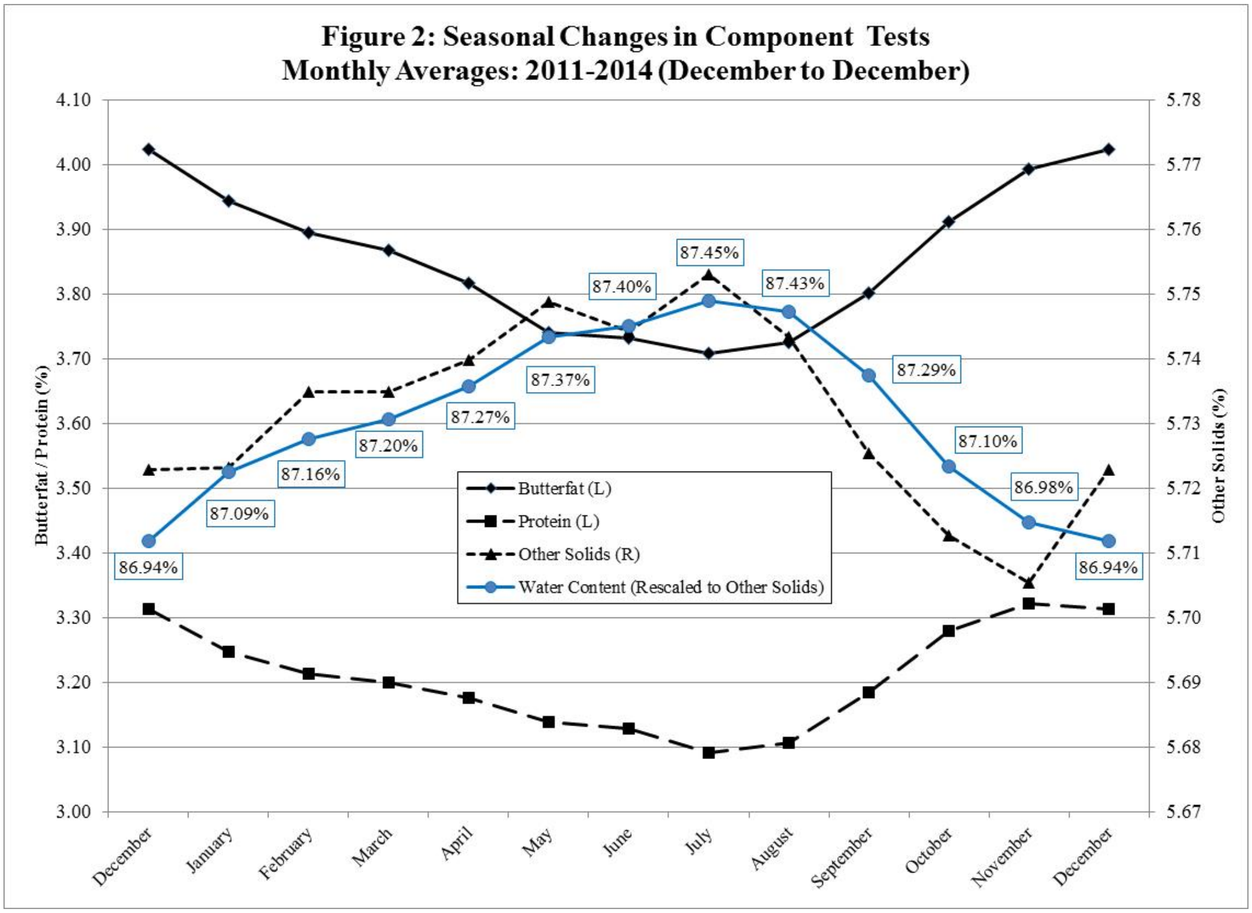
[3] Milk Composition and Synthesis Resource Library, University of Illinois, Urbana-Champaign, Copyright® 2009 by Walter L. Hurley: http://ansci.illinois.edu/static/ansc438/Milkcompsynth/milkcompsynthresources.html.

[4] Other Solids also includes minerals which contribute a negligible portion relative to lactose. Based on MA lab results, the mineral content of milk in the Pacific Northwest is slightly higher in the winter than during the summer. This suggests that minerals counterbalance the seasonality of lactose, dampening the seasonality of other solids to a slight degree.

concentration) of both butterfat and protein, i.e., the higher the lactose test, the lower the butterfat/protein test. However, the relationship between other solids and the water content of milk changes across the year and has roughly two phases: 1) December through August; and 2) September through November.

The number of daylight hours and temperature affect many biological processes. In addition, daylight hours and temperature are correlated but their relationship is complex. The changing number of daylight hours is a result of the angle of the Earth's axis in relation to the sun across the year. The earth acts as a heat sink, absorbing and releasing energy as the daylight hours increase and decrease resulting in a lagged relationship between daylight hours and temperature. Day length is a function of latitude which also affects how temperature may vary across the year in different locations. Proximity to geographic features (e.g. Pacific Ocean) influences the relationship between day length and temperature as well, enhancing or diminishing temperature averages and extremes. Figure 1 shows the cycles of average daylight hours, temperature and water content of milk. Seasonal changes in daylight hours reflect a symmetric cycle. Seasonal changes in temperature are affected by geography and larger scale, temporary weather patterns that can slightly distort the symmetry of temperature cycles. The timing of changes in daylight hours and temperature can be compared to graphs of the weighted average component test of butterfat, protein and other solids across the year in Figure 2. Note also that the water content of milk is rescaled as a function of daylight hours and other solids to show three or more variables in Figure 1 and 2, respectively. While there are certainly additional factors of cow physiology and phenology that influence and/or underlie the seasonality of milk component tests, daylight hours and temperature are fundamental, pervasive, and accessible environmental variables.





II. DATA

The data set consists of monthly individual farm milk production data of pounds of milk and components for 2011-2014. Milk that was historically associated with the order but was not pooled due to price relationships is included in this analysis. Only producers with a full forty-eight months of records are included in the analysis. The preceding criteria resulted in a balanced panel data set representing an annual average of 7.61 billion pounds and 492 producers located across Northern California, Idaho, Oregon, and Washington, with the vast majority being in Oregon and Washington (See Table 1). The amended database differs from published data by milk not pooled due to price, primarily associated with larger farms, and due to relatively smaller farms being primarily those that have gone out of business.

Table 1: Selected Characteristics of Published and Amended Datasets: 2011-2014

Dataset	Percent of Published	Average Annual Pounds of Milk (Billion)	Average Annual Number of Producers	Average Annual Daily Delivery	Average Test			
					Butterfat	Protein	Other Solids	H_2O
Published	100%	7.72	561	37,599	3.838	3.192	5.732	87.238
Amended	99%	7.61	492	42,261	3.844	3.198	5.733	87.226
Amended less Published		-0.11	-69	4,662	0.006	0.006	0.001	-0.012

The Pacific Northwest Order was divided into ten regions each of which is associated with a site (airport) from which climate information was collected. Sites were chosen based on proximity to each production area, and the quality and completeness of available data. Table 2 shows simple descriptive statistics by site/region in order of latitude for the period 2011-2014. The regions and their related sites are: 1) Yakima Valley [Yakima, WA]; 2) Columbia River [Hermiston, OR]; 3) Northwest Washington [Bellingham, WA]; 4) Southwest OR [Eugene, OR]; 5) Coastal OR/WA [Astoria, OR]; 6) Central Western Washington [Seattle, WA]; 7) Southwest Central WA [Olympia, WA]; 8) Northern Willamette Valley [Portland, OR]; 9) Eastern WA [Spokane, WA]; and 10) South Central OR [Redmond, OR]. [5] Appendix Table A-1 shows which counties are associated with which region and respective climate data location. The relative proportion and respective tests of each region are shown in Table 2. Generally higher tests for butterfat and protein are evident in Coastal OR/WA and Columbia River. Table 3 shows monthly average component tests for the period 2011-2014. Table 4 shows the annual average component tests for 2011 through 2014.

Table 2: Region, Climate City, Pounds, Percent of Total and Component Tests Sorted by Latitude: Averages, 2011-2014

Region 1/	Climate City 1/	Pounds (Billion)	Portion of Pounds	Average Test: Butterfat	Protein	Other Solids	H_2O
Northwest WA	Bellingham, WA	1.15	15.1%	3.90	3.16	5.71	87.23
Eastern WA	Spokane, WA	0.25	3.3%	3.90	3.22	5.73	87.15
Central Western WA	Seattle, WA	0.34	4.5%	3.77	3.14	5.73	87.36
Southwest Central WA	Olympia, WA	0.24	3.1%	3.73	3.13	5.74	87.40
Yakima Valley	Yakima, WA	3.00	39.5%	3.73	3.15	5.74	87.38
Coastal OR/WA	Astoria, OR	0.49	6.4%	4.34	3.35	5.75	86.55
Columbia River	Hermiston, OR	1.26	16.6%	3.95	3.35	5.73	86.98
Northern Willamette Valley	Portland, OR	0.25	3.3%	3.82	3.18	5.74	87.27
South Central OR	Redmond, OR	0.06	0.8%	3.63	3.14	5.76	87.47
Southwest OR	Eugene, OR	0.56	7.3%	3.74	3.13	5.76	87.36
Total/Average		7.61	100.0%	3.84	3.20	5.73	87.23

1/ See Appendix Table A for region definition and respective source of climate information.
Note: Coloration of tests are based on standard conditional formatting of Microsoft Excel and only serves to highlight differences in tests. Scale is defined by tests for each component separately.

Table 3: Component Tests by Year: 2011-2014

Year	Butterfat Test	Butterfat Change	Protein Test	Protein Change	Other Solids Test	Other Solids Change	H_2O Test	H_2O Change
2011	3.771		3.172		5.735		87.322	
2012	3.819	0.047	3.186	0.014	5.739	0.004	87.256	-0.066
2013	3.878	0.059	3.216	0.030	5.734	-0.005	87.172	-0.084
2014	3.902	0.025	3.216	0.000	5.723	-0.011	87.159	-0.014

[5] The use of Astoria to represent Coastal OR/WA is based on the absence of NOAA climate data for Tillamook, Oregon.

Table 4: Component Tests by Month: 2011-2014

Month	Average Test			
	Butterfat	Protein	Other Solids	H_2O
January	3.944	3.247	5.723	87.086
February	3.894	3.213	5.735	87.158
March	3.867	3.200	5.735	87.199
April	3.816	3.176	5.740	87.269
May	3.739	3.138	5.749	87.373
June	3.732	3.128	5.744	87.396
July	3.707	3.090	5.753	87.449
August	3.725	3.105	5.743	87.426
September	3.801	3.183	5.725	87.290
October	3.911	3.278	5.713	87.097
November	3.993	3.322	5.705	86.980
December	4.024	3.313	5.723	86.941
Average	3.844	3.198	5.733	87.226

Note: Coloration of tests are based on standard conditional formatting of Microsoft Excel and only serves to highlight differences in tests. Scale is defined by tests for each component separately.

Table 5: Component Tests by Period of Year: 2011-2014

Period of Year 1/	Butterfat		Protein		Other Solids		H_2O	
	Test	Change	Test	Change	Test	Change	Test	Change
Dec-Jun (DL↑)	3.857		3.201		5.736		87.206	
Jun-Dec (DL↓)	3.809	-0.048	3.183	-0.019	5.731	-0.005	87.277	0.072
Dec-Aug (T↑)	3.825		3.178		5.739		87.259	
Aug-Dec (T↓)	3.855	0.030	3.221	0.043	5.722	-0.017	87.202	-0.057

1/ DL is daylight hours. T is average temperature. The directional arrow implies increasing (↑) and decreasing (↓).

Average temperature and daylight hours were chosen to measure climate conditions. The measures include: the average number of daylight hours in a month and monthly average temperatures (F^o). Daylight hours can be thought of as a measure of radiant heat while average temperature is a measure of ambient heat. Monthly average temperature data were gathered from the National Oceanic and Atmospheric Administration (NOAA) reports for each month for ten sites (airports) near the major milk production regions of the Pacific Northwest. [6] For each month, the average number of daylight hours was calculated for these same sites using tables available from the United States Naval Observatory. [7]

In the Pacific Northwest, daylight hours range from about 8.5 hours in December at the winter solstice to about 16.0 hours in June at the summer solstice. Temperatures vary by region with more extreme variation occurring in Eastern Oregon and Eastern Washington. The entire Pacific Northwest experiences relatively low humidity and cooler night time temperatures during the

[6] NOAA, National Climactic Data Center, Quality Controlled Local Climatological Data. Climate information is available at: http://cdo.ncdc.noaa.gov/qclcd/QCLCD.
[7] US Naval Observatory, Data Services. Daylight tables are available at: http://aa.usno.navy.mil/data/docs/RS_OneYear.php.

summer due the effect of cold water temperatures of the Pacific Ocean. In addition, relatively warmer night time temperatures are common in the winter due to cloud cover. Table 6 provides a basic understanding of the average and relative range of daylight and temperature by region. The relative range, or maximum minus minimum, indicates how regional changes in temperature compare to the associated changes in daylight hours. Coastal regions had the lowest relative range (≈2) while Eastern Oregon and Eastern Washington had the highest (≈4). (See Table 6).

Table 6: Descriptive Statistics of Average Temperature and Daylight Hours for Cities in Pacific Northwest

Region 1/	Monthly Avg. Seasonal Temperatures 1/			Average Daylight Hours 2/		Relative Range
	High	Low	Average	June	December	
	A	B		C	D	(A-B) / (C-D)
Bellingham, WA	57.8	41.9	49.8	16.09	8.35	2.05
Spokane, WA	57.6	38.6	48.1	15.52	8.50	2.71
Seattle, WA	60.2	45.0	52.6	15.92	8.50	2.06
Olympia, WA	60.4	40.6	50.5	15.84	8.58	2.73
Yakima, WA	63.1	36.2	49.7	15.77	8.64	3.77
Astoria, OR	58.6	43.9	51.3	15.62	8.78	2.14
Hermiston, OR	65.4	39.4	52.4	15.67	8.73	3.74
Portland, OR	63.1	45.6	54.4	15.63	8.92	2.61
Redmond, OR	62.1	32.1	47.1	15.47	8.92	4.58
Eugene, OR	63.3	41.6	52.4	15.43	8.95	3.35

1/ NOAA, National Climate Data Center, 1981-2010. Normals, at designated weather station. See Appendix Table A-1.
2/ US Naval Observatory, Data Services: 2011-2014.

III. METHODOLOGY

Each model has the same form but each uses a different subset of the data. The subsets of data were based on the cyclical periods of daylight and temperature, respectively. There are four subsets of data: 1) December to June (increasing daylight); 2) June to December (decreasing daylight); 3) December to August (increasing temperature); and 4) August to December (decreasing temperature). Models were calculated for each of milk's primary constituents: butterfat, protein, other solids and water. The relative magnitude of the coefficients resulting from the four models may provide one way to understand the relationship between daylight and temperature and the seasonality of milk component tests and its water content. An alternative to breaking the data into periods of monotonic change of daylight and temperature would have been to use dummy variables for month. The method used preserves degrees of freedom for regional dummy variables.

While the average test of butterfat, protein and by extension, water, have relatively smooth, seasonal cycles, the cycle of other solids appears to be somewhat different. Other solids shows steady increases from December through July which parallel increases in daylight hours and temperature, but with the onset of peak temperatures in August, other solids drops and then drops further to season lows in September through November. The pattern of changes in other solids matches the period when butterfat and protein begin their relatively steep climb into the late fall and winter months.

Other variables not included in the models (e.g. temperature variation, cloud cover, precipitation, economic conditions) may have influenced component tests. In addition, the climate data chosen to reflect a region may not sufficiently or consistently reflect conditions affecting dairy farms and milk produced in that particular region. Additional condition information may include breed, genetics, average stage of lactation, average cow age, feed and housing.

Regressions were of the form $Y = X'\beta + \varepsilon$, where Y represents the natural log of the test of butterfat, protein, other solids, and water, respectively. The natural log form of the dependent variable allows for the coefficients of the independent variables to be interpreted as a unit change associated with a percentage change in the dependent variable. X is an $n \times k$ matrix of conditioning information including: daylight hours, average temperature, an interaction term, a lagged dependent variable (Y_{t-1}), and individual dummy variables for region, year, and for $n-1$ individual producers. The use of the lagged dependent variable as an independent variable is intended to recognize that current tests are a function of previous tests in the context of changes in daylight hours and temperature. The model estimated was of the form:

$$\text{Ln}(y_{it}) = \alpha + x'_{it}\beta + c_i + u_{it}, \text{ for } i = 1,\ldots,492 \text{ and } t = 1,\ldots,48,$$

where α is a constant, β are coefficients, c_i is an *individual-specific effect* and u_{it} is an *idiosyncratic error term*. For all models, results of Hausman tests indicate the fixed effect model is more consistent than a simple pooled ordinary least square regression. A fixed effect model assumes that the individual specific effect is correlated with the independent variables. Breusch-Godfrey tests indicate serial correlation is evident in the residuals of the fixed effect models. Serial correlation in the residuals suggests that the standard errors of the coefficients are biased and the estimation of the coefficients using generalized least squares is warranted. Since generalized least squares is not compatible with R^2 statistics, these statistics are drawn from the ordinary least squares, fixed effect form of each model.

IV. REGRESSION RESULTS

Ordinary and generalized least square regression were used to estimate linear relationships between milk component tests and temperature and daylight. [8] General results of the ordinary least squared regression equations are summarized in Appendix B. Details of the generalized least square regression parameter estimates are summarized in Appendix C. All regression equations performed reasonably well, though the models to estimate butterfat, protein, and water content appear to perform relatively better than the models for other solids. All coefficients were of the expected sign reflecting seasonal changes in daylight and temperature relative to component tests with a few exceptions relating to protein and other solids. The exceptions appear to be a function of using temperature cycles to define the dataset analyzed. In July and August, temperatures reach their seasonal peaks and component tests change direction.

The magnitude of the coefficients generated may represent one way to understand the relationship between changes in daylight and temperature and the seasonality of component tests. A table comparing the coefficients of daylight (DL) and temperature (T) are shown in Table 5, 6, & 7. It should be remembered that the scale of daylight and temperature are different, with temperature having a range of about 2 to nearly 5 times greater than daylight, depending on the region. More complete statistics can be found in Appendix C.

[8] R was used to estimate the coefficients of the equations (http://www.r-project.org/).

Table 7: Comparison of Coefficients (GLS)

Component	Variable	Coefficient (β)				exp(β) 1/			
		D→J	J→D	D→A	A→D	D→J	J→D	D→A	A→D
Butterfat	DL	-0.00950	0.02005	-0.00974	0.03771	-0.946%	2.025%	-0.969%	3.842%
	T	-0.00266	0.00515	-0.00153	0.00518	-0.266%	0.516%	-0.153%	0.520%
	DLxT	0.00018	-0.00043	0.00015	-0.00058	0.018%	-0.043%	0.015%	-0.058%
Protein	DL	0.00023	0.02903	0.00167	0.04025	0.023%	2.946%	0.167%	4.107%
	T	-0.00108	0.00680	0.00037	0.00660	-0.108%	0.682%	0.037%	0.662%
	DLxT	0.00004	-0.00057	-0.00003	-0.00065	0.004%	-0.057%	-0.003%	-0.065%
Other Solids	DL	0.00049	-0.00490	-0.00028	-0.00401	0.049%	-0.489%	-0.028%	-0.400%
	T	0.00037	-0.00107	0.00000	-0.00089	0.037%	-0.107%	0.000%	-0.089%
	DLxT	-0.00002	0.00009	0.00000	0.00007	-0.002%	0.009%	0.000%	0.007%
H_2O	DL	0.00043	-0.00164	0.00042	-0.00291	0.043%	-0.164%	0.042%	-0.290%
	T	0.00013	-0.00043	0.00005	-0.00044	0.013%	-0.043%	0.005%	-0.044%
	DLxT	-0.00001	0.00004	-0.00001	0.00005	-0.001%	0.004%	-0.001%	0.005%

1/ A one-unit increase in the independent variable is associated with a percentage increase in the geometric mean of the component test: exp(-0.00950) -1 = 0.99054 - 1 = -0.946%.

Table 8: Comparison of Absolute Values of Coefficients (GLS)

Component	DL, T	A	B	B/A	
		J→D:D→J	A→D:D→A		
Butterfat	DL	2.11	3.87	1.84	
	T	1.94	3.39	1.75	
	DLxT	2.36	3.88	1.64	
Protein	DL	***126.41***	24.11	***0.19***	1/
	T	6.29	17.66	2.81	
	DLxT	14.97	22.52	1.50	
Other Solids	DL	10.03	14.47	1.44	
	T	2.87	***809.27***	***282.28***	2/
	DLxT	3.65	***46.47***	***12.72***	2/
H_2O	DL	3.83	6.86	1.79	
	T	3.35	9.71	2.90	
	DLxT	3.89	7.67	1.97	

1/ Dec to Jun daylight coefficient not significantly different from zero.

2/ Dec to Aug temperature (p-value=0.15) and daylight-temperature interaction (p-value=0.09) are not significantly different from zero.

Table 9: Ratios of Coefficients (GLS)

Component	Coefficients DL:T			
	D→J	J→D	D→A	A→D
Butterfat	3.57	3.90	6.37	7.27
Protein	***-0.21*** 1/	4.27	4.47	6.10
Other Solids	1.31	4.58	***-251.91*** 2/	4.50
H_2O	3.37	3.85	9.42	6.65

1/ Dec to Jun daylight coefficient not significantly different from zero.

2/ Dec to Aug temperature coefficient not significantly different from zero.

While there are certainly additional factors of cow physiology and phenology that influence and/or underlie the seasonality of milk component tests, an analysis and comparison of the coefficients for daylight and temperature for each component model reveals that:

- During the period studied, between May and June there is a general decline in other solids test which appears to resolve itself by July. This may reflect generally more cloudy weather conditions common in the Pacific Northwest during this time period.
- The peak temperatures of August in the Pacific Northwest are associated with a subsequent and significant decrease in milk's other solids test and a change in its relationship to the water content of milk which does not resolve itself until about December.
- The asymmetric cycles of component tests are reflected in the coefficients of daylight and temperature, i.e., their absolute values are relatively smaller in the spring/summer and larger in the fall/winter, and vice versa for other solids and water content.
- The association of butterfat and protein tests with daylight is larger in the period when temperature is decreasing (Aug-Dec) than when daylight is decreasing (Jun-Dec).
- The association of butterfat, protein, other solids and water tests with temperature is roughly the same in the months when daylight is decreasing (Jun-Dec) as when temperature is decreasing (Aug-Dec).
- Daylight and temperature have a relatively more consistent and significant association with butterfat and water content than with protein or other solids, i.e., ratio of the coefficients (DL:T) does not change as much between the different phases of the daylight and temperature cycles.
- For protein (Dec-Jun), the coefficient for daylight has a p-value of 0.54, suggesting changes in protein tests are more consistently associated with changes in temperature than changes in daylight.
- For other solids (Dec-Jun), changes are more associated with changes in temperature than changes in daylight.
- In the December –June period, on average, for a 1 degree Fahrenheit increase:
    - the butterfat test would decrease by 0.0018 percentage points
    - the protein test would decrease by 0.0020 percentage points
    - the other solids test would increase by 0.0005 percentage points
    - the water test would increase by 0.0016 percentage points
- In the June-December period, on average, for a 1 degree Fahrenheit increase
    - the butterfat test decrease by 0.0006 percentage points
    - the protein test would decrease by 0.0008 percentage points
    - the other solids test would increase by 0.0001 percentage points
    - the water test would increase by 0.0007 percentage points
- The preceding two points suggest that, theoretically, for an even 1 degree Fahrenheit increase across the year, annual average butterfat and protein tests would decrease, all other conditions being the same. Similarly, annual average other solids and water tests would increase.

V. CONCLUSION

This study demonstrates that: 1) daylight hours and temperature can be used to model seasonal cycles in component tests with relative accuracy; and 2) it may be possible to quantify to some degree the complex relationships between these selected environmental variables and component tests. While the models include lagged component tests, regional average daylight hours, and regional average temperatures, other variables (e.g. environmental and economic) may add to the accuracy and relevance of the models. In addition, the use of more sophisticated statistical techniques beyond ordinary and generalized least squares regression could result in a better understanding of factors affecting seasonal cycles in the component test of milk. Measures of temperature closer to the location of each farm may enhance the precision of the comparisons.

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Appendix A

Table A-1: Counties Included in Regional Aggregations *

Region No.	Region Name	Climate Site Location	Climate City	Site Latitude	Site Longitude	Washington	Oregon	California
1	Northwest WA	BELLINGHAM INTL AIRPORT (24217)	Bellingham, WA	48.45	122.29	Skagit, Whatcom		
2	Eastern WA	SPOKANE INTERNATIONAL AIRPORT (24157)	Spokane, WA	47.40	117.25	Adams, Lincoln, Spokane, Stevens		
3	Central Western WA	SEATTLE-TACOMA INTERNATIONAL AIRPORT (24233)	Seattle, WA	47.38	122.2	Clallam, King, Pierce, Snohomish		
4	Southwest Central WA	OLYMPIA AIRPORT (24227)	Olympia, WA	47.02	122.53	Grays Harbor, Lewis, Pacific, Thurston		
5	Yakima Valley	YAKIMA AIR TERMINAL/MCALSR FIELD AP (24243)	Yakima, WA	46.35	120.31	Kittitas, Grant, Yakima		
6	Coastal OR/WA	ASTORIA REGIONAL AIRPORT (94224)	Astoria, OR	46.11	123.49	Wakiakum	Clatsop, Tillamook	
7	Columbia River	HERMISTON MUNICIPAL ARPT (04113)	Hermiston, OR	45.5	119.17	Benton, Franklin, Klickitat	Morrow, Umatilla	
8	Northern Willamette Valley	PORTLAND INTERNATIONAL AIRPORT (24229)	Portland, OR	45.31	122.39	Clark, Cowlitz	Clackamas, Multnomah, Washington, Yamhill	
9	South Central OR	ROBERTS FIELD AIRPORT (24230)	Redmond, OR	44.17	121.11		Deschutes, Klamath	
10	Southwest OR	MAHLON SWEET FIELD AIRPORT (24221)	Eugene, OR	44.03	123.06		Benton, Jackson, Josephine, Lane, Linn, Marion, Polk	Siskiyou

* Only counties with milk pounds in the amended database are shown.

Appendix B

Table B-1: Summary of Regression Results by Component (OLS, FE) 1/

Component	Period	R-Squared	Adjusted R-Squared	SE of Estimates	F-Statistic	Sig. 2/
Butterfat	Dec-Jun	0.955	0.954	0.022	568.6	***
	Jun-Dec	0.953	0.951	0.024	542.1	***
	Dec-Aug	0.954	0.953	0.022	720.8	***
	Aug-Dec	0.956	0.954	0.023	410.2	***
Protein	Dec-Jun	0.946	0.944	0.015	464.5	***
	Jun-Dec	0.948	0.946	0.016	487.3	***
	Dec-Aug	0.945	0.943	0.016	593.7	***
	Aug-Dec	0.950	0.947	0.016	356.7	***
Other Solids	Dec-Jun	0.875	0.870	0.005	186.8	***
	Jun-Dec	0.881	0.876	0.005	196.8	***
	Dec-Aug	0.867	0.864	0.005	226.1	***
	Aug-Dec	0.890	0.884	0.005	151.8	***
H_2O	Dec-Jun	0.966	0.965	0.001	758.5	***
	Jun-Dec	0.965	0.964	0.001	730.7	***
	Dec-Aug	0.967	0.966	0.001	997.3	***
	Aug-Dec	0.968	0.967	0.001	575.3	***

1/ The number of observations for all equations 492x#months included, less 9 due to singularities.

2/ *, **, *** indicate significance at 90%, 95%, and 99% level, respectively.

Appendix Table C: Regression Results by Component (GLS)

Table C-1: Regression Results for Butterfat

Variable	Dec-Jun			Jun-Dec			Dec-Aug			Aug-Dec		
	β	SE	p-value	β	SE	p-value	β	SE	p-value	β	SE	p-value
Constant	6.06E-01	7.35E-03	0.00	2.16E-01	8.21E-03	0.00	5.69E-01	6.70E-03	0.00	1.04E-01	1.04E-02	0.00
T	-2.66E-03	1.68E-04	0.00	5.15E-03	1.38E-04	0.00	-1.53E-03	1.47E-04	0.00	5.18E-03	1.72E-04	0.00
TxDL	1.83E-04	1.18E-05	0.00	-4.31E-04	1.21E-05	0.00	1.49E-04	1.05E-05	0.00	-5.77E-04	1.60E-05	0.00
DL	-9.50E-03	5.50E-04	0.00	2.01E-02	7.13E-04	0.00	-9.74E-03	4.81E-04	0.00	3.77E-02	1.06E-03	0.00
BF(-1)	2.26E-01	5.16E-04	0.00	2.36E-01	5.82E-04	0.00	2.28E-01	4.71E-04	0.00	2.37E-01	6.74E-04	0.00
Bellingham	-3.03E-03	6.52E-04	0.00	2.15E-03	7.09E-04	0.00	-3.97E-03	5.81E-04	0.00	8.17E-04	8.35E-04	0.33
Eugene	-4.42E-03	8.43E-04	0.00	-2.71E-03	9.35E-04	0.00	-7.97E-03	7.55E-04	0.00	1.67E-03	1.10E-03	0.13
Hermiston	-9.93E-03	1.07E-03	0.00	9.93E-03	1.20E-03	0.00	-1.21E-02	9.60E-04	0.00	1.17E-02	1.38E-03	0.00
Olympia	-6.68E-03	9.05E-04	0.00	2.49E-03	9.82E-04	0.01	-6.01E-03	8.05E-04	0.00	1.86E-03	1.16E-03	0.11
Portland	-3.13E-03	9.69E-04	0.00	3.12E-03	1.08E-03	0.00	-6.80E-03	8.67E-04	0.00	9.14E-03	1.28E-03	0.00
Redmond	-1.32E-02	2.11E-03	0.00	-6.69E-04	2.26E-03	0.77	-1.11E-02	1.86E-03	0.00	-1.01E-04	2.68E-03	0.97
Seattle	-6.64E-03	8.61E-04	0.00	-9.08E-05	9.52E-04	0.92	-9.00E-03	7.70E-04	0.00	2.92E-03	1.12E-03	0.01
Spokane	-1.24E-02	1.15E-03	0.00	1.13E-02	1.17E-03	0.00	-9.02E-03	9.76E-04	0.00	1.12E-02	1.38E-03	0.00
Yakima	-1.24E-02	7.84E-04	0.00	8.93E-03	8.74E-04	0.00	-1.33E-02	6.89E-04	0.00	9.59E-03	9.90E-04	0.00
2012	2.44E-03	5.77E-04	0.00	8.73E-04	6.24E-04	0.16	1.02E-03	5.13E-04	0.05	-6.41E-04	7.40E-04	0.39
2013	3.40E-03	5.83E-04	0.00	5.20E-03	6.29E-04	0.00	2.26E-03	5.17E-04	0.00	2.81E-03	7.36E-04	0.00
2014	4.64E-04	6.04E-04	0.44	2.51E-03	6.41E-04	0.00	-9.47E-04	5.24E-04	0.07	2.58E-03	7.71E-04	0.00

Table C-2: Regression Results for Protein

Variable	Dec-Jun			Jun-Dec			Dec-Aug			Aug-Dec		
	β	SE	p-value	β	SE	p-value	β	SE	p-value	β	SE	p-value
Constant	2.71E-01	5.47E-03	0.00	-1.17E-01	5.93E-03	0.00	2.18E-01	4.96E-03	0.00	-1.80E-01	7.50E-03	0.00
T	-1.08E-03	1.15E-04	0.00	6.80E-03	9.20E-05	0.00	3.74E-04	1.00E-04	0.00	6.60E-03	1.16E-04	0.00
TxDL	3.83E-05	8.06E-06	0.00	-5.74E-04	8.07E-06	0.00	-2.91E-05	7.15E-06	0.00	-6.54E-04	1.08E-05	0.00
DL	2.30E-04	3.78E-04	0.54	2.90E-02	4.75E-04	0.00	1.67E-03	3.28E-04	0.00	4.02E-02	7.16E-04	0.00
PRO(-1)	2.85E-01	6.83E-04	0.00	2.96E-01	7.53E-04	0.00	2.88E-01	6.18E-04	0.00	2.96E-01	8.82E-04	0.00
Bellingham	-4.43E-03	4.45E-04	0.00	5.66E-03	4.75E-04	0.00	-3.77E-03	3.95E-04	0.00	4.32E-03	5.67E-04	0.00
Eugene	-2.82E-03	5.67E-04	0.00	5.99E-03	6.13E-04	0.00	-3.42E-03	5.05E-04	0.00	8.10E-03	7.30E-04	0.00
Hermiston	-4.88E-03	7.29E-04	0.00	1.76E-02	7.91E-04	0.00	-4.13E-03	6.47E-04	0.00	1.74E-02	9.23E-04	0.00
Olympia	-4.66E-03	6.22E-04	0.00	2.52E-03	6.54E-04	0.00	-3.25E-03	5.49E-04	0.00	5.17E-04	7.83E-04	0.51
Portland	-2.87E-03	6.60E-04	0.00	8.17E-03	7.16E-04	0.00	-4.02E-03	5.87E-04	0.00	1.06E-02	8.58E-04	0.00
Redmond	-6.55E-03	1.44E-03	0.00	8.87E-03	1.50E-03	0.00	-2.47E-03	1.26E-03	0.05	5.88E-03	1.80E-03	0.00
Seattle	-5.70E-03	5.88E-04	0.00	6.61E-03	6.31E-04	0.00	-5.25E-03	5.23E-04	0.00	6.40E-03	7.54E-04	0.00
Spokane	-9.57E-03	7.84E-04	0.00	1.74E-02	7.79E-04	0.00	-4.56E-03	6.61E-04	0.00	1.66E-02	9.28E-04	0.00
Yakima	-8.05E-03	5.17E-04	0.00	1.81E-02	5.65E-04	0.00	-6.64E-03	4.53E-04	0.00	1.84E-02	6.47E-04	0.00
2012	1.46E-03	3.95E-04	0.00	-2.20E-03	4.15E-04	0.00	-5.31E-04	3.48E-04	0.13	-2.73E-03	5.00E-04	0.00
2013	2.28E-03	3.99E-04	0.00	4.29E-03	4.18E-04	0.00	8.74E-04	3.51E-04	0.01	4.07E-03	4.96E-04	0.00
2014	1.03E-03	4.14E-04	0.01	1.77E-03	4.25E-04	0.00	-1.26E-03	3.56E-04	0.00	2.34E-03	5.20E-04	0.00

Appendix Table C: Regression Results by Component (GLS) (Continued)

Table C-3: Regression Results for Other Solids

Variable	Dec-Jun			Jun-Dec			Dec-Aug			Aug-Dec		
	β	SE	p-value	β	SE	p-value	β	SE	p-value	β	SE	p-value
Constant	8.29E-01	3.43E-03	0.00	8.40E-01	3.80E-03	0.00	8.38E-01	3.15E-03	0.00	8.25E-01	4.52E-03	0.00
T	3.73E-04	3.46E-05	0.00	-1.07E-03	2.82E-05	0.00	1.10E-06	3.08E-05	0.97	-8.90E-04	3.54E-05	0.00
TxDL	-2.39E-05	2.42E-06	0.00	8.73E-05	2.48E-06	0.00	-1.50E-06	2.20E-06	0.51	6.97E-05	3.30E-06	0.00
DL	4.89E-04	1.13E-04	0.00	-4.90E-03	1.46E-04	0.00	-2.77E-04	1.01E-04	0.01	-4.01E-03	2.18E-04	0.00
OS(-1)	1.59E-01	5.65E-04	0.00	1.68E-01	6.16E-04	0.00	1.59E-01	5.21E-04	0.00	1.69E-01	7.06E-04	0.00
Bellingham	3.27E-05	1.31E-04	0.80	-1.83E-04	1.43E-04	0.20	-1.21E-04	1.19E-04	0.31	-1.07E-03	1.68E-04	0.00
Eugene	2.38E-04	1.69E-04	0.16	8.59E-05	1.87E-04	0.65	4.02E-04	1.54E-04	0.01	-5.28E-04	2.21E-04	0.02
Hermiston	8.73E-04	2.19E-04	0.00	-1.56E-03	2.44E-04	0.00	5.88E-04	1.99E-04	0.00	-2.05E-03	2.81E-04	0.00
Olympia	-2.59E-04	1.83E-04	0.16	-2.63E-04	1.99E-04	0.19	-5.49E-04	1.65E-04	0.00	-3.00E-04	2.36E-04	0.20
Portland	-2.85E-04	1.97E-04	0.15	-2.75E-04	2.20E-04	0.21	9.20E-06	1.79E-04	0.96	-4.40E-04	2.61E-04	0.09
Redmond	1.48E-03	4.30E-04	0.00	-4.18E-04	4.61E-04	0.36	8.03E-04	3.86E-04	0.04	-1.84E-03	5.50E-04	0.00
Seattle	3.38E-04	1.72E-04	0.05	-1.23E-04	1.90E-04	0.52	1.95E-04	1.56E-04	0.21	-4.52E-04	2.25E-04	0.05
Spokane	1.52E-03	2.34E-04	0.00	-1.51E-03	2.37E-04	0.00	4.05E-04	2.01E-04	0.04	-2.33E-03	2.79E-04	0.00
Yakima	1.45E-03	1.52E-04	0.00	-1.52E-03	1.67E-04	0.00	9.70E-04	1.35E-04	0.00	-2.36E-03	1.89E-04	0.00
2012	-9.70E-04	1.19E-04	0.00	2.60E-06	1.28E-04	0.98	-2.82E-04	1.07E-04	0.01	-8.56E-04	1.53E-04	0.00
2013	-4.41E-04	1.20E-04	0.00	-1.63E-03	1.29E-04	0.00	-3.76E-04	1.08E-04	0.00	-1.86E-03	1.51E-04	0.00
2014	-5.05E-04	1.23E-04	0.00	4.43E-04	1.31E-04	0.00	-2.87E-04	1.09E-04	0.01	1.06E-03	1.59E-04	0.00

Table C-4: Regression Results for Water (H2O)

Variable	Dec-Jun			Jun-Dec			Dec-Aug			Aug-Dec		
	β	SE	p-value	β	SE	p-value	β	SE	p-value	β	SE	p-value
Constant	3.50E+00	1.88E-03	0.00	3.49E+00	2.07E-03	0.00	3.50E+00	1.67E-03	0.00	3.48E+00	2.42E-03	0.00
T	1.27E-04	9.46E-06	0.00	-4.26E-04	7.77E-06	0.00	4.50E-05	8.10E-06	0.00	-4.37E-04	9.74E-06	0.00
TxDL	-9.00E-06	6.61E-07	0.00	3.50E-05	6.82E-07	0.00	-6.00E-06	5.78E-07	0.00	4.60E-05	9.06E-07	0.00
DL	4.28E-04	3.09E-05	0.00	-1.64E-03	4.01E-05	0.00	4.24E-04	2.64E-05	0.00	-2.91E-03	6.00E-05	0.00
H_2O(-1)	1.10E-02	2.13E-05	0.00	1.14E-02	2.39E-05	0.00	1.11E-02	1.89E-05	0.00	1.16E-02	2.79E-05	0.00
Bellingham	2.37E-04	3.70E-05	0.00	-2.90E-04	4.05E-05	0.00	2.89E-04	3.23E-05	0.00	-1.34E-04	4.80E-05	0.01
Eugene	2.04E-04	4.72E-05	0.00	-1.69E-04	5.25E-05	0.00	3.91E-04	4.14E-05	0.00	-4.24E-04	6.22E-05	0.00
Hermiston	4.99E-04	6.02E-05	0.00	-1.03E-03	6.75E-05	0.00	6.18E-04	5.27E-05	0.00	-1.11E-03	7.80E-05	0.00
Olympia	3.66E-04	5.12E-05	0.00	-2.58E-04	5.57E-05	0.00	3.25E-04	4.46E-05	0.00	-1.68E-04	6.61E-05	0.01
Portland	2.28E-04	5.45E-05	0.00	-3.99E-04	6.09E-05	0.00	4.42E-04	4.77E-05	0.00	-7.59E-04	7.24E-05	0.00
Redmond	5.62E-04	1.18E-04	0.00	-4.55E-04	1.27E-04	0.00	3.56E-04	1.02E-04	0.00	-2.79E-04	1.52E-04	0.07
Seattle	3.49E-04	4.87E-05	0.00	-3.33E-04	5.39E-05	0.00	4.59E-04	4.26E-05	0.00	-4.36E-04	6.40E-05	0.00
Spokane	7.87E-04	6.47E-05	0.00	-1.02E-03	6.64E-05	0.00	5.57E-04	5.37E-05	0.00	-9.60E-04	7.83E-05	0.00
Yakima	6.60E-04	4.38E-05	0.00	-1.06E-03	4.92E-05	0.00	6.91E-04	3.77E-05	0.00	-1.06E-03	5.59E-05	0.00
2012	-3.70E-05	3.24E-05	0.25	1.25E-04	3.51E-05	0.00	6.20E-05	2.82E-05	0.03	2.87E-04	4.19E-05	0.00
2013	-1.05E-04	3.28E-05	0.00	-2.14E-04	3.54E-05	0.00	-7.00E-06	2.84E-05	0.81	-9.60E-05	4.16E-05	0.02
2014	8.80E-05	3.40E-05	0.01	-9.40E-05	3.60E-05	0.01	2.21E-04	2.88E-05	0.00	-1.40E-04	4.36E-05	0.00