UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Marketing Service
Dairy Programs

1930-220th Street SE, Ste. 102
Bothell, WA 98021
Phone: (425) 487-6009
Fax: (425) 487-2775
Email: fmmaseattle@fmmaseattle.com

FEDERAL MILK ORDERS 124 & 131

4835 E. Cactus Road, Ste. 365
Scottsdale, AZ 85254
Phone: (602) 547-2909
Fax: (602) 547-2906

MODELS FOR UNDERSTANDING SEASONAL CYCLES IN REGIONAL MILK PRODUCTION PER DAY

PACIFIC NORTHWEST ORDER: 2012-2015

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John Mykrantz

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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 seasonal cycles in milk production associated with the Pacific Northwest (FO 124) Federal Milk Marketing Order during 2012-2015. The data represent a balanced panel of 467 producers. Model variables include: regional monthly average daylight hours; regional monthly average temperatures; lagged production per day; and dummy variables for region, year, and individual farm fixed effects.

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MODELS FOR UNDERSTANDING
SEASONAL CYCLES IN REGIONAL MILK PRODUCTION PER DAY
PACIFIC NORTHWEST ORDER: 2012-2015 [1]

John Mykrantz [2]

I. INTRODUCTION

This study uses Ordinary Least Squares (OLS) and Generalized Least Squares (GLS) to model relationships between daylight hours and temperature and seasonal cycles in milk production per day. The data represent a balanced panel of 467 producers whose milk was associated milk with the Pacific Northwest (FO 124) Federal Milk Marketing Order during 2012-2015. [3] With an understanding of what general changes in milk production per day 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 milk production per day; and dummy variables for region, 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.

In the Pacific Northwest Order, milk production changes 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. The seasonality of milk production is a function of many factors including breed, genetics, daylight hours, temperature and other atmospheric conditions, feed type/quality/quantity, the biological cycle of cows, and miscellaneous other management practices.

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 production per day. 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. Figure 2 shows the cycles of average production per producer per day per hour of daylight, per degree (F˚), and per hour-

[1] This paper is an extension and reframing of a paper entitled, Models for Understanding Asymmetric Seasonal Cycles in Milk Component Tests, Pacific Northwest Order: 2011-2014, Staff Paper 15-01, November 2015.

[2] 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).

[3] Originally, five years of data were to be used in the analysis (2011-2015), however, 2011 data reflected a large increase in production across the year and was therefore excluded. This increase in production across 2011 reflects large increases in cow numbers as shown in the NASS monthly Milk Production report.

degree (daylight hours x degrees). Note that milk production per day is rescaled as a function of daylight hours to show three variables of different scales graphically.[4] While there are certainly additional factors of cow physiology and phenology that influence and/or underlie the seasonality of milk production, daylight hours and temperature are fundamental, pervasive, and accessible environmental variables.[5]

Figure 1: Relationships between Average Daylight Hours, Average Temperature and Production Per Day (PPD, Million Pounds) Monthly Averages: 2012-2015 (January to January)

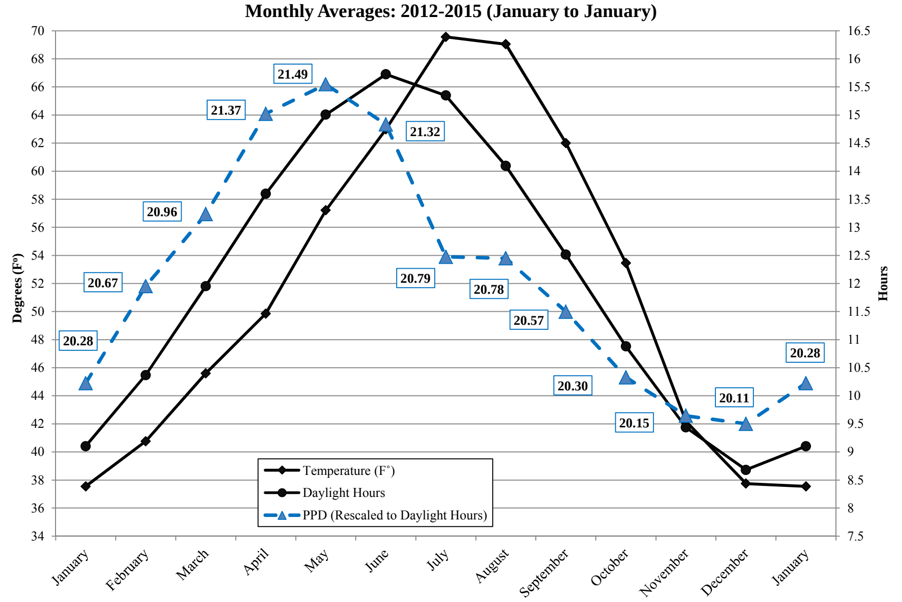
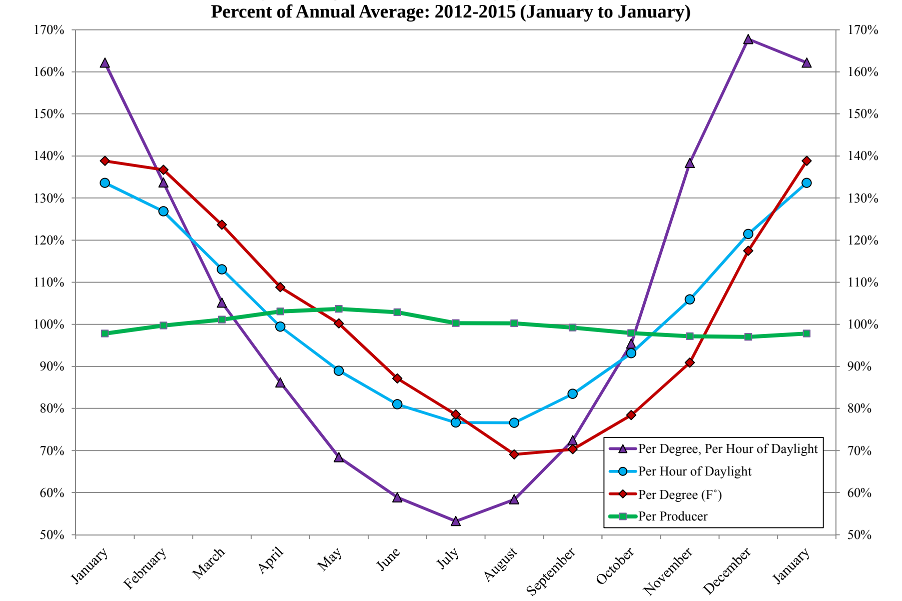


Figure 2: Milk Production Per Day-Per Degree (F°), Per Day-Per Hour of Daylight, Per Day-Per Degree-Per Hour of Daylight, and Per Producer: Percent of Annual Average: 2012-2015 (January to January)



[4] The rescaling of production per day was accomplished by a simple regression of the form: y = c + bx.
[5] Physiology is the branch of biology that deals with the normal functions of living organisms and their parts. Phenology is the study of cyclic and seasonal natural phenomena, especially in relation to climate and plant and animal life.

II. DATA

The data set consists of monthly individual farm milk production data of pounds of milk for 2012-2015. 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 of 22,416 records representing an annual average of 7.58 billion pounds and 467 producers located across Northern California, Idaho, Oregon, and Washington, with the vast majority being in Oregon and Washington. 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 those that do not have production in all months of the study period (See Table 1).

Table 1: Selected Characteristics of Published and Amended Datasets: 2012-2015

Dataset	Percent of Published	Average Annual Pounds of Milk (Billion)	Average Production Per Day (Million)	Average Annual Number of Producers	Average Annual Daily Delivery Per Producer
Published	100%	7.37	20.18	528	38,198
Amended	103%	7.58	20.75	467	44,439
Amended less Published		0.21	0.57	-61	6,241

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. In order of pounds of milk represented, the regions and their related sites are: 1) Yakima Valley [Yakima, WA]; 2) Columbia River [Hermiston, OR]; 3) Northwest WA [Bellingham, WA]; 4) Southwest OR [Eugene, OR]; 5) Coastal OR/WA [Astoria, OR]; 6) Central Western WA [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].[6] Table 2 shows simple descriptive statistics by site/region in order of latitude for the period 2012-2015. Appendix Table A-1 shows which counties are associated with which region and the respective climate data location. The relative proportion and respective average production per day of each region are shown in Table 2. Appreciably higher production per day is evident in the Yakima Valley, Columbia River and Northwest WA regions. Table 3 shows monthly average production per day for the period 2012-2015. (See also Figure 2.) Table 4 shows the annual average production per day for 2012 through 2015.

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

Table 2: Region, Climate City, Pounds, Pounds Per Day: Averages, 2012-2015

Region	Climate City 1/	Pounds (Billion)	Percent of Total Pounds	Production Per Day (Million)
Northwest WA	Bellingham, WA	1.12	14.8%	3.08
Eastern WA	Spokane, WA	0.26	3.4%	0.71
Central Western WA	Seattle, WA	0.33	4.4%	0.92
Southwest Central WA	Olympia, WA	0.25	3.2%	0.67
Yakima Valley	Yakima, WA	3.00	39.5%	8.20
Coastal OR/WA	Astoria, OR	0.48	6.3%	1.31
Columbia River	Hermiston, OR	1.30	17.2%	3.56
Northern Willamette Valley	Portland, OR	0.25	3.3%	0.69
South Central OR	Redmond, OR	0.06	0.8%	0.16
Southwest OR	Eugene, OR	0.53	6.9%	1.44
Total 2/		7.58	100.0%	20.74

1/ Sorted by latitude. See Appendix A for region definition and respective source of climate information.
2/ May not add due to rounding.

Table 3: Production Per Day by Month: Averages, 2012-2015

Month	Production Per Day (Million)	Production Per Day			
		Per Producer	Per Degree (F°)	Per Hour of Daylight	Per Degree, Per Hour of Daylight
		- - - - - - - Pounds	- - - - - - -		
January	20.28	43,420	1,245	5,047	127
February	20.67	44,260	1,226	4,791	105
March	20.96	44,883	1,109	4,271	82
April	21.37	45,751	976	3,756	67
May	21.49	46,007	898	3,360	54
June	21.32	45,660	781	3,059	46
July	20.79	44,515	704	2,895	42
August	20.78	44,501	619	2,893	46
September	20.57	44,039	630	3,152	57
October	20.30	43,471	703	3,517	75
November	20.15	43,139	815	4,000	108
December	20.11	43,069	1,053	4,588	131

Note: Coloration of values is based on standard conditional formatting of Microsoft Excel and only serves to highlight differences in production per day across the year.

Table 4: Production Per Day by Year: Averages, 2012-2015

Year	Production Per Day (Million)	Production Per Day			
		Per Producer	Per Degree (F°)	Per Hour of Daylight	Per Degree, Per Hour of Daylight
		- - - - - - - Pounds	- - - - - - -		
2012	19.778	42,353	869	3,604	77
2013	20.432	43,751	908	3,713	81
2014	21.213	45,425	909	3,860	81
2015	21.555	46,158	900	3,928	80

Note: Coloration of values is based on standard conditional formatting of Microsoft Excel and only serves to highlight differences in production per day across the period.

Temperature and daylight hours were chosen to measure climate conditions. The measures include: monthly average temperatures (F^o), and the average number of daylight hours in a month. 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. [7] For each month, the average number of daylight hours was calculated for these same sites using tables available from the United States Naval Observatory. [8]

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 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 relative range (≈4). (See Table 5).

Table 5: Descriptive Statistics of Average Temperature (F°) and Daylight Hours for Cities in Pacific Northwest

Region	Climate City 1/	Monthly Avg. Seasonal Temperatures 2/			Average Daylight Hours 3/		Relative
		High	Average	Low	June	December	Range Ratio
		A		B	C	D	(A-B) / (C-D)
Northwest WA	Bellingham, WA	57.8	49.8	41.9	16.09	8.35	2.05
Eastern WA	Spokane, WA	57.6	48.1	38.6	15.93	8.50	2.56
Central Western WA	Seattle, WA	60.2	52.6	45.0	15.92	8.50	2.05
Southwest Central WA	Olympia, WA	60.4	50.5	40.6	15.73	8.67	2.80
Yakima Valley	Yakima, WA	63.1	49.7	36.2	15.77	8.64	3.77
Coastal OR/WA	Astoria, OR	58.6	51.3	43.9	15.62	8.78	2.15
Columbia River	Hermiston, OR	65.4	52.4	39.4	15.67	8.73	3.75
Northern Willamette Valley	Portland, OR	63.1	54.4	45.6	15.62	8.77	2.55
South Central OR	Redmond, OR	62.1	47.1	32.1	15.47	8.92	4.58
Southwest OR	Eugene, OR	63.3	52.4	41.6	15.43	8.95	3.35
Simple Average		61.2	50.8	40.5	15.73	8.68	2.96

1/ Sorted by latitude. See Appendix A for region definition and respective source of climate information.
2/ NOAA, National Climate Data Center, 1981-2010. Normals, at designated weather station. See Appendix A.
3/ US Naval Observatory, Data Services: 2012-2015.
Note: Coloration of values are based on standard conditional formatting of Microsoft Excel and only serves to highlight differences in the relative range of temperatures and daylight hours among the regions.

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

Table 6: Average Annual Temperatures (F°) for Cities in Pacific Northwest: 2012-2015

Region	Climate City 1/	Average 2/			
		2012	2013	2014	2015
Northwest WA	Bellingham, WA	50.4	50.9	52.7	52.2
Eastern WA	Spokane, WA	49.1	47.6	49.4	51.7
Central Western WA	Seattle, WA	52.3	53.8	55.0	55.6
Southwest Central WA	Olympia, WA	49.9	50.6	52.1	52.9
Yakima Valley	Yakima, WA	51.5	52.2	53.0	55.0
Coastal OR/WA	Astoria, OR	50.6	51.0	53.4	54.0
Columbia River	Hermiston, OR	52.9	52.4	54.0	55.6
Northern Willamette Valley	Portland, OR	54.5	54.2	56.0	57.4
South Central OR	Redmond, OR	47.7	47.3	48.1	49.7
Southwest OR	Eugene, OR	53.0	53.1	54.9	55.5

1/ Sorted by latitude. See Appendix A for region definition and respective source of climate information.

2/ Simple average of monthly average temperatures. Not adjusted for calendar composition.

Note: Coloration of values are based on standard conditional formatting of Microsoft Excel and only serves to highlight differences in the relative range of temperatures and daylight hours among the regions.

III. METHODOLOGY

Each model has the same basic 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). 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 production. 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 which are meant to capture the unique profile of dairy farms of each region.

Other variables not included in the models (e.g. number and breed of cows being milked, temperature variation, cloud cover, precipitation, winds, economic conditions) may have influenced milk production. 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 production per day. 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 milk production per day is a function of the previous month's milk production per day in the context of changes in daylight hours and temperature. The natural log is taken of both production per day (dependent variable) and the lagged production per day (independent variable) since changes in production are proportional to the size of producers' farms which are very diverse. The model estimated was of the form:

$$y_{it} \quad = \quad \alpha + x'_{it}\beta + c_i + u_{it}, \text{ for } i = 1,\ldots,467 \text{ and } t = 1,\ldots,48,$$

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.

VI. REGRESSION RESULTS

Ordinary least squares regression was used to estimate linear relationships between milk production per day and temperature and daylight. [9] General results of the ordinary least squares 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 well, with very high R-squared statistics (greater than 0.99). All coefficients were of the expected sign reflecting seasonal changes in daylight and temperature relative to milk production per day. The magnitude of the coefficient of the lagged production per day variable, near 1, suggests that nearly all of the variation in production per day is captured by the other variables.

The magnitude of the coefficients generated may represent one way to understand the relationship between changes in temperature and daylight and the seasonality of milk production. A table comparing the coefficients of daylight (DL), temperature (T) and the interaction term (TxDL) are shown in Tables 7, 8, and 9. More complete statistics can be found in Appendix C.

Table 7: Comparison of Coefficients (GLS)

Independent Variable	Dec→Jun (↑DL)	Jun→Dec (↓DL)	Dec→Aug (↑T)	Aug→Dec (↓T)
	Coefficient (β)			
T (F°)	0.003712	-0.002003	0.004122	-0.003128
TxDL	-0.000375	0.000129	-0.000418	0.000406
DL	0.019418	-0.008057	0.021465	-0.034368
	exp(β) 1/			
T (F°)	0.372%	-0.200%	0.413%	-0.312%
TxDL	-0.037%	0.013%	-0.042%	0.041%
DL	1.961%	-0.802%	2.170%	-3.378%

1/ A one-unit increase in the independent variable is associated with a percentage change in the geometric mean of the production per day: exp(0.003712) -1 = 1.003712 - 1 = 0.372%.

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

Table 8: Comparison of Coefficients: Production Per Day (GLS)

DL, T	Dec→Jun (↑DL): Jun→Dec (↓DL)	Dec→Aug (↑T): Aug→Dec (↓T)
T (F˚)	1.86	1.32
TxDL	2.91	1.03
DL	2.44	0.64

Table 9: Change in Production Per Day (GLS)

Change	Dec→Jun (↑DL)	Jun→Dec (↓DL)	Dec→Aug (↑T)	Aug→Dec (↓T)
+1 Hour DL	**0.17%**	-0.08%	**0.17%**	**-1.13%**
+1˚ F	-0.08%	-0.04%	-0.09%	**0.19%**
+ 1 Hour DL, 1˚ F	0.05%	**-0.10%**	0.03%	**-0.90%**

While there are certainly additional factors of cow physiology and phenology that influence and/or underlie the seasonality of milk production, this analysis shows that:

- Production typically plateaus at season highs in April, May, and June and declines to season lows in November and December.
- The onset of peak temperatures in July and August are associated with a steep decline in production per day, but the steepness of the decline moderates by September.
- The seasonality of milk production per day appears to be more correlated with seasonal changes in daylight hours than temperature.
- A comparison of the coefficients of daylight, temperature and the interaction term between the defined periods (increasing vs decreasing) suggest the effect of both daylight and temperature are stronger when they are increasing than when they are decreasing with one exception (See Table 8 above)
    - Exception: using data based on the temperature cycle, daylight hours have a stronger effect when temperatures are decreasing.
- In the following periods, the effect of an additional hour of daylight or degree Fahrenheit are (See Table 9 above):
    - In the December – June period, on average, for an increase of one hour of daylight, production per day would increase 0.17 percent
    - In the December-August period, on average, for an increase of one hour of daylight, production per day would increase by 0.17 percent
    - In the August-December period, on average, for an increase of one hour Fahrenheit, production per day would decrease by 1.13 percent
    - In the August-December period, on average, for an increase of one degree Fahrenheit, production per day would increase by 0.19 percent
    - In the June-December period, on average, for an increase of one hour of daylight and an increase of 1 degree Fahrenheit, production per day would decrease by 0.10 percent
    - In the August-December period, on average, for an increase of one hour of daylight and an increase of one degree Fahrenheit, production per day would decrease by 0.90 percent
    - For the other periods not mentioned, on average, for an increase of one hour of daylight and/or an increase of one degree Fahrenheit, production per day would change less than 0.10 percent.

V. CONCLUSION

This study demonstrates that: 1) daylight hours and temperature can be used to model seasonal cycles of milk production; and 2) it may be possible to quantify to some degree the complex relationships between these selected environmental variables and changes in milk production. While the models include lagged production per day, 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 least squares or generalized least squares regression could result in a better understanding of factors affecting seasonal cycles in milk production. Measures of temperature and additional environmental factors, such as heat stress, closer to the location of each farm may enhance the precision of this type of modeling.

Appendix A

Table A-1: Counties Included in Regional Aggregations 1/

Region No.	Region Name	Climate Site Location 2/	Climate City Location	Site Latitude	Site Longitude	California	Oregon	Washington
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	122.20			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		Clatsop, Tillamook	Wakiakum
7	Columbia River	HERMISTON MUNICIPAL ARPT (04113)	Hermiston, OR	45.50	119.17		Morrow, Umatilla	Benton, Franklin, Klickitat
8	Northern Willamette Valley	PORTLAND INTERNATIONAL AIRPORT (24229)	Portland, OR	45.31	122.39		Clackamas, Multnomah, Washington, Yamhill	Clark, Cowlitz
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	Siskiyou	Benton, Jackson, Josephine, Lane, Linn, Marion, Polk	

1/ Sorted by latitude. Only counties with milk pounds in the amended database are shown.

Appendix B

Appendix Table B-1: Summary of Regression Results by Period (OLS) 1/

Period	R-Squared	Adjusted R-Squared	SE of Estimates	F-Statistic	Sig. 2/
Dec-Jun (↑DL)	0.9954	0.9952	0.0905	5,739	***
Jun-Dec (↓DL)	0.9973	0.9972	0.0694	9,767	***
Dec-Aug (↑T)	0.9958	0.9957	0.0858	8,166	***
Aug-Dec (↓T)	0.9972	0.9971	0.0709	6,766	***

1/ The number of observations for all equations is 467x#months, less 9 due to singularities.

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

Appendix C

Table C-1: Regression Results for Production Per Day (GLS)

	Dec-Jun (↑DL)				Jun-Dec (↓DL)				Dec-Aug (↑T)				Aug-Dec (↓T)			
Variable 1/	β	SE	p-value	Sig. 2/	β	SE	p-value	Sig. 2/	β	SE	p-value	Sig. 2/	β	SE	p-value	Sig. 2/
Constant	-1.12E-01	2.72E-02	0.00	♦	6.64E-02	2.14E-02	0.00	♦	-1.59E-01	2.34E-02	0.00	♦	2.42E-01	2.98E-02	0.00	♦
T (F˚)	3.71E-03	6.13E-04	0.00	♦	-2.00E-03	3.65E-04	0.00	♦	4.12E-03	5.13E-04	0.00	♦	-3.13E-03	4.94E-04	0.00	♦
TxDL	-3.75E-04	4.32E-05	0.00	♦	1.29E-04	3.21E-05	0.00	♦	-4.18E-04	3.65E-05	0.00	♦	4.06E-04	4.72E-05	0.00	♦
DL	1.94E-02	2.11E-03	0.00	♦	-8.06E-03	1.96E-03	0.00	♦	2.15E-02	1.73E-03	0.00	♦	-3.44E-02	3.22E-03	0.00	♦
PPD (-1)	9.93E-01	7.63E-04	0.00	♦	1.00E+00	5.91E-04	0.00	♦	9.95E-01	6.41E-04	0.00	♦	1.00E+00	7.24E-04	0.00	♦
Bellingham	2.44E-03	2.68E-03	0.36		3.69E-03	2.04E-03	0.07	*	4.27E-03	2.23E-03	0.06	*	7.01E-03	2.51E-03	0.01	***
Eugene	7.07E-04	3.44E-03	0.84		3.55E-03	2.67E-03	0.18		1.67E-03	2.88E-03	0.56		6.97E-03	3.27E-03	0.03	**
Hermiston	1.46E-02	4.51E-03	0.00	♦	-2.93E-04	3.53E-03	0.93		1.99E-02	3.78E-03	0.00	♦	1.54E-03	4.24E-03	0.72	
Olympia	-4.66E-03	3.60E-03	0.20		3.15E-03	2.74E-03	0.25		-2.57E-03	3.00E-03	0.39		1.66E-02	3.38E-03	0.00	♦
Portland	-1.05E-03	3.94E-03	0.79		8.88E-03	3.08E-03	0.00	♦	2.86E-03	3.30E-03	0.39		8.66E-03	3.79E-03	0.02	**
Redmond	2.73E-03	8.39E-03	0.74		8.06E-04	6.34E-03	0.90		5.95E-03	6.94E-03	0.39		5.81E-03	7.88E-03	0.46	
Seattle	4.00E-03	3.50E-03	0.25		5.96E-03	2.72E-03	0.03	**	6.92E-03	2.93E-03	0.02	**	3.50E-03	3.34E-03	0.29	
Spokane	-8.21E-04	4.65E-03	0.86		3.17E-03	3.39E-03	0.35		5.33E-03	3.74E-03	0.16		1.04E-02	4.16E-03	0.01	***
Yakima	1.53E-02	3.39E-03	0.00	♦	-2.51E-04	2.65E-03	0.92		1.99E-02	2.82E-03	0.00	♦	1.30E-03	3.13E-03	0.68	
2013	4.62E-03	2.36E-03	0.05	**	-2.40E-03	1.81E-03	0.18		5.17E-03	1.97E-03	0.01	***	-3.98E-03	2.23E-03	0.07	*
2014	8.19E-03	2.38E-03	0.00	♦	-1.03E-03	1.82E-03	0.57		8.11E-03	1.97E-03	0.00	♦	-6.36E-03	2.26E-03	0.00	♦
2015	4.23E-03	2.48E-03	0.09	*	-1.50E-03	1.84E-03	0.42		6.89E-03	2.00E-03	0.00	♦	-3.45E-03	2.22E-03	0.12	

1/ T = Temperature; DL = Daylight Hours; PPD(-1) = Lagged Production Per Day.

2/ *, **, ***, ♦ indicate significance at 90%, 95%, 99%, and 99.9% level, respectively.