AN INTEGRATED ANALYSIS OF FEDERAL MILK MARKETING ORDER PRICE DIFFERENTIAL POLICY AND CLIMATE CHANGE EFFECTS IN DAIRY INDUSTRY

A Dissertation

by

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ABSTRACT

This dissertation investigates the match of current Federal Milk Marketing Order (FMMO) price differential policy with current conditions and the effects of shifting diesel prices on price differentials along with climate effects on milk production. A spatial mathematical model (MilkOrdIII) of the dairy industry is modified to include milk components and organic milk then used to study milk pricing, and the effects of changing diesel prices. Subsequently, climate impacts are explored using spatial econometric panel modeling.

This work is reported from three aspects. Firstly, it addresses how the present Class I price differentials under FMMOs compare to an model-generated idealized set. It also does a comparison for Class II, III, and IV milk and constructs price surfaces for organic milk, and milk components. The results show that the current Class I price differentials are not a good reflection of ideal differentials under today's conditions. We find the price differential pattern is similar to that of today's policy but the range of values is substantially wider. Thus updating may be desirable. For organic, Class II and IV milk and butterfat may merit regionally differentiated prices. Class III and the other milk components appear to be handled with a uniform price.

Secondly, this research examines the diesel price influences on price differentials and the possibility of updating the differentials as diesel prices change. The results show price differentials are significantly affected by diesel price with higher prices increasing the differentials for raw milk and protein; decreasing those for butterfat and other solids non-fat. Formulas for updating differentials as the diesel price shifts are developed based on econometric estimation over the ideal price differential results.

Thirdly, the climate change analysis examines climate impacts on milk production then estimates the impact of projected climate change. The results show heat stress index, exerts an inverse U-shaped relationship with a threshold of 72; under an RCP 8.5 climatic projection for 2030 milk production would increase in the West and Northeast and decline in the Mid-west and South. Also using spatial econometric panel models improves model fit likely due to reduced biases from spatially correlated omitted variables.

DEDICATION

To my parents and younger brother

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Contributors

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1 INTRODUCTION

1.1 Introduction and Objectives

The United States dairy industry is highly regulated. The major regulation arises through the Federal Milk Marketing Order (FMMO), which is designed to stabilize the dairy market and attract milk to deficit markets. It does this by requiring that handlers pay a minimum price (a Class I price differential) to dairy farmers. However, the price differentials are somewhat old being established in 2000 and since then, many aspects of the dairy industry have changed including milk supply and demand locations, and transportation costs. Consequently the current Class I price differentials may not reflect today's market conditions. Hence exploring the effects of dairy market evolution and transportation costs as they effect Class I price differentials and milk component values is a goal of this study.

Additionally the dairy industry may be vulnerable to climate change. Livestock have been found to be sensitive to weather conditions and climate is projected to change with a likely global temperature increase of 0.3 - 4.8℃ by 2100 along with more frequent, intense and long-lasting extreme climate events and increased weather variability (IPCC 2013). Thus another item studied here is the effect of climate change on milk production.

1.2 Plan of Dissertation

This dissertation contains three essays:

- Essay 1 addresses the effects of changes in milk market conditions on an idealized set of spatial milk price differentials in comparison with existing ones. The essay also covers spatial price surfaces for milk components – butterfat, protein and other solids non-fat. In the work an idealized price differential surface is developed using a spatial mathematical program (MilkOrdIII) that is an expanded version of the model used in Seo (2015), and includes the characteristics of raw milk in terms of butterfat, protein, and other solids non-fat as they vary regionally.

- Essay 2 addresses how the shifting transport costs due to altered diesel prices affect milk price differentials and milk component prices and develops a formula for updating differentials when the diesel price changes. This is done by econometrically estimating a function relating idealized differentials generated with the MilkOrdIII model across a range of alternative diesel prices.
- Essay 3 investigates the effects of climate on milk production first using historical data and then looking at the effects of a climate change projection. In this case, an econometric spatial panel model is estimated over historical milk production data at the state level to quantify climate effects on milk yields per cow.

2 AN ANALYSIS OF FEDERAL MILK MARKETING ORDER PRICE DIFFERENTIALS

2.1 Introduction

The United States is one of the world's largest milk producers. In 2013, U.S. milk farmers provided about 1/6th of the global cow milk supply[1]. The milk production (dairy industry) makes a significant contribution to the economy. For example, in 2014 the California dairy industry experienced nearly $65 billion in total sales, and almost 200 thousand jobs (Sumner, Medellín-Azuara, and Coughlin 2015).

Milk prices are highly regulated. The main regulation arises through the Federal Milk Marketing Orders (FMMOs). The FMMOs control milk prices over space using a classified milk pricing system. That system is designed to facilitate Grade A milk production and its movement from surplus to deficit areas, along with compensating producers for the extra movement costs (e.g., Chouinard et al. 2010).

Class I price differentials, a key component of the FMMO pricing system, have received substantial attention from economists (e.g., Dobson and Salathe 1979; Hallberg et al. 1978; McDowell, Fleming, and Spinelli 1995). Generally the analyses have embodied the assumption that efficiency can be enhanced by using an appropriate interregional milk pricing structure (McDowell, Fleming, and Fallert 1988; Novakovic and Pratt 1991). However, the pricing differentials that are currently being used were set in the year 2000 with only a few revisions

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[1] Calculated from the data of FAO (FAOSTAT).

since then. Meanwhile, industry supply demand location and the cost of transportation has changed substantially leading to the question: Are the current price differentials reflective of price differentials under current conditions?

The current relevance of the differentials depends in part on potential spatial movements of milk and transport costs. There have been locational shifts in both supply and demand plus in transport costs. Major changes have occurred in location of milk supply (figure 2-1), and product categories of consumption. In particular, milk production has moved west and north (MacDonald et al. 2007 and Seo 2015). Additionally there have been alterations in form of consumption (figure 2-2) with reduced consumption of fluid products and increased that of manufactured products. Transport costs have also changed as they are greatly affected by fuel prices. Fuel prices have also gone up with diesel price rising to about 4.00 $/gallon in 2012 and today are almost triple the price that was in place when the differentials were established in 2000. All three of these factors influence milk prices across space and in turn the appropriate level of differentials. Consequently there is a high probability that the current price differentials are not reflective of today's production, consumption and transport conditions.

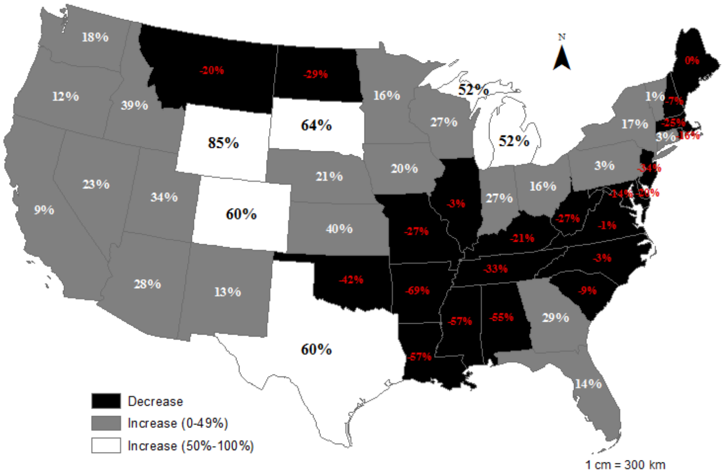

Figure 2-1. Percentage Change of Milk Production in U.S. (comparing 2015 with 2005)

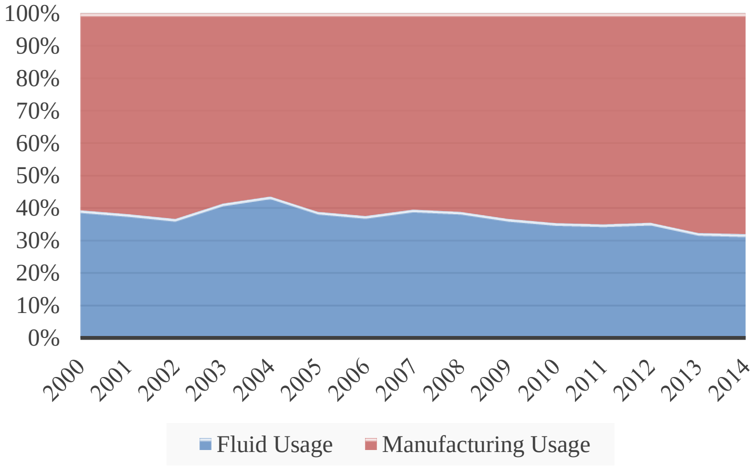

Figure 2-2. Utilization of U.S. Milk (2000-2014) (USDA, AMS)

This essay reports on an analysis examining the match between the current FMMO price differentials and an idealized set. In doing this we examine the consequences of shifts in production and consumption and in a subsequent analysis examine the effects of shifts in transport costs. The analysis will be done employing a spatial, mathematical programming model of the US dairy industry called MilkOrdII. MilkOrdII was developed by Seo (2015) and expands on the MilkOrd model developed by McCarl, Schwart and Siebert (1996). In turn MilkOrd integrated features from the DAMPS model by Novakovic et al. (1979) plus the dairy processing model of Baker, Dixit, and McCarl (1981). Here the model will be further expanded resulting in a new version denoted as MilkOrdIII. The main expansion involves incorporation of accounting for butterfat, protein, and other solids characteristics of raw milk as they vary regionally plus alteration of the processing component so that the product yield depends on the raw milk characteristics. We also added organic milk and Greek yogurt. MilkOrdIII is used herein to generate an idealized set of price differentials which will be examined relative to the currently implemented differentials. Analysis will also be done on the spatial price surfaces for milk components – butterfat, protein and other solids non-fat.

2.2 Milk Marketing Background

The dairy industry is subject to many government programs and regulations. These mainly involve three policy instruments: Dairy Product Price Support Program (DPPSP); import quotas on dairy products; and Federal Milk Marketing Orders (FMMOs) (Chouinard, et al 2010). Before the mid-1980s, these policy instruments were jointly used to form prices for milk and manufactured products (such as farm, wholesale, and retail prices).

However, after that, milk price supports were reduced and under the World Trade Organization's Uruguay Round Agreement on Agriculture, the dairy policies were altered to avoid distorting the domestic market (Langley, Somwaru, and Normile 2006). Today, the FMMO policy is dominant. That policy, authorized in the Agricultural Marketing Agreement Act of 1937, regulated the prices paid by dairy handlers when purchasing raw milk from dairy farmers, and aims to: "(1) assure consumers of an adequate supply of wholesome milk at a reasonable price; (2) promote greater producer price stability and orderly marketing; and (3) provide adequate producer prices to ensure an adequate current and future fresh fluid milk supply"[2].

Raw milk supply is divided into Grade A and Grade B milk depending on sanitary conditions. Organic milk[3] can be viewed as an upgraded type of Grade A milk with yet more

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[2] Source: https://www.ams.usda.gov/rules-regulations/moa/dairy

[3] Organic milk is produced by cows raised from organic farming system. https://www.usda.gov/oig/webdocs/01601-0002-32.pdf

production requirements. In turn, the cost for producing Grade A and organic milk is higher than the cost for Grade B.

The FMMO policy classifies milk into four classes according to different usages: Class I which is raw milk used for fluid beverage products; Class II which is that used for soft dairy products such as ice cream, cottage cheese and yogurt; Class III that is used for cream cheese and hard manufactured cheeses; and Class IV used to manufacture dry milk and butter[4].

The FMMO pricing system[5] differs across the classes of raw milk. Spatially independent, identical prices are imposed for Class II, III, and IV milk and are based on U.S. average wholesale prices of dairy products in the class[6]. Class I milk prices vary spatially and are the minimum price on a regional basis that dairy handlers must pay to dairy farmers (producers). They are composed by adding regional Class I price differentials to the higher of the prices for Class III or IV milk. Additionally, this system pools the value of all classes of qualified milk receipts in a milk order region and calculates a uniform price (blend price) that is paid to the farmers. The FMMO also does testing, weighing and classifying of milk, and provides market information[7]. Currently, there are 10 federal milk marketing orders, covering about 70% of all milk sold in the U.S. Furthermore most of the remaining milk is regulated by state marketing orders. California has the largest state order applying to nearly 20% of U.S. milk and works

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[4] Source: http://www.ers.usda.gov/topics/animal-products/dairy/definitions.aspx

[5] The six orders paid on component pricing system are the Pacific Northwest, the Upper Midwest, the Central, the Southwest, the Mideast and the Northeast. The orders paid on hundredweights of skimmed milk and milkfat (the “advanced” system) are Florida, Southeast, Appalachian and Arizona – Las Vegas. California is the only state that has own system.

Available at http://www.progressivedairy.com/topics/management/producer-milk-payment-systems-in-the-us

[6] The description of classified milk pricing could be found in Jesse and Cropp (2008).

[7] Available at http://www.progressivedairy.com/news/industry-news/federal-milk-marketing-orders-history-purpose-and-future

much like the federal order system[8]. In this thesis, FMMOs are represented as if they covered 12 order regions (figure 2-3), including the 10 FMMO regions, the California state marketing order, and a composite rest of the county (unregulated/free) region.

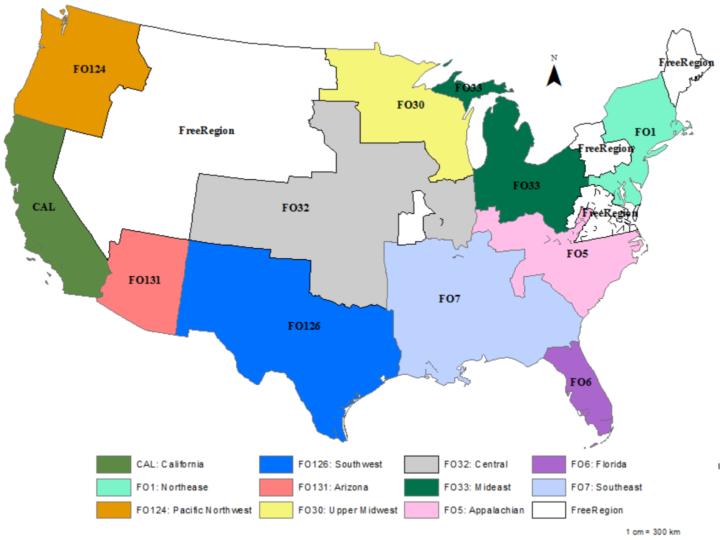

Figure 2-3. Marketing Areas under the Current Federal Milk Marketing Orders

The currently used Class I price differentials were mainly established in 2000. Some of them were increased in May, 2008 , namely those in the Appalachian (FO5), Florida (FO6) and Southeast (FO7) orders[9]. The current price differentials range from $1.60 to $6.00 per hundredweight (cwt.), with an average of $2.46 per cwt[10]. The differentials are relatively higher in the Southeast, South Central States, and Northeast while being lower in the Great Basin and Upper Midwest[11].

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[8] Source: USDA Agricultural Marketing Service – Dairy Program

[9] The range of this increase is up to $1.80 per cwt.

[10] Source: https://www.ams.usda.gov/sites/default/files/media/DYFMMOCA%20Table%203%20Class%20I%20Differentials.pdf

[11] Source: https://www.cdfa.ca.gov/dairy/pdf/SP_104__FMMO_and_CA_Comparison.pdf

2.3 Literature Review

2.3.1 Theoretical Analysis of Price Differentials

French and Kehrberg (1960) provided an initial conceptual framework for Class I price differentials, arguing that they should reflect “the differential costs of products and/or factors resulting from difference in the distance shipped”. Later, many studies examined whether the existing Class I price differentials were appropriate (e.g., Schiek 1994; Cox and Chavas 2001).

Christ (1980) argued that the Class I differentials must be higher than the transportation cost between markets and found in 1980 that these differentials were too low to attract adequate supply. Novakovic and Pratt (1991) concluded that the differentials exerted weak motivation for milk production or Class I utilization. They also projected that the Class I price differentials could be revised to both reflect increased milk consumption and changing regional shares of milk production (Novakovic and Pratt 1991).

2.3.2 Modeling Methods Applied to Milk Differential Analysis

A large body of research addressing milk price differentials has used linear programming based network models, which solve for a Class I market equilibrium assuming cost minimizing milk movement across a spatial network that depicts locations of supply, demand and movement cost (e.g. Pratt et al., 1997).

Linear programming (LP) was developed and first used for logistics problems by Dantzig (1948), and then was quickly utilized to examine economic issues by Enke (1951) and Samuelson (1952). There are three typical LP formulations that have been used. First, there are models that only incorporate direct shipments. In the study of Novakovic (1979), the transportation problem, which minimized the interregional movement costs of dairy products directly from supply to demand points under fixed demand and supply, was established to "duplicate current conditions" or what would be if there were "alternative market structures or regulations". Second there are transshipment models in which the goods can be shipped not only directly from supply source to point of ultimate demand but can also pass through one or more intermediate points. Generally those using transshipment models set them up to minimize total cost of milk movement through the industry's supply chain[12] under fixed demand and supply, where cost included the assembly, processing and distribution costs meeting fixed demands (e.g. Pratt et al. 1997; Testuri, Kilmer, and Spreen 2001; Seo 2015). But, these "fixed production and consumption" models (e.g. Stollsteimer 1963) ignored many realistic factors, such as the response of milk production to price changes. Third, there is the multi-commodity network including milk processing as in the MilkOrd family of models (McCarl, Schwart and Siebert 1996) and Seo (2015). In those models raw milk is shipped (or transshipped) to processing facilities and in turn fluid milk, yogurt, cheese etc. are created through processing activities then these commodities are shipped to consumption points.

2.3.3 Determining Class I Differentials and Effects of Changing them

Two approaches have been used for evaluating Class I price differentials.

The first approach uses existing Class I differentials as the minimum price difference between two regions (e.g., Novakovic 1979; Yavuz et al. 1996). For instance, in the linear programming model of Yavuz et al. (1996), one of the constraints required that the existing price differentials were imposed as the minimum interregional price difference between the fluid milk price and the Minnesota-Wisconsin (M-W) price, that is, in a region the amount of class I price

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[12] Supply Chain refers to a system connecting a market from the upstream raw material suppliers to the final product's consumers. And the supply chain used here includes three levels: farms, plants, and consumer markets for dairy products.

differential was added to the M-W price to obtain the fluid milk price in another marketing order. In turn studies examined spatial rearrangement of milk and dairy products if the Class I differentials were changed. Generally these studies found that regions with lower differentials or less Class I utilization were more affected (Cox and Jesse 1995).

The second approach involves comparisons between model generated Class I differentials and the current actual FMMO ones. In this case, the model differentials are typically constructed as the differences between the LP model shadow prices from regional constraints balancing Class I supply with demand (e.g., Pratt et al. 1997). The basic logic is the shadow prices give the value of the milk in the regions and differencing them gives an ideal set of differentials (Testuri, Kilmer, and Spreen 2001). Moreover, these studies found that the estimated differentials were not constant through out the year rather expressing “a smooth seasonal pattern through the monthly sequence (Testuri, Kilmer, and Spreen 2001)” and that the current differentials did not fully represent model shadow price diversity (i.e. see Kawaguchi, Suzuki, and Kaiser 2001).

A few papers in recent years have focused on whether the Class I price differentials as implemented today are appropriate under current economic situation. Class I price differentials were mostly established based on the situation existing in the year 2000. Since then there have been changes in transportation costs and the spatial distribution of milk supply and demand. This was investigated by Seo (2015) who finds the Class I price differentials is likely in need of updating and that the price for class II milk could also be spatially different. Testuri, Kilmer, and Spreen (2001) used a network model minimizing the costs across the supply chain of the southeastern dairy industry, to estimate the seasonal pattern of Class I price differentials, and found that the lowest and highest price differentials respectively appeared in April and September.

2.3.4 Considering Milk Components

Another issue in model specification involves balancing the quantity of total milk supply and demand, in terms of both the total milk quantity and milk components considering butterfat and protein. Pratt et al. (1997) constructed the United States Dairy Sector Simulator (USDSS) model and balanced milk components received at plants as a set of constraints. These constraints accounted for the amount of butterfat and solid non-fat contained in the raw milk being shipped to a plant and balanced it with the needs for intermediate and final products dairy products that would satisfy consumption.

2.4 Objectives

This work will investigate whether the existing Class I price differentials are appropriate today in comparison to idealized ones arising from a model much as did Seo (2015). We also extend Seo's study by examining this in a frameworks that considers spatially varying milk components – butterfat, protein, and other solids non-fat leading to alternative product yields from processing.

In order to achieve these objectives, this study will

- Add to Seo’s version of the MilkOrdII model so as to incorporate spatially differing milk components in terms of butterfat, protein, and other solids non-fat and a processing sector where the yields of alternative products depend upon the composition of the raw milk.
- Update the spatial supply and demand plus the transport cost data in MilkOrdII to reflect present conditions.
- Use the model to simulate price differentials under current conditions.

- Compare the idealized MilkOrdIII price differentials with the current FMMO Class I price differentials being used.
- Investigate the differences brought about by including components by comparing price surfaces with and without the components part.
- Constructing a spatial price surface for milk components butterfat, protein and other solids non-fat.

2.5 Revisions to the MilkOrdII Model

Referring to the framework of the transshipment problem, the MilkOrdIII model is based on the work done by Seo (2015) [13], originated from McCarl's earlier work (Baker, Dixit, and McCarl 1981; McCarl, Schwart, and Siebert 1996).

The model aims to minimize the assembling, processing and distribution costs subject to the balances of composition and volume in dairy supply and demand. It is a multi product, seasonal version of the cost-minimizing transshipment model merged with a milk product manufacturing module in a linear programming formation. It runs on a quarterly basis. Spatially it disaggregates the continental U.S. into 303 regions[14] which are the NASS crop reporting districts (figure 2-4).

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[13] Refer to the dissertation of Seo (2015) for the detailed background.

[14] Refer to https://www.nass.usda.gov/Charts_and_Maps/Crops_County/indexgif.php

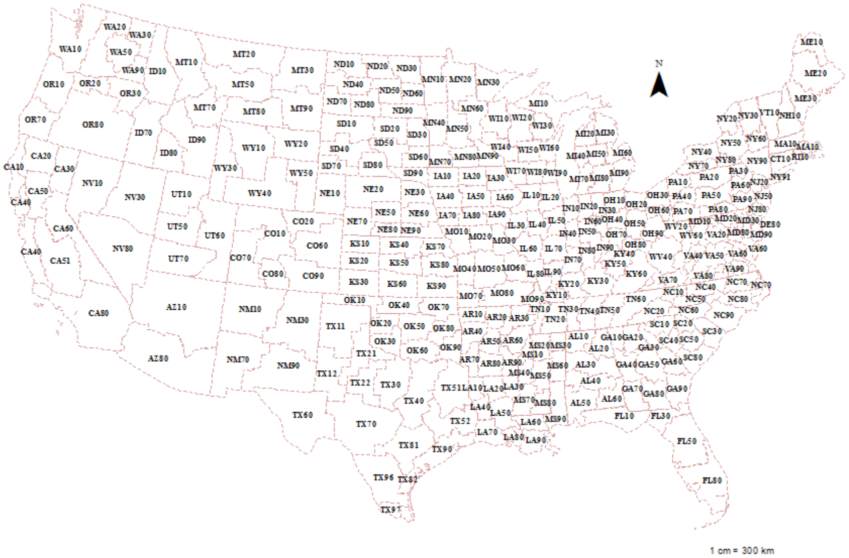

Figure 2-4. Agricultural Statistics Districts (303 regions)

The economic activities of the total milk/dairy product supply chain in the US dairy industry fall into five sections within MilkOrdIII model: production – dairy farm supply, assembly/raw milk transport, processing at manufacturing plants, dairy product distribution/transport and delivery of dairy products to consumers (figure 2-5). Raw milk, intermediate milk products and final dairy products flow through the total network.

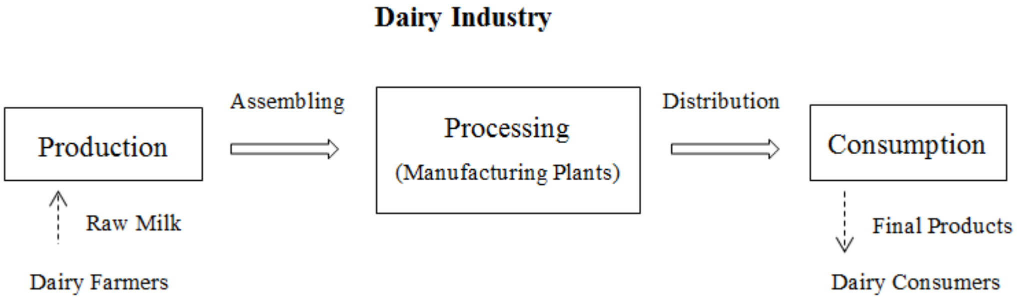

Figure 2-5. Supply Chain of the Dairy Industry

In the revised model organic milk is added and thus it represents four grades of raw milk - Grade A, Grade B, Organic and unregulated milk where about 98% of the supplies are Grade A milk and 1% are Organic milk in 2012 (USDA AMS). Meanwhile, milk usage is categorized into the four different classes, depending on the specific dairy products it is used to make at manufacturing plants. Not all milk can go into all classes of use. Grade A milk is primarily used for Class I, but since there is more than the fluid milk demand it is also downgraded into Class II to IV; Organic milk is firstly used for Class IO (organic Class I) and then can be downgraded to other classes (Class I to IV); Grade B milk is for Class III and IV; unregulated milk is for Class I to IV. Five broad types of processing plants are included in the model: Class IO (organic fluid milk) plants, Class I (fluid milk) plants, Class II (yogurt[15], ice cream, sour cream, and cottage cheese) plants, Class III (Italian cheese and cheddar cheese) plants, and Class IV (butter and powder) plants. In total, 27 products are produced, among which intermediate products, such as cream and skim milk, are transferred between plants, and final dairy products are directly distributed to dairy market (table 2-1).

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[15] There are two products produced in yogurt plant: regular yogurt with 1.00% butterfat; Greek yogurt with 0.70% butterfat.

Table 2-1. Dairy Products Defined in MilkOrdIII model

Final Product	**Intermediate Product**
Regular fluid milk	Skim milk
Organic fluid milk	Cream
Skim milk	Condense skim powder
Cream	Whole powder
Regular yogurt	Butter whey
Greek yogurt	Butter milk
Ice cream	Mozzarella whey
Sour cream	Cottage whey
Butter	Cheddar whey
Non-fat dry powder	Ice cream mix
Condense whole powder	Cottage cheese dressing
Cheddar cheese	
Italian cheese	
Cottage cheese	
Dry butter milk	
Dry cheddar whey	
Dry cottage whey	
Dry mozzarella whey	

Relative to the MilkOrdII model (Seo 2015), this version adds: the organic milk supply, processing, and organic fluid milk demand; Greek yogurt production and demand; quarterly private storage balance[16]; raw milk component heterogeneity and component dependent input-output formulas for products obtained from raw milk processing, the details of which are:

- Added milk components of butterfat, protein, and other solids non-fat that vary by region and season and result in differing processing yields by region. MilkOrdII was altered so it divided milk into 24 different groupings stratified depending on the three components and the 24 different groupings we assigned regionally and seasonally according to USDA component data. These 24 component categories were defined by

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[16] Refer to equation (2.19) in 2.7.2.

dividend the domain of butterfat% into 4 ranges, the domain of protein% into 3, and the domain of other solids non-fat% into 2. The exact ranges are given in table 2-2. Second, we combined all combinations of these ranges into $4 \times 3 \times 2 = 24$ alternative component cases for raw milk. Then, we used the average value for each component in each range – average butterfat%, average protein% and average other solids non-fat% (table 2-3) to calculate processed product yields as discussed next.

Table 2-2. The Ranges Divided for the Domains of Raw Milk Component% in 2012

	Butterfat% in Raw Milk			
Minimum	3.50	3.64	3.76	3.89
Maximum	3.64	3.76	3.89	4.02
Average	3.57	3.70	3.82	3.95
	Protein% in Raw Milk			
Minimum	2.86	3.01	3.15	
Maximum	3.01	3.15	3.30	
Average	2.94	3.08	3.23	
	other Solids non-fat% in Raw Milk			
Minimum	5.52	5.67		
Maximum	5.67	5.82		
Average	5.60	5.75		

Table 2-3. Raw Milk Type for the Revised MilkOrdII Model in 2012

Type	Avg. Butterfat%	Avg. Protein%	Avg. other Solids non-fat%
1	3.57	2.94	5.60
2	3.57	2.94	5.75
3	3.57	3.08	5.60
4	3.57	3.08	5.75
5	3.57	3.23	5.60
6	3.57	3.23	5.75
7	3.70	2.94	5.60
8	3.70	2.94	5.75
9	3.70	3.08	5.60
10	3.70	3.08	5.75
11	3.70	3.23	5.60
12	3.70	3.23	5.75
13	3.82	2.94	5.60
14	3.82	2.94	5.75
15	3.82	3.08	5.60
16	3.82	3.08	5.75
17	3.82	3.23	5.60
18	3.82	3.23	5.75
19	3.95	2.94	5.60
20	3.95	2.94	5.75
21	3.95	3.08	5.60
22	3.95	3.08	5.75
23	3.95	3.23	5.60
24	3.95	3.23	5.75

- We added a set of formulas for dairy product yield given raw milk characteristics that we obtained the USDA FMMO offices in Dallas[17]. These formulas give the amount of each dairy product yielded given use of each of the 24 milk component cases. Thus the amount of milk is needed to produce one unit of dairy product depends on the raw milk component content case. Take fluid milk processing plants as an example, the

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[17] See Appendix A

inputs are the units of raw milk, which equal to

$\frac{\%\, butterfat\ of\ cream - \%\, butterfat\ of\ fluid\ milk}{\%\, butterfat\ of\ cream - \%\, butterfat\ of\ raw\ milk}$; the outputs are 1 unit of fluid milk and

$(the\ units\ of\ raw\ milk - 1)$ units of cream.

2.6 Full Revised MilkOrdII Model Formulation

The formulation of the MilkOrdIII model is represented mathematically below[18].

2.6.1 Notation

The full set of symbols used in the model is given below

The subscripts used are

$i, j \in I$;	i and j identify the NASS districts of which there are 303 (I) for and contain supply from dairy farms, processing plants, and consumption markets
i^{sp} and I^{sp}	denote regions having supply plants
$c \in C$;	c identifies the classes of raw milk: Class IO, Class I, Class II, Class III, and Class IV of which there are C
$y \in TY$;	y identifies the component case types of raw milk which each have different component (butterfat, protein, other solid non-fat) composition of which there are TY
$l \in L$;	l identifies type of Manufacturing plants[19]of which there are L

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[18] The model includes the transportation credit program (TCP), which applies in FO5 and FO7 to subsidize hauling cost with the purpose of attracting raw milk from outside the marketing order

$k \in K$;	k identifies type of Processes of manufacturing plants of which there are K
$p \in P$;	p identifies type of final or intermediate dairy product of which there are P
$m \in M$;	m identifies type of mixed dairy products(ice cream and cottage cheese dressing) of which there are M
$t \in T$;	t identifies type quarters in a year of which there are T
$\tilde{T}$	is the last quarter in the year

The parameters are as follows.

$AssemblingCost_{ijt}$: the unit cost of assembling raw milk from the i^{th} production regions to the j^{th} processing region in the t^{th} quarter.

$ProcessingCost_{iklt}$: the unit cost of producing dairy product in the k^{th} process of the l^{th} plant in the i^{th} place and t^{th} quarter.

$DistributionCost_{ijpt}$: the unit cost of transporting the p^{th} dairy product from the i^{th} place to the j^{th} place in the t^{th} quarter.

$StockValue_{p}$: the unit value of the p^{th} storable product.

$FixedPrice_{p}$: the fixed price of selling the p^{th} dairy product.

$\overline{SM_{\imath yt}^{GA}}$: the amount of the y^{th} component case of Grade A milk supplied in the i^{th} place and t^{th} quarter.

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[19] Manufacturing (processing) plants: regular fluid plant, organic fluid plant, sour cream plant, yogurt plant, cottage plant, ice cream plant, cheddar cheese plant, Italian cheese plant, butter plant, powder plant.

$\overline{SM_{\imath yt}^{OR}}$: the amount of the y^{th} component case of Organic milk supplied in the i^{th} place and t^{th} quarter.

$\overline{SM_{\imath yt}^{GB}}$: the amount of the y^{th} component case of Grade B milk supplied in the i^{th} place and t^{th} quarter.

$\overline{SM_{\imath yt}^{Unregulated}}$: the amount of the y^{th} component case of Unregulated milk supplied in the i^{th} place and t^{th} quarter.

$\overline{PC_{\jmath ct}}$: plant capacity for the c^{th} class of raw milk in the j^{th} place and t^{th} quarter.

$\overline{QMR_{klcy}^{Used}}$: the units of the y^{th} component case of the c^{th} class of raw milk used in one unit of the k^{th} process at the l^{th} plant.

$\overline{QIR_{klpy}^{ProductUsed}}$: the units of the p^{th} intermediate product used in one unit of the k^{th} process at the l^{th} plant by the y^{th} component case of raw milk.

$\overline{BTF_y}$: the amount of butterfat in one unit of the y^{th} component case of raw milk.

$\overline{PNT_y}$: the amount of protein in one unit of the y^{th} component case of raw milk.

$\overline{BTF_p}$: the amount of butterfat in one unit of the p^{th} dairy product.

$\overline{PNT_p}$: the amount of protein in one unit of the p^{th} dairy product.

$\overline{BTF_m}$: the amount of butterfat in one unit of the m^{th} mixed dairy product.

$\overline{PNT_m}$: the amount of protein in one unit of the m^{th} mixed dairy product.

$\overline{QM\imath xR_{klmy}^{ProductUsed}}$: the units of the m^{th} combined material used in one unit of the k^{th} process in the l^{th} plant, which are constant for different component cases of raw milk.

$\overline{QP_{klpy}^{ProductMade}}$: the units of the p^{th} dairy product produced in one unit of the k^{th} process at the l^{th} plant by the y^{th} component case of raw milk.

$\overline{DF_{Jpt}^{Product}}$: the amount of the p^{th} dairy product demanded in the j^{th} place and t^{th} quarter.

The variables are as follows.

$QM_{ijcyt}^{GAMoved}$: the amount of the c^{th} class of Grade A milk in the y^{th} component case moved from the i^{th} production place to the j^{th} place in the t^{th} quarter.

$QM_{ijcyt}^{SupplyPlant}$: the amount of the c^{th} class of Grade A milk in the y^{th} component case moved from the i^{th} production place to the j^{th} place having supply plant (or from the i^{th} place with supply plant to the j^{th} place with fluid milk plant) in the t^{th} quarter.

$QM_{ijcyt}^{ORMoved}$: the amount of the c^{th} class of Organic milk in the y^{th} component case moved from the i^{th} production place to the j^{th} place in the t^{th} quarter.

$QM_{ijcyt}^{GBMoved}$: the amount of the c^{th} class of Grade B milk in the y^{th} component case moved from the i^{th} production place to the j^{th} place in the t^{th} quarter.

$QM_{iiyt}^{UnregulatedforFluid}$: the amount of Unregulated milk in the y^{th} component case moved in the i^{th} place and the t^{th} quarter.

$Q_{iklyt}^{PlantProcess}$: the amount of the k^{th} process of the l^{th} plant occurring with the y^{th} component case of raw milk in the i^{th} place and t^{th} quarter.

$QF_{ijpt}^{ProductMoved}$: the amount of the p^{th} final dairy product moved from the i^{th} place to the j^{th} place in the t^{th} quarter.

$QI_{ijpt}^{ProductMoved}$: the amount of the p^{th} intermediate dairy product moved from the i^{th} place to the j^{th} place in the t^{th} quarter.

$QS_{ijpt}^{ProductReleased}$: the amount of the p^{th} storable dairy product released from the i^{th} place to the j^{th} place in the t^{th} quarter.

$QS_{ipt}^{ProductAdded}$: the amount of the p^{th} storable dairy product added from the i^{th} place to the j^{th} place in the t^{th} quarter.

$QS_{ipt}^{Product}$: the amount of the p^{th} storable dairy product in the i^{th} place at the end of the t^{th} quarter ($\tilde{T}$ is the last quarter[20]).

QW_{ipt}^{Sold}: the amount of the p^{th} whey product sold in the i^{th} place and t^{th} quarter.

$Q_{ijcyt}^{GADownGrade}$: the amount of the y^{th} component case of Grade A milk downgraded from the $(c-1)^{th}$ class of milk to the c^{th} class in the i^{th} place in t^{th} quarter, where $(c-1)$ is Class I, Class II, or Class III.

$Q_{ijcyt}^{ORDownGrade}$: the amount of the y^{th} component case of Organic milk downgraded from the $(c-1)^{th}$ class of milk to the c^{th} class in the i^{th} place in t^{th} quarter, where $(c-1)$ is Class IO, Class I, Class II, or Class III.

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[20] The last month depends on the period used in the model.

$Q_{ijcyt}^{GBDownGrade}$: the amount of the y^{th} component case of Grade B milk downgraded from the $(c-1)^{th}$ class of milk to the c^{th} class in the i^{th} place in t^{th} quarter, where $(c-1)$ is Class III.

$QM_{iiyt}^{UnregulatedforFluid}$: the amount of Unregulated milk used for fluid milk in the i^{th} place and the t^{th} quarter.

$QM_{iyt}^{UnregulatedforGB}$: the amount of the y^{th} component case of Unregulated milk used for Grade B milk in in the i^{th} place and the t^{th} quarter.

α: the maximum percentage of Unregulated milk used for fluid milk

$QM_{jcyt}^{PlantReceived}$: the amount of the c^{th} class of raw milk in the y^{th} component case received by the i^{th} place with matching plants in the t^{th} quarter.

QM_{imcyt}: the amount of Class II (c) milk in the y^{th} component case used for the m^{th} mixed product in the i^{th} place and the t^{th} quarter.

$QInt_{jmpt}$: the amount of the p^{th} intermediate product used for the m^{th} mixed product in the i^{th} place and the t^{th} quarter.

$QMix_{imt}^{Product}$: the amount of the m^{th} mixed product produced in the i^{th} place and the t^{th} quarter.

2.6.2 Objective Function

The objective function Z (2.6) minimizes the costs of transport and processing through the US. dairy industry supply chain plus contains adjustments for stocks[21]. To be more specific, the cost terms reflect

- the assembly and conveyance costs for moving Grade A, Organic, Grade B, Unregulated, and supply plant[22] milk from farms to plants;
- the manufacturing costs of processing raw milk into dairy products at the plants;
- the costs of shipping intermediate products between plants along with the costs of shipping final dairy products from plants to consumers, and
- the costs of storing dairy products.

We also have a price at which stocks are released.

All the items have dimensions for location or locations (for shipments), different component cases of raw milk, type of manufacturing plant and within plant processes, products made, and time of year.

(2.6)

Minimize

$$Z = \sum_i \sum_j \sum_c \sum_y \sum_t AssemblingCost_{ijt} \times (QM_{ijcyt}^{GAMoved} + QM_{i^{sp}jcyt}^{SupplyPlant}$$

$$+ QM_{ijcyt}^{ORMoved} + QM_{ijcyt}^{GBMoved} + QM_{ijyt}^{UnregulatedforFluid})$$

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[21] Selling the surplus whey products at lower fixed prices into the market is to avoid them left at the consumer level.

[22] Supply plant helps to ensure proper supply of milk to produce fluid beverage and it sometimes works as bottling plant. Supplying milk refers to some Grade A milk which is moved to supply plants and then goes to fluid milk plants.

$$+\sum_{i}\sum_{k}\sum_{l}\sum_{y}\sum_{t} ProcessingCost_{iklt} \times Q_{iklyt}^{PlantProcess}$$

$$+\sum_{i}\sum_{j}\sum_{p}\sum_{t} DistributionCost_{ijpt} \times (QF_{ijpt}^{ProductMoved} + QI_{ijpt}^{ProductMoved} + QS_{ijpt}^{ProductReleased} + QS_{ijpt}^{ProductAdded})$$

$$+\sum_{i}\sum_{j}\sum_{p}\sum_{t} ReleasingPrice_{p} \times QS_{ijpt}^{ProductReleased}$$

$$+\sum_{i}\sum_{p}\sum_{t} ReleasingPrice_{p} \times QS_{ipt}^{Surplus}$$

$$-\sum_{i}\sum_{p} StockValue_{p} \times QS_{ip\tilde{T}}^{Product}$$

$$-\sum_{i}\sum_{p}\sum_{t} FixedPrice_{p} \times QW_{ipt}^{Sold}$$

This objective is minimized subject to a number of constraints

2.6.3 Grade A Milk Balance

This is a set of constraints for raw Grade A milk supply available in a district controlling the Grade A milk supply volume by class, component composition case, place, and quarter. (2.7.3a) controls the amount of Grade A milk used as Class I where it can be moved to fluid manufacturing plants or supply plants plus can be downgraded into Class II. Those uses are equal to the exogenous Grade A milk supply for each component case; (2.7.3b) balances the amount of Class II and Class III milk by component case. Usages are shipments to manufacturing plants plus milk downgraded to lower classes and those uses equal the amount of milk downgraded from Class I (Class II in the Class III balance) by component case; (2.7.3c) balances the amount of Class IV milk by component case with that moved to butter or powder plants set equal to the amount downgraded from Class III.

$\forall i \in I, \forall y \in TY, \forall t \in T$:

$$\sum_j \left(QM_{ijcyt}^{GAMoved} + QM_{ij^{sp}cyt}^{SupplyPlant}\right) + QM_{i(c+1)yt}^{GADownGrade} = \overline{SM_{\imath yt}^{GA}} \qquad c \text{ is Class I (2.7.3a)}$$

$$\sum_j QM_{ijcyt}^{GAMoved} + QM_{i(c+1)yt}^{GADownGrade} = \sum_j QM_{icyt}^{GADownGrade} \qquad c \text{ is Class II or III (2.7.3b)}$$

$$\sum_j QM_{ijcyt}^{GAMoved} = QM_{icyt}^{GADownGrade} \qquad c \text{ is Class IV (2.7.3c)}$$

2.6.4 Organic Milk Balance

These are a set of constraints that limit organic milk supply available in a district. (2.7.4a) balances the amount of Class IO moved to organic fluid milk plants and downgraded into Class I for a component case with the exogenous organic milk supply in that component case; (2.7.4b) balances the amount of Class II and Class III in a component case. It limits that shipped to manufacturing plants plus that downgraded to equal milk downgraded from Class IO (or Class II) in that component case; in (2.7.4c) the amount of Class IV in each component case shipped to plants is equal to the amount of milk downgraded from Class III.

$\forall i \in I, \forall y \in TY, \forall t \in T$:

$$\sum_j QM_{ijcyt}^{ORMoved} + QM_{i(c+1)yt}^{ORDownGrade} = \overline{SM_{\imath yt}^{OR}} \qquad c \text{ is Class IO (2.7.4a)}$$

$$\sum_j QM_{ijcyt}^{ORMoved} + QM_{i(c+1)yt}^{ORDownGrade} = \sum_j QM_{icyt}^{ORDownGrade} \qquad c \text{ is Class I, II or III (2.7.4b)}$$

$$\sum_j QM_{ijcyt}^{ORMoved} = QM_{icyt}^{ORDownGrade} \qquad c \text{ is Class IV (2.7.4c)}$$

2.6.5 Grade B Milk Balance

This is a similar set of constraints to those above limiting Grade B milk supply. (2.7.5a) balances the amount of milk used as Class III and that downgraded into Class IV with the exogenous milk supply of Grade B and the Grade B converted from unregulated milk for a component case; (2.7.5b) balances the amount of Class IV moved to butter or powder plants with the amount of milk downgraded from Class III for each component case.

$\forall i \in I, \forall y \in TY, \forall t \in T$:

$$\sum_j QM_{ijcyt}^{GBMoved} + QM_{i(c+1)yt}^{GBDownGrade} = \overline{SM_{iyt}^{GB}} + QM_{iyt}^{UnregulatedforGB} \qquad c \text{ is Class III } (2.7.5a)$$

$$\sum_j QM_{ijcyt}^{GBMoved} = QM_{icyt}^{GBDownGrade} \qquad c \text{ is Class IV } (2.7.5b)$$

2.6.6 Unregulated Milk Balance

(2.7.6) is a set of constraints for unregulated milk supply balance at farm level. (2.7.6a) balances the amount of unregulated milk moved to fluid milk plants and that converted into Grade B milk to equal the exogenous unregulated milk supply in that component case; (2.7.6b) limits the amount of unregulated milk used for fluid milk to be not greater than α% of the exogenous unregulated milk supply.

$\forall i \in I, \forall y \in TY, \forall t \in T$:

$$QM_{iiyt}^{UnregulatedforFluid} + QM_{iyt}^{UnregulatedforGB} \leq \overline{SM_{iyt}^{Uregulated}} \qquad (2.7.6a)$$

$$\sum_y QM_{iyt}^{UnregulatedforFluid} \leq \alpha \times \sum_y \overline{SM_{iyt}^{Uregulated}} \qquad (2.7.6b)$$

2.6.7 Milk Supply Balance at Processing Plants

Expression (2.7.7) balances milk at manufacturing plants and restricts that, for each class by quarter, the total amount of milk in a component case received in a manufacturing region is equal to the amount of milk supplied by incoming shipments.

$\forall j \in I, \forall y \in TY, \forall t \in T$:

$$QM_{jcyt}^{PlantReceived} = \sum_i QM_{ijcyt}^{ORMoved}$$

c is Class IO (2.7.7a)

$$QM_{jcyt}^{PlantReceived} = \sum_i (QM_{ijcyt}^{GAMoved} + QM_{i^{sp}jcyt}^{SupplyPlant} + QM_{ijcyt}^{ORMoved}) + QM_{jjyt}^{UnregulatedforFluid}$$

c is Class I (2.7.7b)

$$QM_{jcyt}^{PlantReceived} = \sum_i (QM_{ijcyt}^{GAMoved} + QM_{ijcyt}^{ORMoved})$$

c is Class II (2.7.7c)

$$QM_{jcyt}^{PlantReceived} = \sum_i (QM_{ijcyt}^{GAMoved} + QM_{ijcyt}^{ORMoved} + QM_{ijcyt}^{GBMoved})$$

c is Class III or IV (2.7.7d)

2.6.8 Milk Balance at Supplying Plants

Equation (2.7.8) balances milk at supply plants, where the amount of Grade A milk received from production regions equals the milk shipped into fluid milk plants by component case.

$\forall j \in I, \forall y \in TY, \forall t \in T$:

$$\sum_i QM_{ij^{sp}cyt}^{SupplyPlant} = \sum_i QM_{j^{sp}icyt}^{SupplyPlant}$$

c is Class I

2.6.9 Maximum Plant Capacity Constraints

Equation (2.7.9) imposes manufacturing capacity constraints where the amount of milk arriving is not greater than the maximum capacity of plants by class in a region for each quarter.

$\forall j \in I, \forall c \in C, \forall t \in T$:

$$\sum_y QM_{jcyt}^{PlantReceived} \leq \overline{PC_{jct}}$$

2.6.10 Milk Demand Balance at Processing Plants

Equation (2.7.10) balances the milk at each plant type by class and component case where the milk received by plants equals use. (2.7.10b) restricts the amount of Class II milk in a component case supplied for all Class II type of plants and mixed products to be equal to the plants' usages by region. And (2.7.10a) is the constraint balancing the other classes of milk in each component case by place.

$\forall j \in I, \forall y \in TY, \forall t \in T$:

$$\sum_k \sum_l \overline{QMR_{klcy}^{Used}} \times Q_{jklyt}^{PlantProcess} = QM_{jcyt}^{PlantReceived} \qquad c \text{ is Class IO, I, III or IV} \quad (2.7.10a)$$

$$\sum_k \sum_l \overline{QMR_{klcy}^{Used}} \times Q_{jklyt}^{PlantProcess} + \sum_m QM_{jmcyt} = QM_{jcyt}^{PlantReceived} \qquad c \text{ is Class II} \quad (2.7.10b)$$

2.6.11 Intermediate Product Balance

Equation (2.7.11) balances intermediate product usage as plants' direct use plus used to blend into mixes for dairy products in a place is equal to the total units of intermediate products shipped into that place. And the amounts of intermediate products needed in each process depend on the input and output formulas with products' components. In the model, those products' components are constant in terms of component case of milk.

$\forall j \in I, \forall p \in P, \forall t \in T$:

$$\sum_k \sum_l \sum_y \overline{QIR_{klpy}^{ProductUsed}} \times Q_{jklyt}^{PlantProcess} + QInt_{jmpt} = \sum_i QI_{ijpt}^{ProductMoved}$$

2.6.12 Mixed Product Balances

Equation (2.7.12) is a set of constraints that controls making blends of dairy products for ice cream and cottage cheese dressing by place and quarter. (2.7.12a) restricts the volume of Class II milk and intermediate products used to make each blend equals to the volume of the blended product produced. In equations of (2.7.12b), (1) insures the total amount of butterfat input to the blend equals the amount of butterfat in the blend for each blended product; (2) insures the amount balance of protein. (2.7.12c) balances the amount of each blended product made with that used in manufacturing.

(2.7.12a) Volume Balance for Mixed Products

$\forall i \in I, \forall m \in M, \forall t \in T, c\ is\ Class\ II$:

$$\sum_{y} QM_{imcyt} + \sum_{p} QInt_{impt} = QMix_{imt}^{Product}$$

(2.7.12b) Component Balance for Mixed Products

$\forall i \in I, \forall m \in M, \forall t \in T, c\ is\ Class\ II$:

$$\textstyle\sum_{y} \overline{BTF}_{y} \times QM_{imcyt} + \sum_{p} \overline{BTF}_{p} \times QInt_{impt} = \overline{BTF}_{m} \times QMix_{imt}^{Product} \quad (1)$$

$$\textstyle\sum_{y} \overline{PNT}_{y} \times QM_{imcyt} + \sum_{p} \overline{PNT}_{p} \times QInt_{impt} = \overline{PNT}_{m} \times QMix_{imt}^{Product} \quad (2)$$

(2.7.12c) Demand Balance for Mixed Products

$\forall i \in I, \forall m \in M, \forall t \in T$:

$$\sum_{k}\sum_{l}\sum_{y} \overline{QMixR_{klmy}^{ProductUse}} \times Q_{iklyt}^{PlantProcess} = QMix_{imt}^{Product}$$

2.6.13 Product Supply Balance

Equation (2.7.13) balances the supply and demand of each dairy product for each district, product type and quarter. Dairy products made at plants in a district by quarter can be: sold at the markets, shipped into other plants as intermediate products, moved to meet the consumer demand, and added into private storages and this is balanced with the amount manufactured.

$\forall i \in I, \forall p \in P, \forall t \in T$:

$$QW_{ipt}^{Sold} + \sum\nolimits_{j} \left(QI_{ijpt}^{ProductMoved} + QF_{ijpt}^{ProductMoved} + QS_{ijpt}^{ProductAdded}\right)$$
$$= \sum\nolimits_{k} \sum\nolimits_{l} \sum\nolimits_{y} \overline{QP_{klpy}^{ProductMade}} \times Q_{iklyt}^{PlantProcess}$$

2.6.14 Product Demand Balance

Equation (2.18) requires that the amount of each final dairy product shipped to a place plus the amount of the same product released from private storages satisfy the market demand in an area by quarter

$\forall i, j \in I, \forall p \in P, \forall t \in T$:

$$\sum\nolimits_{i} \left(QF_{ijpt}^{ProductMoved} + QS_{ijpt}^{ProductReleased}\right) = \overline{DF_{jpt}^{Product}}$$

2.6.15 Seasonal Product Balance at Private Storage

Constraint (2.7.15) controls storage volumes. In particular at the end of time t, the amount of each storable dairy products in private storages in a region equals to the product left at the end of last quarter plus the product added from other regions minus that released to other regions during this quarter.

$\forall i \in I, \forall p \in P, \forall t \in T$:

$$QS_{ipt}^{Product} = QS_{ip(t-1)}^{Product} + \sum\nolimits_{j} QS_{jipt}^{ProductAdded} + \sum\nolimits_{j} QS_{ijpt}^{ProductReleased}$$

2.6.16 Non-negativity

A set of constraints in (2.7.16) is used to make sure that all variables are non-negative.[23]

$$\forall i, j \in I, \forall c \in C, \forall k \in K, \forall l \in L, \forall p \in P, \forall y \in TY, \forall t \in T$$

All variables:

$$\begin{gathered} QM_{ijcyt}^{GAMoved}, QM_{ijcyt}^{SupplyPlant}, QM_{ijcyt}^{ORMoved}, QM_{ijcyt}^{GBMoved}, QM_{iiyt}^{UnregulatedforFluid}, Q_{iklyt}^{PlantProcess}, QF_{ijpt}^{ProductMoved} \\ QI_{ijpt}^{ProductMoved}, QS_{ijpt}^{ProductReleased}, QS_{ijpt}^{ProductAdded}, QS_{ipt}^{Product}, QS_{ip\tilde{T}}^{Product}, QW_{ipt}^{Sold}, QM_{icyt}^{GADownGrade} \\ QM_{icyt}^{ORDownGrade}, QM_{icyt}^{GBDownGrade}, QM_{ijcyt}^{SupplyPlant}, QM_{jcyt}^{PlantReceived}, QM_{imcyt}, QI_{jmpt}, QMix_{imt}^{Product} \\ \geq 0 \end{gathered}$$

2.7 Using Shadow Values to Construct Price Differentials

The MilkOrdIII model solves the spatial cost-minimizing problem with limited resources under fixed supply and demand. Solution of MilkOrdIII yields the optimal shadow prices from the equation (2.7.10) which balances demand and supply of different classes of raw milk after delivery at a place where it will be processed into product for a quarter. This shadow price U_{jcyt} as expressed below in equation (2.8.1) shows, for the j^{th} location, the quarterly marginal cost reduction encountered when having one more unit of raw milk of a particular component composition (y), of a particular class (c) at a place. They are formed as a reflection of the value of more milk going into processing and in turn meeting spatial demands plus the cost of getting

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[23] The constraints that are the same with the model of Seo (2015) are not described in this study.

the milk to this place. In other words this is the price that the handler in a region would be willing to pay to obtain one more unit of milk. Differences in these shadow prices are used as the model price differentials and they reflect transportation costs involved with inter-regional movements of raw milk as well as the products that can be made from it and their costs.

(2.8.1) $\forall j \in I, \forall c \in C, \forall y \in TY, \forall t \in T$

$$U_{jcyt} = \frac{\partial TotalCost}{\partial Q_{jcyt}^{PlantMilkReceived}}$$

To form the model price differentials, for each milk class and quarter the minimum shadow price across the whole country for any place and component is subtracted from all model generated shadow price U_{jcyt}, giving a set of price differentials with the minimum of zero, $\widetilde{U_{Jcyt}}$.

(2.8.2) $\forall j \in I, \forall c \in C, \forall y \in TY, \forall t \in T$

$$\widetilde{U_{Jcyt}} = U_{jcyt} - Minimum(j, U_{jcyt})$$

Using the notation above, we form $\widetilde{U_{Jct}}$ using (2.8.3)[24] which is the weighted average across the different component cases $\widetilde{U_{Jcyt}}$.

(2.8.3) $\forall j \in I, \forall c \in C, \forall t \in T$

$$\widetilde{U_{Jct}} = \frac{\sum_y [\widetilde{U_{Jcyt}} \times \sum_i \left(Q_{ijcyt}^{GAMoved^*} + QM_{i^{sp}\,jcyt}^{SupplyPlant^*}\right)]}{\sum_i \sum_y (Q_{ijcyt}^{GAMoved^*} + QM_{i^{sp}\,jcyt}^{SupplyPlant^*})}$$

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[24] Grade A milk supply is the majority and less than 10% milk supply is from other grades, so the study only uses the quantity of Grade A milk moved by component case and class as the weight to get the average value. So does expression (2.24).

Where

$Q_{ijcyt}^{GAMoved^*}$: the optimal amount of the c^{th} class of Grade A milk in the y^{th} component case moved from the i^{th} production place to the j^{th} place in the t^{th} quarter.

$QM_{i^{sp}jcyt}^{SupplyPlant^*}$: the optimal amount of supply plant milk[25] (also Grade A milk) in the y^{th} component case moved from the i^{th} place to the j^{th} place in the t^{th} quarter.

Expression (2.8.4) is used to compute the annually weighted price differential averaging out the quarters.

$\forall j \in, \forall c \in C$

$$\widetilde{U_{Jc}} = \frac{\sum_t \sum_y [\widetilde{U_{Jcyt}} \times \sum_i \left(Q_{ijcyt}^{GAMoved^*} + QM_{i^{sp}jcyt}^{SupplyPlant^*} \right)]}{\sum_t \sum_i \sum_y (Q_{ijcyt}^{GAMoved^*} + QM_{i^{sp}jcyt}^{SupplyPlant^*})}$$

In summary, the shadow prices model generated by the MilkOrdIII model are used to develop both time dependent and independent spatial price differentials for each class of raw milk.

2.7.1 Forming a Price Surface for Milk Components

This section discusses the method used to derive the model generated price differentials for components. There are three components of concern with regard to milk: butterfat, protein and other solids non-fat. On average relative to weight butterfat accounts for 3.7%, protein for 3.0%, and other solids non-fat 5.5% and water 87.8%.

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[25] Supplying milk is used for Class I milk.

The annual average shadow prices for delivered Grade A milk at the processing plant for different milk types reflecting different components are calculated by averaging $\widetilde{U_{Jcyt}}$ across time t, that is, $\widetilde{U_{Jcy}}$ calculated as in (2.8.5).

(2.8.5) $\forall j \in I, \forall c \in C, \forall y \in TY$

$$\widetilde{U_{Jcy}} = \frac{\sum_t [\widetilde{U_{Jcyt}} \times \sum_i \left(Q_{ijcyt}^{GAMoved^*} + QM_{i^{sp}jcyt}^{SupplyPlant^*} \right)]}{\sum_i \sum_t (Q_{ijcyt}^{GAMoved^*} + QM_{i^{sp}jcyt}^{SupplyPlant^*})}$$

Then we assume the overall shadow price for a particular type of milk is a function of its composition and in turn develop a procedure to infer the component prices from the variation in the raw milk shadow prices. To do this we use regression to estimate the marginal effect of the components estimating the equation:

(2.8.6)

$$\widetilde{U_{Jcy}} = SP^{bf}{}_j * PCT_{jcy}^{bf} + SP^{pn}{}_j * PCT_{jcy}^{pn} + SP^{otherSNF}{}_j * PCT_{jcy}^{otherSNF} + \varepsilon$$

Subject to:

(2.8.7) $P^{bf}{}_j, P^{pn}{}_j, P^{otherSNF}{}_j \geq 0$

Where j denotes agricultural district, c denotes the c^{th} class of milk in C (Class IO, Class I, Class II, Class III and Class IV), y is a milk type. And for every class of milk $c \in C$, $\widetilde{U_{Jcy}}$ is the shadow price of the y^{th} type in the j^{th} district; PCT_{jcy}^{bf} is the percentage of butterfat in the c^{th} milk class belonging to the y^{th} type in the j^{th} region; PCT_{jcy}^{pn} is the percentage of protein in the c^{th} milk class of the y^{th} type in the j^{th} region; $PCT_{jcy}^{otherSNF}$ is the percentage of other solids non-fat in the c^{th} milk class of the y^{th} type in the j^{th} region. In turn the coefficients estimated are the marginal contributions to the raw milk shadow prices for a one percent change in butterfat $SP^{bf}{}_{j}$; for protein $SP^{pn}{}_{j}$; for other solids non-fat $SP^{otherSNF}{}_{j}$; ε is the error term.

(2.8.7) requires non negative values for the estimated coefficients.

This regression is done for each district using the data of price differentials of multiple milk classes generated from MilkOrdIII model. The results in the next section are the resultant calculated component prices for butterfat, protein, and other solids non-fat in one unit of milk, calculated by:

$$(2.8.8)\ \widetilde{SP^{com}}_{j} = SP^{com}{}_{j} * AVG\_PCT_{j}^{com}$$

Where j is one of the 303 agricultural districts; com denotes butterfat, protein or other solids non-fat. For every component, $AVG\_PCT_{j}^{com}$ is the arithmetical average of component percentage in the raw milk processed in the j^{th} region; $SP^{com}{}_{j}$ is shadow prices for butterfat, protein or other SNF, derived from (2.8.6); $\widetilde{SP^{com}}_{j}$ is the prices for milk components in one unit of milk.

2.8 Results on Price Differentials

Now let us analyze the MilkOrdIII model generated price differentials for Class I to IV milk and milk components by region. Then for Class I milk, we will compare the model generated results with the existing price differentials.

2.8.1 Price Surface for Class I

The current FMMO Class I price differentials range from \$1.60 to \$6.00/cwt. The highest differentials occur in the Miami area of South Florida. Generally speaking, the current differentials are relatively higher in the southeast and decrease as one moves from the Southeast toward the Northwest. Some districts in the Midwest and West have the lowest non zero differential of $1.60/cwt. In order to compare the existing Class I price differentials with the model generated ones, the differentials are all expressed as differences from the lowest differential nationally and thus the current ones range is from $0.00 to $4.40 per cwt.[26] Figure 2-6 contains a map of the adjusted existing Class I price differentials with the colors denoting their magnitude. Contour lines are added at $0.40/cwt. intervals. The darker the grey shading the higher the price differential. Note here the highest differentials appears in Florida with Florida prices varying from $2.40 to $4.40/cwt. The lowest prices are marked with a 0 and are in Minnesota, the Dakotas, Wyoming and plus in a couple of Southwestern regions in New Mexico, Arizona and Eastern California.

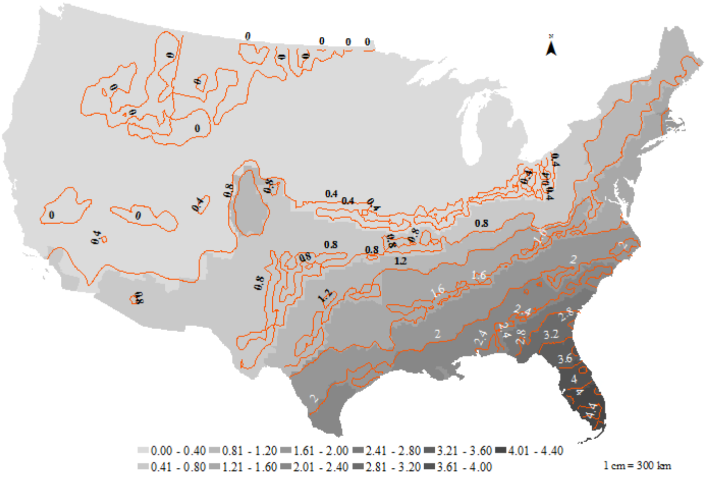

Figure 2-6. FMMO Class I Price Differentials with Zero Minimum ($/cwt.)

Now let us examine the MilkOrdIII generated Class I price differentials as averaged across the component cases and quarters of the year which are normalized so the minimum is

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[26] In the following parts, all the analysis related to the current Class I price differentials is based on the differentials with zero minimum.

zero. These are depicted in figure 2-7 for the MilkOrdIII model which contains milk components. There we see the high values are concentrated in the Southeast regions mainly including Eastern Texas, Louisiana, South Carolina, Mississippi and Florida, with the peak in the Miami area in Florida ($7.78/cwt.), and the price decreases with movement to the Northwest. This price pattern is very close in overall pattern with that of the current Class I pricing policy but exhibits a wider range of differentials. A statistical summary for the Class I price differentials appears in table 2-4.

The maximum differential arising under the MilkOrdIII simulation is $7.78/cwt., which is nearly 30% higher than the maximum differential under the current policy. On the other side, 60% of the MilkOrdIII generated differentials fall in the range $1.61- $3.20/cwt. which is close to the range exhibited by the current differential policy. Meanwhile, the national average MilkOrdIII differential is $2.69/cwt., which is $1.83/cwt. more than the currently implemented differentials. The results indicate that it may be desirable to revise the differentials to reflect changes since 2000, such as the regional changes in milk supply and demand and the increase in transportation cost.

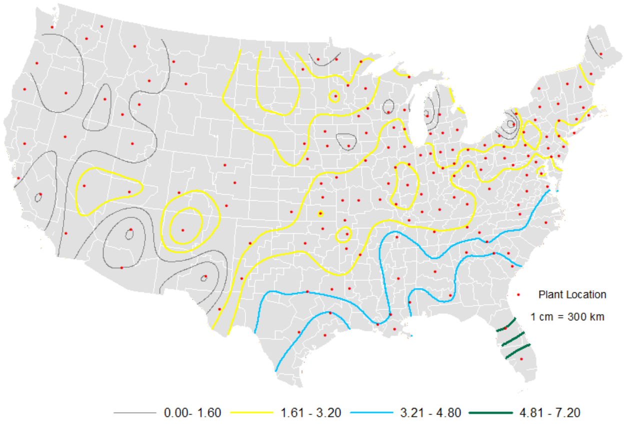

Figure 2-7. The MilkOrdIII Model generated Class I Price Differentials, 2012 Average ($/cwt.)

Note: The fluid milk processing plants are located in 159 regions.

The map in figure 2-8 shows the differences between the MilkOrdIII model generated differentials and the current ones. The divergence between these two sets of differentials ranges from $ -0.50 to $3.39/cwt. with the average being $1.86/cwt. Here 51% of the cases fall between $0.00 and $2.00/cwt. and 46% fall in the range from $2.01- $3.39/cwt. The Midwest and East Coast regions exhibit the positive differences (a larger differential than those now in use) with the higher ones in Ohio (OH50, $3.13/cwt.), New Mexico (NM10, $3.17/cwt.), Minnesota (MN50, $3.22/cwt.), southern Florida (FL80, $3.78/cwt.), and in southeast Texas (TX90, $3.39/cwt.). Negative differences (a smaller differential than those now in use) appear in 5 districts: New Mexico (NM90, $-0.50/cwt.), New York (NY70, $-0.50/cwt.), Arizona (AZ10, $-0.30/cwt.), Michigan (MI40, $-0.20/cwt.), California (CA51, $-0.10/cwt.). Generally, most of the eastern districts have higher model generated price differentials than the currently used ones while a few in the South West are smaller and they tend to converge in the Midwest and Southeast U.S.

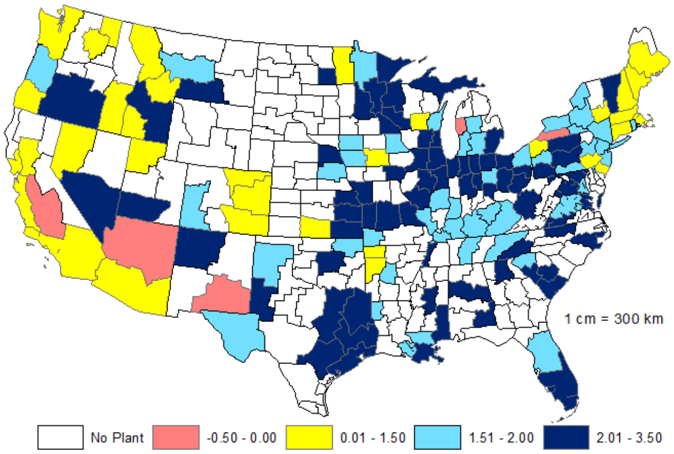

Figure 2-8. Differences between the MilkOrdIII Model generated Class I Price Differentials and the Current Policy, 2012 ($/cwt.)

Note: The fluid milk processing plants are located in 159 regions

To sum up, generally the model exhibits larger and wider ranging differentials than do the existing FMMO differentials. This may imply that it is desirable to update the current differentials so they better reflect current conditions.

2.8.2 Price Differentials for Other Classes

Price differential surfaces were also constructed using MilkOrdIII shadow price results for organic milk and classes II-IV. Figure 2-9, gives those for Class IO[27]; figure 2-10 for Class II; figure 2-11 for Class III; and figure 2-12 for Class IV. Also summary statistics on these price differentials appear in table 2-4.

Class IO price differentials

The price distribution for organic milk exhibits a quite different pattern compared with that of Class I milk. The highest differentials now appear in the West, such as ones in California (CA50, $8.35/cwt.; CA51, $8.01/cwt.; CA80, $7.29/cwt.), Nevada (NV10, $7.56/cwt.). Florida differentials are still relatively high with Miami at $6.22/cwt. The Midwest and Northeast are the areas that now exhibit the smaller differentials. Statistically, 86% of the differentials are below $4.00/cwt. and the average of these differentials is $2.06/cwt. with a standard deviation of $1.82/cwt. The results imply that it would be reasonable to have an alternative set of spatial differentials for organic milk.

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[27] Class IO refers to organic milk used to produce organic fluid milk at plants.

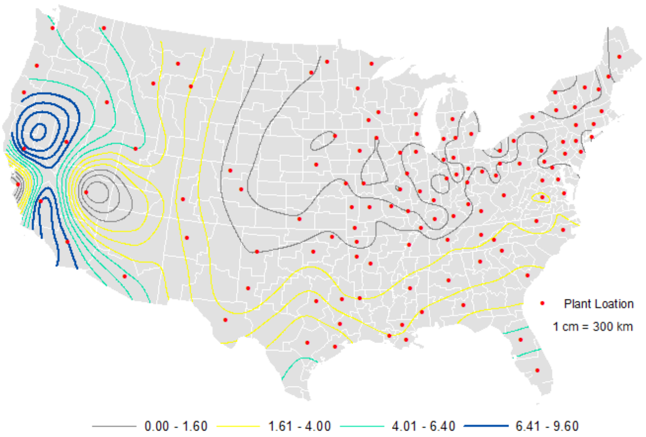

Figure 2-9. The MilkOrdIII Model generated Class IO Price Differentials, 2012 Average ($/cwt.)

Note: Class IO milk processing plants are located in 123 regions.

Class II price differentials

For Class II milk, the model generated price surface shows spatial differentials that are arrayed in a similar pattern to those for Class I milk. The differentials range up to $8.25/cwt. with an average value of $2.13/cwt. and its standard deviation ($1.27/cwt.) is higher than that of Class I price differentials. Again higher differentials concentrate in the Gulf and East Coast regions with a maximum in Florida while most Central and Northwest regions are lower. A high differential also occurs in North Dakota. This suggests that it may be desirable to also use differentials for Class II milk as opposed to the current geographically uniform practice.

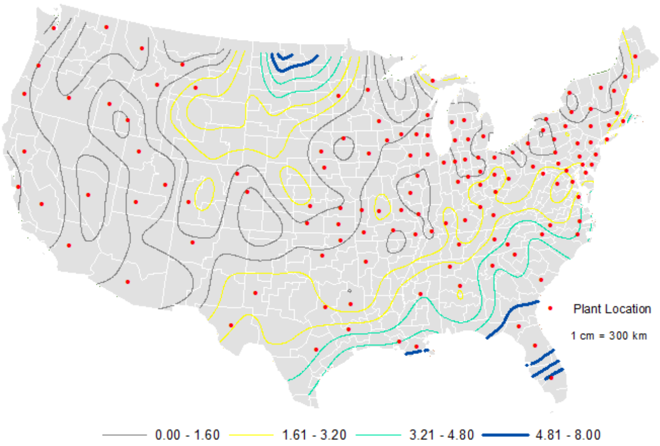

Figure 2-10. The MilkOrdIII Model generated Class II Price Differentials, 2012 Average ($/cwt.)

Note: Class II milk processing plants are located in 134 regions.

Class III price differentials

There are 86 regions processing Class III milk into cheese products, and the price differentials for them are shown in figure 2-11. The colors of the contours on the map represent different levels of prices. The range of these differentials are $0.00-$1.83/cwt with 63% being below $1.00/cwt and the average being $0.83/cwt. The regions in the Midwest, Central Atlantic and New England exhibit higher differentials with lower ones appearing in the West. The Class III range is much narrower than the ones for Class I and II milk. This shows the current uniform policy may adequately represent the spatial variance.

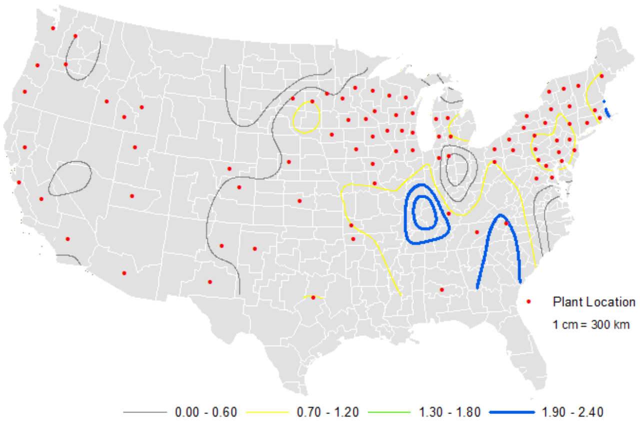

Figure 2-11. The MilkOrdIII Model generated Class III Price Differentials, 2012 Average ($/cwt.)

Note: Class III milk processing plants are located in 86 regions.

Class IV price differentials

Class IV milk is used in 44 districts to produce butter and powder products. The price differentials that the model generates in those districts are presented in figure 2-12. The price differential is greatest in the East declining from East to West and with the largest in Georgia (GA70, $5.06/cwt.). The average price is $1.22/cwt. and it's less than 10% of the federal average Class IV milk order price. Although the class IV differentials are much less variable than those for Class I and II milk, they are higher and exhibit more variability than those for Class III milk. Hence the differential surface implies that it may be satisfactory to use regionally differentiated prices for Class IV milk.

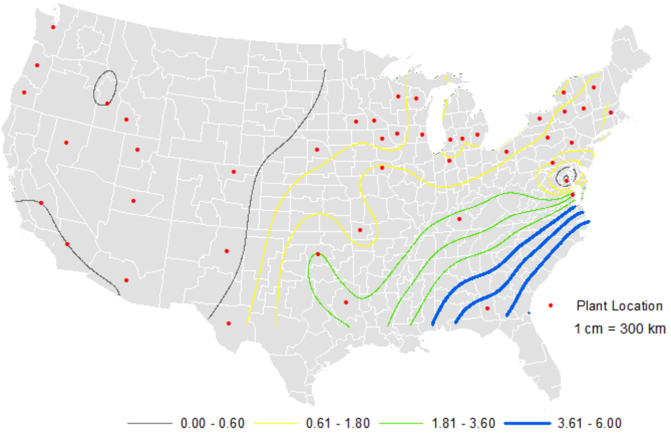

Figure 2-12. The MilkOrdIII Model generated Class IV Price Differentials, 2012 Average ($/cwt.)

Note: Class IV milk processing plants are located in 44 regions.

Table 2-4. Statistical Summary for Price Differentials of Milk Classes, 2012 Average ($/cwt.)

	ClassIO	ClassI	ClassII	ClassIII	ClassIV
Min.	0.00	0.00	0.00	0.00	0.00
1st Quartile	0.83	2.17	1.42	0.65	0.35
Median	1.53	2.57	1.86	0.82	1.04
Mean	2.06	2.69	2.13	0.83	1.22
3rd Quartile	2.64	3.24	2.54	1.14	1.76
Max.	8.35	7.78	8.25	1.83	5.06
Std dev.	1.82	1.15	1.27	0.41	1.00
# of Plants	123	159	134	86	44

Figure 2-13 shows a box and whiskers comparison of the mean and range of the regional price differentials across all the classes of milk. There we see that the median differentials for Class I milk and Class IO are higher than that of others as are their range and standard deviation with Class IO milk being the highest. Class II is the second. Price differentials for Class III and IV milk are relatively more concentrated with smaller median values ($0.82/cwt. for Class III and \$1.04/cwt. for Class IV), ranges and maximum levels. The organic milk (Class IO) also has lower median price (\$1.53/cwt.) but most of the data fall into the 4th quartile.

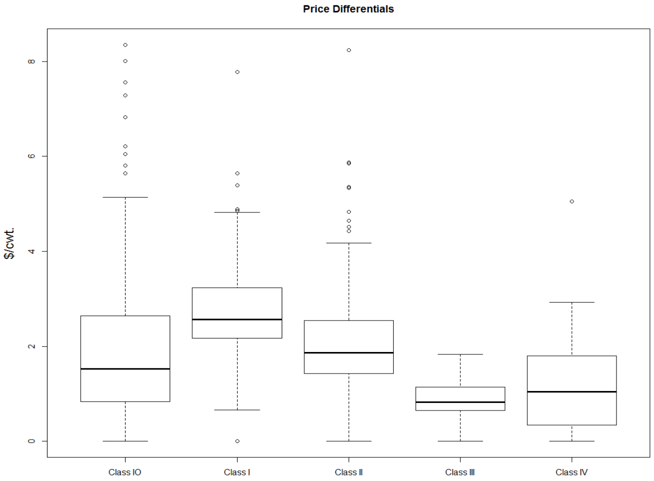

Figure 2-13. Box-and-Whisker Plots of Milk Price Differentials

Note: The boxes cover the interquartile range, and the upper (lower) whisker is at the upper (lower) quartile plus (minus) 1.5 times the interquartile range, or the maximum (minimum) value if it is smaller (larger). Data outside the whiskers are represented with dots

2.8.3 Component Prices

Prices surfaces were also constructed for milk components. These were formed by section 2.7.1: firstly, we regress model generated milk price differentials ($\widetilde{U_{jcy}}$) on relative percentages of components contained in raw milk by region, class and type (PCT_{jcy}^{com}), and use the estimated coefficients ($SP^{com}{}_{j}$) as references of prices for butterfat, protein, and other solid non-fat; next for every region, average the percentages of each milk component in one unit of raw milk across milk class and type ($AVG\_PCT_{j}^{com}$), and then multiply the component prices obtained by their average percentages in one unit of milk to get prices for components in one unit of milk.

Butterfat Price

The figure 2-14 shows the spatial price surface for butterfat in Class I milk. The graph shows that the price distribution for butterfat is fairly smooth with about 80% of the prices are below $2.00/cwt. Southeastern and central regions exhibit higher differentials, ranging from $2.00 to $5.77/cwt. and the majority of the Midwest and Northeast differentials are below $2.00/cwt. Only less than 10% of the regions have differentials greater than $3.00/cwt. the Florida Miami regions is again the highest (FL80, $5.77/cwt.) and the next is Georgia (GA70, $5.27/cwt.). The prices again present a gradually increasing pattern, from the Southeast to the Northwest.

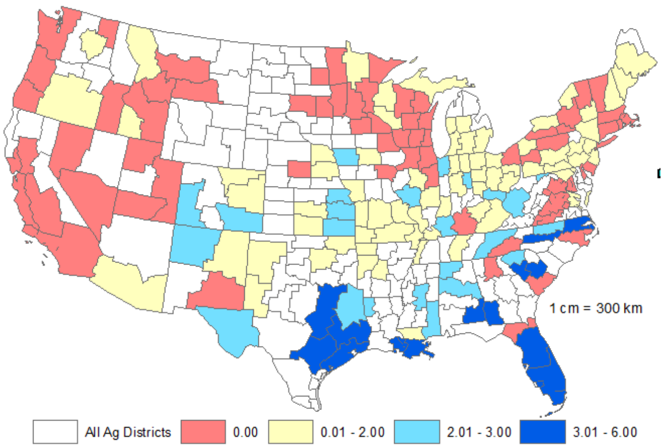

Figure 2-14. The Estimated Butterfat Prices, 2012 Average ($/cwt.)

Protein Price

Protein prices were also derived and their differentials appear in figure 2-15. Here we find the range of the protein prices is $0.00 - $6.88/cwt., with an average of $0.71/cwt. For protein we find the high prices are concentrated in the West and Northeast, and two districts have prices larger than $7.00/cwt. (CA80, $6.29/cwt.; NV10, $6.88/cwt.). More than 4/5 of these prices are lower than $2.00/cwt.

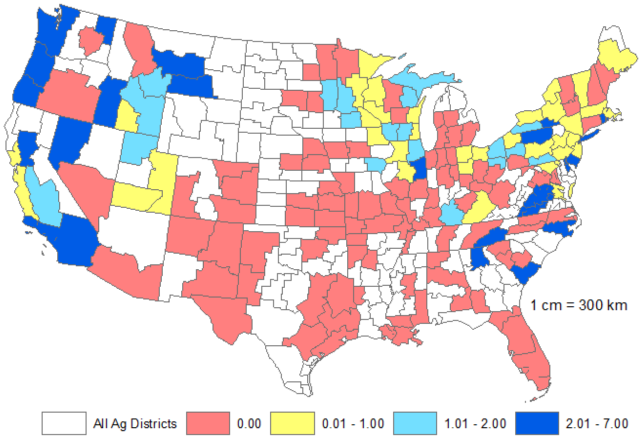

Figure 2-15. The Estimated Protein Prices, 2012 Average ($/cwt.)

Other Solids non-fat Price

On the map of figure 2-16, there are 30 districts out of the 179 with non-zero prices for other solids non-fat, and the maximum differential appears in Florida (FL30, $5.93/cwt.). The average of these differentials is the smallest ($0.28/cwt.) in contrast with butterfat and protein, with the lowest variation ($0.85/cwt.), and the dominated red color on the map denotes a zero price. Therefore, a uniform price for other solids non-fat would be ideal for different districts.

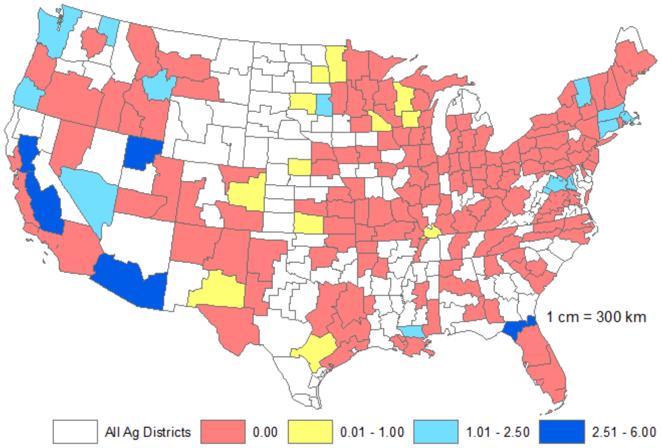

Figure 2-16. The Estimated Other Solid non-fat Prices, 2012 Average ($/cwt.)

All in all, from the maps above and the statistical summary in table 2-5, we can see that the prices of butterfat shows relatively larger spatial differences with a higher average differential than those of the other components; for protein, the differentials in many districts are zero and most of the non-zero districts have a differential below $2.00/cwt.; the other solids non-fat differentials are small with low volatility and might be represented by a uniform price.

Table 2-5. Statistical Summary of Milk Component Prices ($/cwt.)

Price	Non-zero Count	Minimum	Maximum	Average	Standard Deviation
Butterfat	111	0.00	5.77	1.15	1.28
Protein	77	0.00	6.88	0.71	1.30
Other Solids non-fat	30	0.00	5.93	0.28	0.85

2.9 Importance of Including Components

We will also do a comparison between the model without the milk component characteristics (MilkOrdII) and the current Class I price differential policy. Then models with (MilkOrdIII) and without milk components.

Figure 2-17, shows the differences of comparing price differentials generated from the MilkOrdII model without consideration of components with the current price differential policy. There we see inclusion of components makes a substantial difference. The differences of prices vary between $-0.50/cwt. and $6.23/cwt. with more than half falling in the interval of $2.01 - $4.00/cwt. The places with a higher model generated differential relative to the current policy, are located mainly in the East coast and Midwest regions, among which the differences of Florida (FL80, FL50), Ohio (OH50), Vermont (VT10), and Pennsylvania (PA20, PA50) are the largest being higher than $4.50/cwt. Smaller model generated differentials appear in Arizona

(AZ80, AZ10), Utah (UT10), and New Mexico (NM90) (respectively $-0.29, $-0.30, $-0.30, $-0.50 per cwt.).

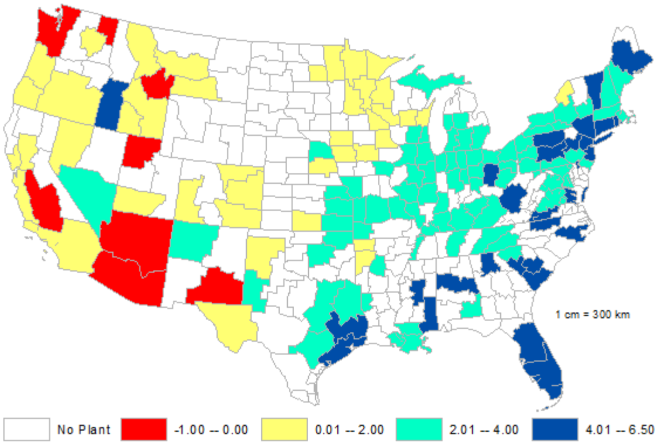

Figure 2-17. Differences between the MilkOrdII Model generated Class I Price Differentials and the Current Policy, 2012 Average ($/cwt.)

Comparing just the models (figure 2-18) shows the with component MilkOrdIII model exhibits smaller differentials in nearly 70% of the regions. The largest differences appear in the Northeast and Southeast, among which NY70 has the highest difference ($4.25/cwt. lower than the without component model version). On the other hand, in the Western US, the with component MilkOrdIII model generates higher differentials, ranging from $0.01 - $2.00/cwt. and the largest differences are in MN50 ($1.81/cwt.) and ND60 ($1.91/cwt.). The comparison shows that from the new model solution, the regions along the east coast of U.S. lower their price differentials and the West increases as a contrast.

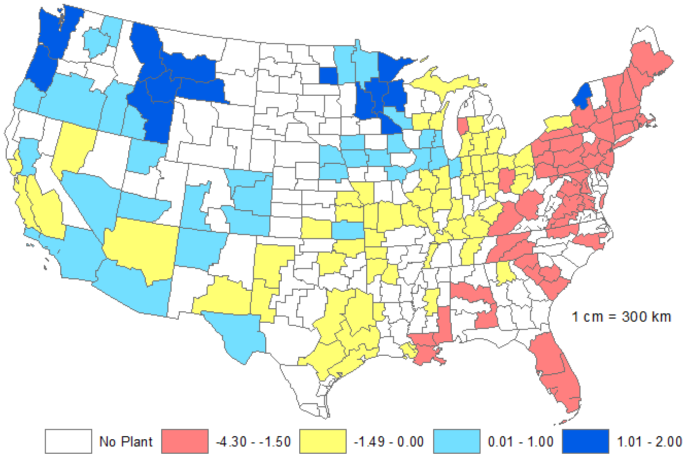

Figure 2-18. Differences between Class I Price Differentials generated from the MilkOrdIII model and that from the MilkOrdII Model, 2012 ($/cwt.)

The difference between these two model versions is the inclusion of raw milk component differences and component related processing activities. And the comparison above shows that when considering components the MilkOrdIII model differentials are flatter exhibiting less variation. All in all this shows adding raw milk component differences and resultant different product yields is important.

2.10 Conclusions and Policy Implications

This chapter reported on an examination regarding how the present Class I price differentials under Federal Milk Marketing Orders compare to an idealized, model generated, set of differentials. There are two basic model setups applied in this study. Fundamentally a model (MilkOrdIII) was built that extends the work of Seo (2015). The MilkOrdIII model includes more dairy products: organic milk supply and demand, Greek yogurt demand; revises the regional private storage balance to be seasonal; and incorporates spatial and temporal differences in raw milk composition in in terms of butterfat, protein and other solids non-fat. In addition the processing part of the model was revised so the yields of products like Greek yogurt vary depending on the component composition of the raw milk used[28]. In our analysis we examine the influence of alternative MilkOrdII versions with and without varying milk component characteristics. In that comparison we find adding consideration of components reduces and flattens out the estimated differentials. This illustrates the importance of including varying milk components. Thus the component model is felt to be superior and is used for the rest of the analysis.

The idealized Class I price differentials generated from the MilkOrdIII model, are found to be distributed in a similar pattern as the currently used Class I price differentials implemented by the FMMO. However, the range and variance of the model generated differentials are substantially larger than those under the current policy. These results suggest that the current Class I price differentials might be updated to better reflect the regional situations in dairy industry.

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[28] Refer to section 2.6

We also find the idealized differentials from the model exhibit regional differences for organic- Class IO, and Class II to IV milk, with them being most significant for Class IO and Class II, IV. This implies that it may be desirable to also have regionalized differentials for Class IO, Class II and Class IV milk. On the other hand, we find the price differentials of Class III milk show small discrepancies across the U.S. which are consistent with the uniform prices used for Class III milk under current policy.

Based on the price differentials of milk, we also estimate the component prices for butterfat, protein and other solids non-fat. To discover these prices we regress model generated raw milk price values across space on their component makeup to get measures of relative contribution to raw milk prices of marginal alterations in butterfat, protein, and other solids non-fat content. And then for every region, we multiply the component prices obtained by their regional average percentages in one unit of milk across milk class and type to obtain a price for the component present in one unit of milk. The results show butterfat price exhibits a relatively more diverse spatial pattern and that it might be ideal to set up different spatial-prices for butterfat. For protein, most of the agricultural districts have a similar price as are those for solids non-fat, prices, implying a uniform price by region would be suitable.

2.11 Limitations and Further Research Directions

This study has several limitations. Firstly, we assume that capacity volumes of the processing plants and per capita consumption of dairy products are constant across a year. However, processing plants could adjust their capacity volumes based on historical experience or data to satisfy seasonal supply from farmers and consumers' demand, and if more idealized consumption data could be available, the model generated results would be more reliable. Secondly, the MilkOrdIII model assumes fixed production and consumption volumes. By including supply and demand curves, the model could be more realistic and provide insight into how policy influences the spatial location of milk supply. Third, the model does not do much with international trade in butter, cheese and powder and an improved representation may be in order as trade importance is growing. Fourth, while we show the differentials are different due to supply locations and transport costs we know transport costs will change and it may be desirable to develop a way of updating given a new diesel price. We do this in the next chapter.

In future research, the MilkOrdIII model could be updated with endogenous price evaluating producers' and consumers' welfare. Also an econometric analysis of milk production against climate factors would be helpful for the model to examine climate change effects on dairy industry. And incorporating international trade may help to expand the model and augment the findings in this study.

Table 2-6. Difference of Annual Model generated Price Differentials and the Current Class I Price Differentials (2012, $/cwt.)

		Class I			Class IO	Class II	Class III	Class IV
District	Policy	the Old vs. Policy	the New vs. Policy	the New vs. the Old	the New Model	the New Model	the New Model	the New Model
AL10	1.60					3.36		
AL20	1.70							
AL30	1.80	4.09	2.48	-1.61	2.72	3.24		
AL40	2.20						1.49	
AL50	2.40							
AL60	2.70	3.94	2.04	-1.90	3.73			
AR10	1.10	1.81	1.20	-0.61	1.49		1.09	
AR20	1.10							
AR30	1.10							
AR40	1.30	1.97	1.31	-0.67	1.76	2.14		
AR50	1.30	2.92	1.93	-0.99	1.83			
AR60	1.30							
AR70	1.60							
AR80	1.60							
AR90	1.60							
AZ10	0.30	-0.30	-0.30	0.00				
AZ80	0.75	-0.29	0.06	0.34	5.09	0.47	0.27	0.05
CA10	0.20							
CA20	0.20							
CA30	0.10							
CA40	0.20	0.84	0.72	-0.12	0.00	0.90	0.22	
CA50	0.10	0.85	1.06	0.21	8.35	0.40	0.31	
CA51	0.10	-0.05	-0.10	-0.05	8.01	0.00	0.04	0.00
CA60	0.10							
CA80	0.50	1.26	1.27	0.01	7.29	1.25	0.47	0.00
CO10	0.30							
CO20	0.85	0.65	1.40	0.76	1.28	1.50	0.55	0.36
CO60	0.95	0.20	1.08	0.89	0.91	0.68	0.64	
CO70	0.40	1.10	1.85	0.75	2.95	2.16		
CO80	0.30							
CO90	0.75	0.66	1.42	0.76				
CT10	1.55	4.16	1.50	-2.66	1.53	2.28	0.90	
DE20	1.45	4.38	1.72	-2.66		2.50	1.32	
DE50	1.45					2.82		
DE80	1.45							

Table 2-6. Difference of Annual Model generated Price Differentials and the Current Class I Price Differentials (2012, $/cwt.) (Continued)

		Class I			Class IO	Class II	Class III	Class IV
District	Policy	the Old vs. Policy	the New vs. Policy	the New vs. the Old	the New Model	the New Model	the New Model	the New Model
FL10	2.70							
FL30	3.00					5.88		
FL50	3.80	4.65	1.85	-2.80	5.13	5.85		
FL80	4.40	6.23	3.38	-2.85	6.22	8.24		
GA10	1.80							
GA20	1.80	4.32	2.85	-1.48	2.60	4.64		
GA30	1.80							
GA40	2.20							
GA50	2.20							
GA60	2.20							
GA70	2.70							5.06
GA80	3.00							
GA90	3.00							
IA10	0.15	1.23	1.51	0.28	0.00	0.78	0.78	
IA20	0.15							
IA30	0.15	1.49	1.70	0.21	0.00	1.53	0.78	0.94
IA40	0.20	1.30	1.76	0.46				
IA50	0.20	1.25	1.28	0.04	0.25	1.26	0.86	
IA60	0.20							
IA70	0.20							
IA80	0.20							
IA90	0.20	2.02	2.31	0.30			0.83	1.87
ID10	0.30							
ID70	0.00	0.08	0.65	0.58	5.81	0.18	0.06	0.00
ID80	0.00	0.52	1.23	0.71		0.00	0.08	0.15
ID90	0.00	1.02	2.03	1.01			0.17	
IL10	0.20	2.19	2.43	0.25	0.77	2.31	0.67	
IL20	0.20	2.13	2.33	0.20	0.94	1.68	0.76	
IL30	0.20							
IL40	0.20	2.93	2.20	-0.73	0.83	1.41		
IL50	0.20	2.52	2.22	-0.29				
IL60	0.20	2.78	2.53	-0.25	0.00	0.85		
IL70	0.20	2.52	1.87	-0.65	0.98			
IL80	0.40	2.61	1.93	-0.68	0.81	1.59		
IL90	0.40							
IN10	0.20	2.43	2.46	0.03		2.21		
IN20	0.20	2.62	2.25	-0.37	0.72	1.60	0.76	1.27

Table 2-6. Difference of Annual Model generated Price Differentials and the Current Class I Price Differentials (2012, $/cwt.) (Continued)

		Class I			Class IO	Class II	Class III	Class IV
District	Policy	the Old vs. Policy	the New vs. Policy	the New vs. the Old	the New Model	the New Model	the New Model	the New Model
IN30	0.20	2.83	2.13	-0.70	1.13	1.35	0.00	
IN40	0.40							
IN50	0.40	2.68	2.17	-0.51	1.67	1.72		
IN60	0.40	2.78	2.01	-0.77	0.00	1.71		
IN70	0.70	2.97	1.89	-1.08	1.06			
IN80	0.70							
IN90	0.70							
KS10	0.40							
KS20	0.60							
KS30	0.60							
KS40	0.40							
KS50	0.40					2.14	0.96	
KS60	0.60	1.84	1.49	-0.35	0.91	1.48		
KS70	0.40	2.27	2.12	-0.15				
KS80	0.40	2.31	2.16	-0.15		1.54		
KS90	0.60	2.03	2.64	0.61		1.14		
KY10	1.10	2.64	1.67	-0.97	1.41	1.55		
KY20	1.00	2.73	1.81	-0.92	0.00	2.50		
KY30	1.00	2.70	1.59	-1.11	1.13	2.15	1.47	2.56
KY40	0.70							
KY50	1.00	2.89	1.68	-1.21	1.49	2.37		
KY60	1.30	3.26	1.61	-1.66	1.86	2.93		
LA10	1.60	3.06	1.94	-1.12	2.41			
LA20	1.60							
LA30	1.60							
LA40	1.80							
LA50	1.80							
LA60	2.20	3.50	1.83	-1.67	3.14			
LA70	2.20							
LA80	2.20	3.18	1.81	-1.37	3.22	4.84		
LA90	2.20	3.90	2.15	-1.75	3.29	5.36		
MA10	1.65	3.51	1.18	-2.33	1.23	2.16	1.34	1.66
MD10	1.00	3.96	2.09	-1.87		2.65		
MD20	1.30	3.91	2.01	-1.89	1.70	2.42	1.26	
MD30	1.40							
MD80	1.40	3.69	1.72	-1.97	2.09	2.42	0.92	0.00
MD90	1.40	2.83	2.13	-0.70	1.13	1.35	0.00	

Table 2-6. Difference of Annual Model generated Price Differentials and the Current Class I Price Differentials (2012, $/cwt.) (Continued)

		Class I			Class IO	Class II	Class III	Class IV
District	Policy	the Old vs. Policy	the New vs. Policy	the New vs. the Old	the New Model	the New Model	the New Model	the New Model
ME10	1.00							
ME20	1.20	4.18	0.33	-3.85	1.91	2.99		
ME30	1.40	3.11	0.78	-2.33	1.52	1.84	1.36	
MI10	0.20	2.78	2.12	-0.66		2.87		
MI20	0.20							
MI30	0.20							
MI40	0.20	2.23	-0.20	-2.43		1.37	1.09	
MI50	0.20	2.38	1.66	-0.72	0.67	1.30	1.06	
MI60	0.20							
MI70	0.20	2.85	1.84	-1.00	0.72	1.21	0.82	0.91
MI80	0.20	2.67	1.86	-0.81	0.79	1.42	1.13	1.17
MI90	0.20	2.77	2.08	-0.69	1.13	1.67		0.99
MN10	0.05	0.81	1.17	0.35	0.70			
MN20	0.05	1.31	1.70	0.39				
MN30	0.05	1.28	2.33	1.05	0.73			
MN40	0.10					2.62	0.64	
MN50	0.10	1.42	3.22	1.81			0.69	
MN60	0.10	1.19	2.34	1.15	0.63	1.41	0.68	
MN70	0.10							
MN80	0.10						0.70	0.95
MN90	0.10	1.09	2.13	1.04	0.48	1.30	0.66	1.02
MO10	0.20	2.49	2.27	-0.22	0.84			
MO20	0.20				0.00			
MO30	0.20						1.14	
MO40	0.40	2.28	2.13	-0.15	1.17	1.63		
MO50	0.40	2.81	2.51	-0.30	1.37	2.56		
MO60	0.40	2.65	2.08	-0.57	1.00	1.93		
MO70	0.80	2.72	1.76	-0.97	1.19	1.98	1.19	1.64
MO80	0.80					1.62		
MO90	0.80					1.79		
MS10	1.30							
MS20	1.30							
MS30	1.60							
MS40	1.60							
MS50	1.70	4.20	2.76	-1.44	2.65	3.93		
MS60	1.70							
MS70	1.80							

Table 2-6. Difference of Annual Model generated Price Differentials and the Current Class I Price Differentials (2012, $/cwt.) (Continued)

		Class I			Class IO	Class II	Class III	Class IV
District	Policy	the Old vs. Policy	the New vs. Policy	the New vs. the Old	the New Model	the New Model	the New Model	the New Model
MS80	1.80							
MS90	2.20	4.28	2.65	-1.63	3.25			
MT10	0.20	0.14	1.20	1.07		1.83		
MT20	0.00							
MT30	0.00							
MT50	0.00	0.56	1.76	1.20	3.74	0.96		
MT70	0.00	0.08	1.14	1.07	4.12	1.42		
MT80	0.00	1.02	2.05	1.03	3.20	2.82		
MT90	0.00							
NC10	1.80						1.83	
NC20	1.80	3.86	2.08	-1.77	2.46	4.17		
NC40	1.80	4.02	2.03	-1.99	2.27	3.53		
NC50	1.80					4.51		
NC60	2.00							
NC70	1.80					3.92		
NC80	2.00	4.43	2.43	-2.00	2.47	4.07		
NC90	2.40							
ND10	0.00							
ND20	0.00							
ND30	0.00							
ND40	0.00							
ND50	0.05							
ND60	0.05	0.82	2.73	1.91	0.83			
ND70	0.00							
ND80	0.05							
ND90	0.05							
NE10	0.20							
NE20	0.15							
NE30	0.15	2.26	2.41	0.16		1.06		0.99
NE50	0.20						0.71	
NE60	0.25	1.83	1.99	0.16	0.18	1.15		
NE70	0.20							
NE80	0.20							
NE90	0.25							
NH10	1.40	3.59	1.18	-2.41	0.68	1.79		
NJ20	1.55	4.37	1.66	-2.71	1.13	1.74	1.31	
NJ50	1.50	4.25	1.55	-2.71	1.12	1.91	1.17	

Table 2-6. Difference of Annual Model generated Price Differentials and the Current Class I Price Differentials (2012, $/cwt.) (Continued)

		Class I			Class IO	Class II	Class III	Class IV
District	Policy	the Old vs. Policy	the New vs. Policy	the New vs. the Old	the New Model	the New Model	the New Model	the New Model
NJ80	1.45	3.93	1.24	-2.69		1.92		
NM10	0.75	3.04	3.17	0.13	2.98	1.43		
NM30	0.75						0.63	0.28
NM70	0.50							
NM90	0.50	-0.50	-0.50	0.00			0.54	
NV10	0.10	1.36	0.79	-0.57	7.56			0.12
NV30	0.30							
NV80	0.40	2.31	2.43	0.12	0.00	1.95		
NY20	0.70	0.16	1.96	1.80	0.03	0.80	0.85	1.29
NY30	0.70						1.02	
NY40	0.60	2.90	1.66	-1.23	1.10	1.72	1.04	1.47
NY50	0.90	3.57	1.54	-2.03	0.55	0.90	1.14	2.06
NY60	1.10	3.99	1.44	-2.55	0.62	1.60	1.11	2.16
NY70	0.50	3.75	-0.50	-4.25		0.90	0.99	
NY80	1.10	3.81	1.68	-2.13		2.18	1.12	
NY90	1.40	4.51	1.80	-2.70	1.07	1.92	1.19	
NY91	1.55	4.43	1.79	-2.64	0.00	2.55		
OH10	0.20	3.13	2.10	-1.02		1.61		
OH20	0.40	3.25	2.01	-1.24		1.81		
OH30	0.40	3.19	1.87	-1.33	0.00	1.53	1.02	1.73
OH40	0.40	2.54	1.92	-0.62	1.25	1.36		
OH50	0.40	4.69	3.13	-1.56	1.78	2.80		
OH60	0.40	3.46	2.12	-1.34	1.74		1.19	
OH70	0.60	3.50	2.78	-0.72	1.77	2.78		
OH80	0.60					2.47		
OH90	0.40	3.49	2.39	-1.10	1.43	2.13		
OK10	0.80							
OK20	0.80							
OK30	1.00							
OK40	0.80							
OK50	1.00	2.32	2.06	-0.26	2.00	1.83		2.41
OK60	1.20							
OK70	1.00	2.48	1.71	-0.77	1.70	1.50		
OK80	1.20							
OK90	1.20							
OR10	0.30	0.11	1.62	1.51	6.05	0.87	0.12	0.33
OR20	0.15						0.00	

Table 2-6. Difference of Annual Model generated Price Differentials and the Current Class I Price Differentials (2012, $/cwt.) (Continued)

		Class I			Class IO	Class II	Class III	Class IV
District	Policy	the Old vs. Policy	the New vs. Policy	the New vs. the Old	the New Model	the New Model	the New Model	the New Model
OR30	0.00							
OR70	0.30	0.35	0.84	0.49	6.83	0.62	0.21	0.39
OR80	0.15	1.10	2.06	0.96		1.57		
PA10	0.50	3.09	1.27	-1.82	1.48	1.64	0.93	
PA20	0.70	4.59	2.98	-1.61		1.74	1.20	1.93
PA30	0.90							
PA40	0.50	3.60	1.93	-1.67			0.86	
PA50	0.70	4.58	2.34	-2.24	1.72	1.65	1.29	
PA60	1.10	4.37	1.90	-2.47	1.25	2.07	1.26	2.18
PA70	0.70	3.87	2.25	-1.62	1.77	1.93		
PA80	1.30	3.87	1.78	-2.09	1.40	2.25	1.24	1.71
PA90	1.45	3.91	1.24	-2.67	1.39	1.88	1.30	
RI10	1.65	4.23	1.90	-2.33		3.34	1.38	
SC10	2.00	3.91	1.96	-1.95	2.72	4.42		
SC20	2.00							
SC30	2.40							
SC40	2.40	4.38	2.41	-1.97				
SC50	2.40	4.18	2.21	-1.97				
SC80	2.70	4.16	2.18	-1.97	3.40	5.34		
SD10	0.05							
SD20	0.05						0.71	
SD30	0.10						1.19	
SD40	0.10							
SD50	0.10							
SD60	0.10							
SD70	0.20							
SD80	0.10							
SD90	0.15							
TN10	1.30	3.78	3.02	-0.76	1.91			
TN20	1.30							
TN30	1.30							
TN40	1.30	3.19	1.96	-1.23	2.03	2.49		
TN50	1.30							
TN60	1.60	3.39	1.70	-1.69	2.27	3.53	1.61	
TX11	0.80	1.70	1.54	-0.16	1.60		0.67	
TX12	0.80	2.38	2.24	-0.14	1.73	2.97		
TX21	1.00							

Table 2-6. Difference of Annual Model generated Price Differentials and the Current Class I Price Differentials (2012, $/cwt.) (Continued)

		Class I			Class IO	Class II	Class III	Class IV
District	Policy	the Old vs. Policy	the New vs. Policy	the New vs. the Old	the New Model	the New Model	the New Model	the New Model
TX22	1.00							
TX30	1.20							
TX40	1.40	3.11	2.57	-0.53	3.50	2.51	1.22	
TX51	1.40	3.25	2.24	-1.00	2.58	1.98		2.44
TX52	1.70	4.26	3.12	-1.14	3.75	3.70		
TX60	0.65	1.46	1.57	0.11	2.63	3.15		0.90
TX70	1.20							
TX81	1.85	2.95	2.88	-0.07	4.60	3.84		
TX82	2.05							
TX90	2.00	4.37	3.39	-0.98	4.42			
TX96	1.85							
TX97	2.05							
UT10	0.30	-0.30	0.62	0.92	4.79	0.45	0.21	0.33
UT50	0.30							
UT60	0.30					0.42		
UT70	0.00	1.75	2.59	0.84		0.53	0.30	0.47
VA20	1.20	3.87	2.14	-1.74	2.22	2.22	0.94	
VA40	1.20							
VA50	1.50	3.96	1.98	-1.98	2.41			
VA60	1.50	4.44	2.37	-2.07	2.24	3.58		2.93
VA70	1.60							
VA80	1.50	4.41	2.44	-1.97				
VA90	1.60							
VT10	1.00	4.62	2.07	-2.55	0.24	1.34	1.04	1.96
WA10	0.30	-0.09	1.17	1.26	5.64	0.30	0.10	0.25
WA20	0.15						0.00	
WA30	0.30	-0.13	0.60	0.73	4.71	2.28		
WA50	0.15	0.56	1.07	0.51				
WA90	0.15							
WI10	0.10	1.59	2.87	1.28			0.64	
WI20	0.10						0.67	1.05
WI30	0.10						0.72	1.42
WI40	0.10	1.48	2.19	0.71	0.50		0.69	
WI50	0.10	1.87	1.41	-0.47			0.71	
WI60	0.10	1.93	1.88	-0.05	0.46	1.44	0.74	
WI70	0.15					1.42	0.75	0.83
WI80	0.15	2.52	2.88	0.36		2.09	0.79	

Table 2-6. Difference of Annual Model generated Price Differentials and the Current Class I Price Differentials (2012, $/cwt.) (Continued)

		Class I			Class IO	Class II	Class III	Class IV
District	Policy	the Old vs. Policy	the New vs. Policy	the New vs. the Old	the New Model	the New Model	the New Model	the New Model
WI90	0.15	2.04	2.19	0.16	0.64	2.27	0.80	1.65
WV20	0.70							
WV40	0.60	4.51	2.85	-1.66	2.22			
WV60	0.60							
WY10	0.00							
WY20	0.05							
WY30	0.00							
WY40	0.30							
WY50	0.30							
Count	303	159	159	159	123	134	86	44
Max.	4.4	6.23	3.39	1.91	8.23	8.24	1.83	5.06
Min.	0	0	0	0	0	0	0	0
>0		153	154	48	113	132	83	40
=<0		6	5	111	10	2	3	4
Avg.	0.86	2.62	1.86	-0.26	2.06	2.13	0.83	1.22
Stdev	0.79	1.40	0.71	1.24	1.82	1.27	0.41	0.00

Table 2-7. Milk Component Prices (2012, $/cwt.)

District	Butterfat	Protein	Other Solids non-fat
AL10	2.70	0.00	0.00
AL30	2.69	0.00	0.00
AL60	3.54	0.00	0.00
AR10	1.20	0.00	0.00
AR40	1.58	0.00	0.00
AR50	1.66	0.00	0.00
AZ80	1.84	0.00	3.06
CA40	0.00	0.78	0.00
CA50	0.00	5.19	3.07
CA51	0.00	1.73	5.82
CA80	0.00	6.29	0.00
CO20	1.29	0.00	0.00
CO60	0.61	0.00	0.39
CO70	2.96	0.00	0.00
CO90	2.35	0.00	0.00
CT10	0.00	0.00	1.55
DE20	0.00	2.33	0.00
DE50	0.00	2.70	0.00
FL30	0.00	0.00	5.93
FL50	4.85	0.00	0.00
FL80	5.77	0.00	0.00
GA20	0.00	2.79	0.00
GA70	5.27	0.00	0.00
IA30	0.00	0.23	0.00
IA40	2.14	0.00	0.00
IA50	0.35	0.00	0.00
IA90	0.00	1.64	0.00
ID70	0.00	5.38	0.00
ID80	0.24	0.25	0.00
ID90	0.00	1.09	0.00
IL10	0.00	0.84	0.00
IL20	0.00	1.14	0.00
IL40	0.92	0.07	0.00
IL50	0.00	2.44	0.00
IL60	2.06	0.00	0.00
IL70	1.10	0.00	0.00
IL80	0.94	0.00	0.00
IN10	2.40	0.00	0.00
IN20	0.86	0.00	0.00
IN30	1.22	0.00	0.00
IN50	1.79	0.00	0.00
IN60	2.02	0.00	0.00

Table 2-7. Milk Component Prices (2012, $/cwt.) (Continued)

District	Butterfat	Protein	Other Solids non-fat
KS50	1.49	0.00	0.00
KS60	0.61	0.00	0.41
KS70	2.77	0.00	0.00
KS80	2.23	0.00	0.00
KS90	2.18	0.00	0.00
KY10	0.62	0.00	0.75
KY20	2.50	0.00	0.00
KY30	0.00	1.39	0.00
KY50	1.58	0.00	0.00
KY60	1.26	0.82	0.00
LA10	2.58	0.00	0.00
LA60	1.03	0.00	1.99
LA80	3.32	0.00	0.00
LA90	3.42	0.00	0.00
MA10	0.00	0.06	1.31
MD10	2.81	0.00	0.00
MD20	1.03	0.71	0.00
MD80	0.00	0.00	2.06
ME20	1.51	0.41	0.00
ME30	1.53	0.00	0.00
MI10	1.49	1.03	0.00
MI40	1.23	0.00	0.00
MI50	0.79	0.00	0.00
MI70	0.77	0.00	0.00
MI80	0.90	0.00	0.00
MI90	1.17	0.00	0.00
MN10	0.00	0.00	0.59
MN20	1.82	0.00	0.00
MN30	0.00	0.92	0.00
MN40	0.00	1.44	0.00
MN50	0.00	1.75	0.00
MN60	0.00	0.90	0.00
MN80	0.00	1.17	0.00
MN90	0.00	0.13	0.30
MO10	0.94	0.00	0.00
MO40	1.30	0.00	0.00
MO50	1.27	0.00	0.00
MO60	1.09	0.00	0.00
MO70	1.19	0.00	0.00
MO80	1.04	0.00	0.00
MO90	1.46	0.00	0.00
MS50	2.71	0.00	0.00

Table 2-7. Milk Component Prices (2012, $/cwt.) (Continued)

District	Butterfat	Protein	Other Solids non-fat
MS90	2.98	0.00	0.00
MT10	1.71	0.00	0.00
MT50	0.00	3.57	0.00
MT70	0.00	1.42	2.39
MT80	0.00	3.19	0.00
NC20	0.00	2.56	0.00
NC40	2.28	0.00	0.00
NC50	4.23	0.00	0.00
NC70	3.83	0.00	0.00
NC80	0.00	2.61	0.00
ND60	0.00	0.00	0.85
NE30	1.69	0.00	0.00
NE50	0.00	0.00	0.71
NE60	0.27	0.00	0.00
NH10	0.72	0.00	0.00
NJ20	0.93	0.19	0.00
NJ50	0.91	0.23	0.00
NJ80	0.00	2.23	0.00
NM10	2.81	0.00	0.00
NM30	1.16	0.00	0.00
NM90	0.00	0.00	0.41
NV10	0.00	6.88	0.00
NV80	0.00	0.00	2.24
NY20	0.31	0.01	0.00
NY30	0.00	0.00	1.01
NY40	0.41	0.70	0.00
NY50	0.00	0.56	0.00
NY60	0.67	0.00	0.00
NY70	0.00	1.35	0.00
NY80	0.00	2.03	0.00
NY90	1.10	0.01	0.00
NY91	0.00	2.83	0.00
OH10	1.32	0.59	0.00
OH20	1.58	0.48	0.00
OH30	0.00	1.69	0.00
OH40	0.71	0.74	0.00
OH50	1.95	0.00	0.00
OH60	0.81	1.01	0.00
OH70	1.87	0.00	0.00
OH80	2.36	0.00	0.00
OH90	1.98	0.00	0.00
OK50	1.91	0.00	0.00

Table 2-7. Milk Component Prices (2012, $/cwt.) (Continued)

District	Butterfat	Protein	Other Solids non-fat
OK70	1.55	0.00	0.00
OR10	0.00	5.59	0.00
OR70	0.00	4.18	1.93
OR80	1.90	0.00	0.00
PA10	1.04	0.46	0.00
PA20	0.00	2.14	0.00
PA40	0.00	1.80	0.00
PA50	1.07	0.66	0.00
PA60	1.10	0.16	0.00
PA70	1.79	0.00	0.00
PA80	0.38	1.06	0.00
PA90	0.83	0.56	0.00
RI10	0.00	2.90	0.00
SC10	2.72	0.00	0.00
SC40	5.10	0.00	0.00
SC50	4.90	0.00	0.00
SC80	0.00	3.52	0.00
SD20	0.00	0.00	0.66
SD30	0.00	0.00	1.06
TN10	1.73	0.00	0.00
TN40	1.88	0.00	0.00
TN60	2.30	0.00	0.00
TX11	1.51	0.00	0.00
TX12	1.48	0.00	0.00
TX40	3.29	0.00	0.00
TX51	2.18	0.00	0.00
TX52	3.55	0.00	0.00
TX60	2.25	0.00	0.00
TX81	3.96	0.00	0.41
TX90	3.89	0.00	0.00
UT10	0.00	1.31	2.66
UT60	0.00	0.31	0.00
UT70	0.00	1.00	0.00
VA20	0.00	0.00	2.21
VA50	0.00	2.64	0.00
VA60	1.98	0.27	0.00
VA80	0.00	4.10	0.00
VT10	0.00	0.26	0.00
WA10	0.00	4.03	1.51
WA30	0.00	2.15	2.24
WA50	1.39	0.00	0.00
WI10	1.35	0.32	0.00

Table 2-7. Milk Component Prices (2012, $/cwt.) (Continued)

District	Butterfat	Protein	Other Solids non-fat
WA30	0.00	2.15	2.24
WA50	1.39	0.00	0.00
WI10	1.35	0.32	0.00
WI20	0.00	0.00	0.78
WI30	0.00	1.20	0.00
WI40	0.27	0.53	0.00
WI50	0.00	0.00	0.90
WI60	0.00	0.44	0.00
WI70	0.00	1.29	0.00
WI80	0.00	1.99	0.00
WI90	0.00	0.92	0.00
WV40	2.34	0.00	0.00
Count (>0)	111	77	30
Max.	5.77	6.88	5.93
Min.	0.00	0.00	0.00
Avg.	1.15	0.71	0.28
Stdev	1.28	1.30	0.85

3 AN ANALYSIS OF HOW DIESEL PRICES AFFECT FEDERAL MILK MARKETING PRICE DIFFERENTIAL AND MILK COMPONENT PRICES

3.1 Introduction

The FMMO pricing system pays different milk prices to producers based on milk usage classification, and location of milk processing[29]. According to Chouinard et al. 2010, the price differentials are designed to "ensure the stability of dairy market from many aspects: motivating framers to make an appropriate producing decision; providing an adequate milk supply to meet the consumption". In particular, the price for milk used for Class I beverage dairy products varies by region, with FMMO pricing policy adding a spatial Class I price differential to the higher of the prices of milk in Class III and Class IV usages as the price to be paid for Class I milk. Jess and Cropp (2008) stated that the price differentials were ideally a reflection of milk hauling costs, and therefore price differentials could promote milk supply in an area facilitating meeting fluid consumption of other areas. They also stated that in general within a marketing order, Class I price differentials trended to higher with respect to greater milk consumption volume in a location.

In this study, we will analyze how diesel prices, an important factor in the cost of transporting milk between regions, contributes to the size of price differentials for raw milk and its components. We also develop a formula relating differentials to the diesel price that might be used to update differentials. The reason for this is that the diesel price has increased dramatically with the

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[29] Refer to section 2 for more details about milk usage and price structure.

price almost doubling in recent years plus exhibiting significant volatility[30] (figure 3-1) but the Class I price differential policy has been basically unchanged since the year 2000[31].

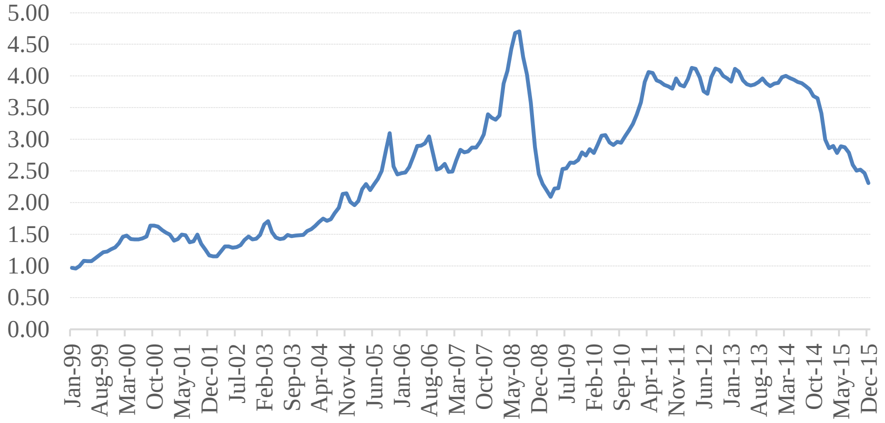

Figure 3-1. Diesel Prices (1999-2015) (Dollars per Gallon)

In order to examine the sensitivity of idealized milk price differentials to changes in diesel price, we will first do an simulate ideal price differentials for milk and its components under a set of alternative diesel prices using the MilkOrdIII model as described in section 2,. We will then estimate an econometric model that links the changes in the model generated price differentials to the diesel price.

3.2 Literature Review

The costs between the farm gate and the retailer who sells to consumer incurred within the dairy industry can roughly be divided into three categories: milk assembly, product processing, and product distribution. More generally for the supply chain, the optimal amounts of

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[30] Refer to http://tonto.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMD_EPD2D_PTE_NUS_DPG&f=M for more details

[31] Excepting a small price increase in Appalachian (FO5), Florida (FO6) and Southeast (FO7) orders.

milk movement, and processing plant activity are often reflective of constrained cost minimization[32].

With respect to the transportation costs of raw milk, many empirical studies focus on identifying major factors that affect the cost of shipping milk from dairy farms to processing plants.

Jacobson and Fairchild (1969) classified the costs of moving raw milk to fluid plants into fixed and variable costs and defined the hauling cost of raw milk as a linear function of the volume of milk transported, and the intercept denoted the stop charge[33] paid by the producer and costs for every unit (cwt.) of milk delivered.

Gallagher, Thraen, and Schnitkey (1993) estimated a trans-logarithmic total cost function using Ohio survey data and found that total cost changed more significantly with respect to a change of delivery distance than with respect to a shift of delivery volume. The most costly portion of the assembly cost for raw milk was the cost of trucking, which included fuel, labor, maintenance, and capital costs.

Newton (2009) quantified the statistical relationship between hauling costs and variables such as delivery volume and delivery distance among others, but fuel prices were not included in the estimation.

At the same time, researchers have found some limitations that constrained the efficiency of hauling raw milk, such as government limitations on load size and labor hours, and limitations related to road conditions. Additionally, milk assembly was found to be an expensive component

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[32] Refer to https://dairymarkets.org/PA/Plant_Capacity.pdf

[33] A stop charge is incurred whenever the hauling firm arrives at a dairy farm

resulting from the unpredictable demand of processors (Depetris de Guiguet and Pratt 1996; Newton 2009).

To our knowledge, only a few studies performed economic analysis on the cost of hauling raw milk from dairy farms to processing plants and most of these studies were conducted more than then year ago. Additionally we did not find any papers working on the effects of transportation costs on Class I price differentials and milk component prices.

Therefore, using the linear programming model built for dairy industry in section 2 and diesel price to indicate transportation costs, we will do sensitivity analysis with different scenarios on diesel prices. As summarized by Hamby (1994) and Saltelli (2002), sensitivity analysis is studying "how the uncertainty in the output of a model (numerical or otherwise) can be decomposed by different sources of uncertainty in the model input". This essay will collect different model outputs with the change of an input parameter - diesel price. Then pool the input and output data into a panel dataset format, and use a panel model approach, which is commonly applied in agriculture (Chen, McCarl, and Schimmelpfennig 2004; Schlenker, Hanemann, and Fisher 2006; Villavicencio et al. 2013; Attavanich and McCarl 2014), to explore the impacts of diesel price changes on price differentials of milk and also on milk component prices.

3.3 The Impact of Diesel Price Changes since 2000

Now we turn to an examination of the influence of diesel price on price differentials and milk component prices. The MilkOrdIII model is again applied under a 2012 baseline in comparison to a case simulated where we lower diesel prices to 2000 levels. The following sections summarize and visualize the results as they influence Class I price differentials and milk component prices.

3.3.1 Effects of Diesel Price Change on Price Differentials

First, let us examine the overall effect of diesel prices on model generated Class I price differentials. The diesel prices of the MilkOrdIII model are changed back to 2000 levels holding all other conditions constant. Since the major portion of the current class I price differential policy was established in 2000, restoring the diesel prices back to 2000 and analyzing the model generated results of the model could isolate the changes only due to diesel prices.

Figure 3-2 shows the changes in Class I differentials when the diesel prices are reverted to 2000 levels. The range of the model generated price differential results with 2000 diesel prices is \$0.00-\$5.58/cwt., which on average is \$0.70/cwt. lower than that with 2012 diesel prices (which has a range of \$7.78/cwt., average value of \$2.69/cwt. As discussed in section 2) which is much closer to the range of the current policy (\$4.40/cwt.)[34]. From the comparison of the model generated Class I differentials between cases of 2012 and 2000, we can find that for about 4/5 of the total Class I milk processing districts, the differentials derived from the base 2012 case are higher than that from the 2000 case in a range of \$1.00/cwt., and on the map below, these districts is painted with yellow and green colors. There are two states having the highest positive differences in differentials: Florida (FL80, \$2.20/cwt.; FL50, \$1.69/cwt.) and Georgia (GA20, \$1.50/cwt.), which are painted by dark blue color on the map. Generally speaking, under 2000 diesel prices, Class I price differentials tend to be lower than the base case of 2012, and the Southeast regions which have a higher Class I price differential in base 2012 case experience a greater price decrease when converting diesel prices into 2000 level.

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[34] The price differentials for the current policy is normalized with zero minimum value.

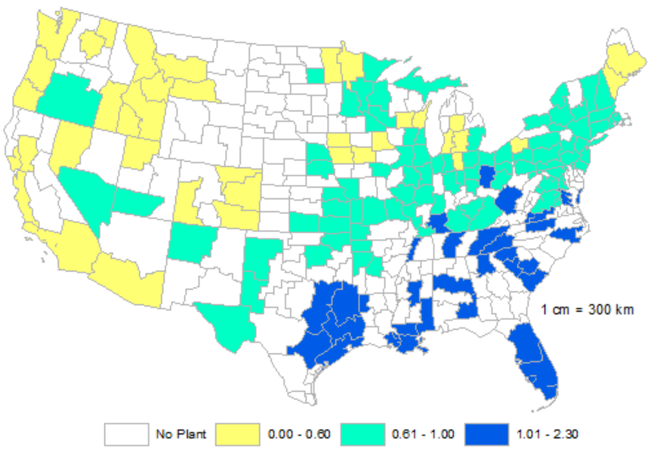

Figure 3-2. Differences between Class I Price Differentials Generated from the MilkOrdIII Model with 2012 Diesel Prices and with 2000 Diesel Prices (Annual Average)

Figure 3-3 represents the differences between the model generated Class I price differentials with 2000 diesel prices and the current Class I price differential policy. Less than 20% of the Class I milk processing districts (colored in blue on the map) have higher model generated differentials than the policy, and the large positive differences are in MN50 ($0.69/cwt.), and NM10 ($0.60/cwt.). The opposite occurs under the base 2012 case, in which the simulation with the 2012 diesel price is likely to be higher than the current Class I price differentials.

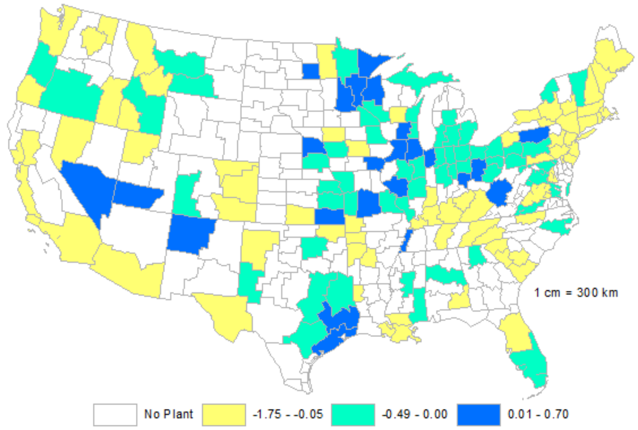

Figure 3-3. Differences between Class I Price Differentials Generated from the MilkOrdIII Model with 2000 Diesel Prices and the Current Policy (Annual Average)

These comparisons show that the change in diesel prices from 2000 to 2012 causes ideal Class I price differentials to be 26% higher than those that would apply in 2000. Thus the diesel prices exerts a significant impact on ideal price differentials. In the next part, we analyze how the diesel price change affects milk component prices.

3.3.2 Effects of Diesel Price Change on Milk Component Prices

Butterfat price

Figure 3-4 shows butterfat price differences between the 2012 diesel price case and the 2000 diesel price case. The butterfat price differentials simulated under the 2012 diesel case are higher in nearly 50% of the milk processing districts, reaching a peak of $3.31/cwt. For the districts where the differentials do not increase, 71% exhibit an small decrease from $0.01 to $1.00/cwt., and GA70 has the highest decline of $5.27/cwt. and the next is FL80 ($3.94/cwt.). On the map, the districts with red color denote where 2012 diesel price differentials in 2012 case is lower than those in the 2000 case; and the yellow and blue mean when it is higher, relatively concentrating in the Northeast and Southeast.

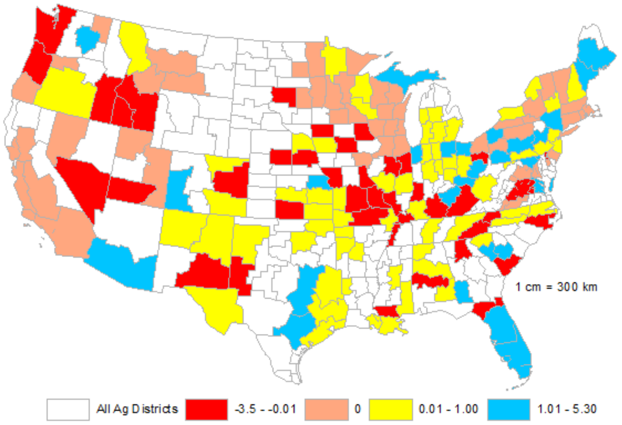

Figure 3-4. The Differences between Butterfat Prices Generated from the Base 2012 Case and 2000 Case (Annual Average)

Protein Price

Protein prices are also derived from the two cases. The price differences between them are portrayed in figure 3-5. Here we find the range of the protein price differences between two cases is -\$4.00 - \$6.88/cwt., with a standard deviation of \$1.23/cwt. The districts with red color on the map have a higher protein price in the 2000 diesel price case, which are concentrated in the East, Midwest and Southwest. The two districts that experience relatively greatest increase under the 2000 diesel prices are GA70, \$3.72/cwt.; FL80, \$2.74/cwt.

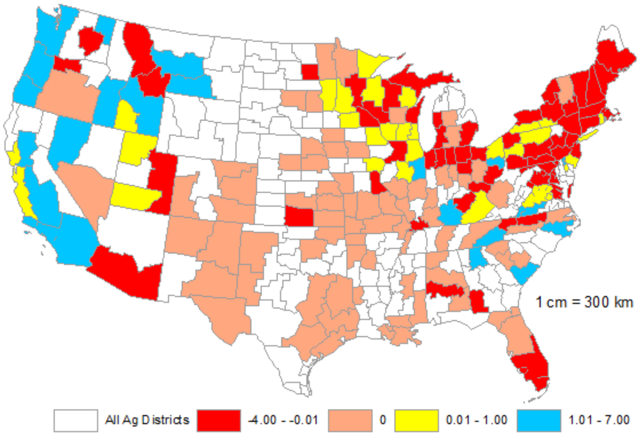

Figure 3-5. The Differences of Protein Price between Base 2012 Case and 2000 Case (Annual Average)

Other Solids non-fat Price

Figure 3-6 displays the differences of other solids non-fat prices between base 2012 case and the 2000 case. For the districts with non-zero differences of prices, 72% of the regions have a higher price with the 2012 diesel prices. The regions colored in red on the map are the ones that the differential generated from 2012 case are lower than those from 2000 case. The greatest differential increase compared with the2000 price case occurs in NV10 ($2.15/cwt.), and California experiences the most price decline (CA51, $4.66/cwt.; CA50, $3.07/cwt.).

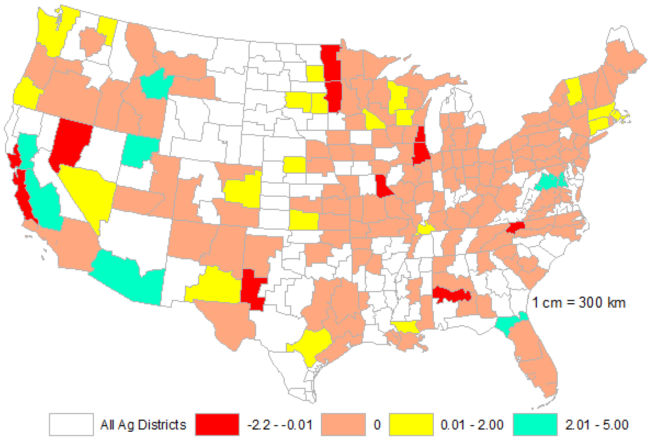

Figure 3-6. The Differences of Other Solid non-fat Price between Base 2012 Case and 2000 Case

3.4 Quantifying Diesel Price Effects

In this section, we do an econometric estimation of the effects of alternative diesel prices on the ideal price differentials. In this case, we run 12 alternative prices, and then use those results as input to an econometric analysis that expresses the relationship between differentials and diesel prices. Such a formula could possibly provide a way of updating differentials as diesel prices vary.

3.4.1 Scenario Construction

The “base” scenario is run with the 2012 regional average highway-diesel price (table 3-1) by quarter derived from U.S. Energy Information Administration (EIA) regional data under the assumption that the prices are the same for the districts falling in each EIA region there the regions are identified in table 3-1. Subsequently alternative diesel price scenarios are constructed by adding or subtracting multiples of 40 cents per gallon from the baseline level with the chosen range reflective of diesel prices observed between 2000 and 2015 (table 3-2). The resultant 12 scenarios are in shown in table 3-3. Here, these scenarios change the 2012 price from a lowering of $3.20/gallon to an increase of $1.20/gallon.

Table 3-1. Regional Diesel Price in the U.S. (2012 Quarterly) – Baseline ($/gallon)

2012	New England	Central Atlantic	Lower Atlantic	Midwest	Gulf Coast	Rocky Mountain	West Coast
Jan.	4.05	4.01	3.82	3.72	3.76	3.83	4.02
Feb.	4.16	4.13	3.95	3.84	3.88	3.86	4.16
Mar.	4.26	4.26	4.10	4.02	4.04	4.08	4.41
Apr.	4.27	4.26	4.08	4.01	4.03	4.11	4.38
May	4.16	4.11	3.94	3.88	3.89	4.00	4.25
Jun.	3.95	3.89	3.70	3.68	3.68	3.85	3.96
Jul.	3.88	3.85	3.69	3.68	3.64	3.70	3.84
Aug.	4.04	4.03	3.92	3.97	3.88	4.00	4.18
Sep.	4.20	4.17	4.04	4.06	4.02	4.24	4.39
Oct.	4.22	4.18	4.00	4.06	3.99	4.22	4.29
Nov.	4.20	4.17	3.94	3.95	3.89	4.10	4.12
Dec.	4.17	4.15	3.94	3.94	3.86	3.87	4.02

Note: New England: CT,NH,MA,ME,RI,VT; Central Atlantic: DE,NJ,NY,MD,PA;
Lower Atlantic: GA,FL,NC,SC,VA,WV; Rocky Mountain: MT,ID,WY,UT,CO;
Midwest: MI,OH,KY,TN,IN,MN,IL,WI,IA,MO,ND,SD,NE,KS,OK
Gulf Coast: NM,TX,AR,LA,MS,AL; West Coast: WA,OR,NV,CA,AZ.
Source: EIA. http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_w.htm

Table 3-2. Statistic Summary for Regional Diesel Prices from 2000 to 2015 (quarterly) in the U.S. ($/gallon)

	New England	Central Atlantic	Lower Atlantic	Midwest	Gulf Coast	Rocky Mountain	West Coast
Minimum	1.29	1.27	1.13	1.13	1.12	1.13	1.22
Maximum	4.86	4.86	4.71	4.63	4.68	4.69	4.85
Difference	3.57	3.60	3.58	3.50	3.56	3.56	3.63

Note: New England: CT,NH,MA,ME,RI,VT; Central Atlantic: DE,NJ,NY,MD,PA;
Lower Atlantic: GA,FL,NC,SC,VA,WV; Rocky Mountain: MT,ID,WY,UT,CO;
Midwest: MI,OH,KY,TN,IN,MN,IL,WI,IA,MO,ND,SD,NE,KS,OK
Gulf Coast: NM,TX,AR,LA,MS,AL; West Coast: WA,OR,NV,CA,AZ.
Source: EIA. http://www.eia.gov/dnav/pet/PET_PRI_GND_A_EPD2D_PTE_DPGAL_M.htm

Table 3-3. Diesel Price Scenarios Constructed

Base (0)	Scenario Name										
	+1.2	+0.8	+0.4	-0.4	-0.8	-1.2	-1.6	-2.0	-2.4	-2.8	-3.2
2012	Base+ 1.20	Base+ 0.80	Base+ 0.40	Base- 0.40	Base- 0.80	Base- 1.20	Base- 1.60	Base- 2.00	Base- 2.40	Base- 2.80	Base- 3.20

3.4.2 Data Summary Analysis

For each diesel price scenario, the MilkOrdIII model yields regional price differentials for five classes of raw milk and we derive prices for milk components[35], across multiple districts. The model solution also yields optimal shipping distances which are averaged across component cases. For each class of raw milk flowing into a manufacturing region by quarter, the milk assembling distances are calculated as a weighted average of incoming shipment distances by expression 3.1.

$$AssemblingDistance_{jc}{}^{*} = \frac{\sum_i [Distance_{ij} \times \sum_y \sum_t (Q_{ijcyt}^{GAMoved^*} + QM_{{i^{sp}}_{jcyt}}^{SupplyPlant^*})]}{\sum_i \sum_y \sum_t (Q_{ijcyt}^{GAMoved^*} + QM_{{i^{sp}}_{jcyt}}^{SupplyPlant^*})} \quad (3.1)$$

Where $AssemblingDistance_{jc}{}^{*}$ is the optimal weighted average distance for the c^{th} class of Grade A milk shipped to the j^{th} processing region; $Distance_{ij}$ denotes the distance between i^{th} and the j^{th} place[36].

Table 3-4 summarizes the data used to regress price differentials of the five milk classes on the independent variables diesel prices and milk assembling distances. The statistical data description for milk component price modeling is in table 3-5.

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[35] Refer to section 2.8.1

[36] Refer to section 2 for other notations.

Table 3-4. Statistical Summary for Raw Milk Price Modeling

Variable	# of obs.	Mean	St.Dev.	Min	Max
ClassI_Distance	2,172	131.994	227.12	0	1221.276
ClassII_Distance	2,172	106.928	185.802	0	1217.662
ClassIII_Distance	2,172	49.92	149.164	0	1405.993
ClassIV_Distance	2,172	20.046	82.779	0	920.853
ClassIO_Distance	2,172	160.964	268.416	0	1315.335
ClassIO_DieselPrice	2,172	1.809	1.784	0	5.37
ClassI_DieselPrice	2,172	2.485	1.659	0	5.435
ClassII_DieselPrice	2,172	2.192	1.773	0	5.435
ClassIII_DieselPrice	2,172	1.157	1.574	0	5.435
ClassIV_DieselPrice	2,172	0.595	1.299	0	5.435
ClassIO_Price	2,172	1.341	1.681	0	10.445
ClassI_Price	2,172	2.077	1.316	0	8.83
ClassII_Price	2,172	1.502	1.364	0	9.396
ClassIII_Price	2,172	0.362	0.474	0	2.099
ClassIV_Price	2,172	0.305	0.712	0	5.97

Table 3-5. Statistical Summary for Milk Component Price Modeling

Variable	# of obs.	Mean	St.Dev.	Min	Max
Butterfat_Price	2,158	0.997	1.226	0	5.923
Protein_Price	2,158	0.804	1.003	0	6.26
OtherSNF[37]_Price	2,158	0.117	0.495	0	6.696
Distance	2,158	94.511	122.487	0	731.674
Diesel_Price	2,158	1.654	1.087	0.1320	5.3700

3.4.1 Econometric Model

Pooling all scenario data together, the model specification assumes a relationship between diesel prices and the model generated price differentials. This is estimates for each class of raw milk usage and for the milk components:

$$y_{sjk} = \alpha_k DP_{sjk} + \beta_k DIS_{sjk} + \gamma DP_{sjk} \times DIS_{sjk} + c_{jk} + e_{sjk} \quad (3.2)$$

$$z_{sjk} = DP_{sjk} \times DIS_{sjk} \quad (3.3)$$

---

[37] SNF denotes solids non-fat

Where $s \in S$ represents the 12 diesel price scenarios; j: the NASS districts; y_{sjk} the model generated price differentials for class or component k of milk that change across j , $s\ and\ k$, calculated by averaging the results of expression (2.8.5), or price differentials of milk component obtained from expression (2.8.8); DP_{sjk}: the regional diesel price for class or component k of milk in scenarios s region j; DIS_{sjk}: the optimal assembling distances for class or component k of milk as they vary by district j and diesel price scenario s, which were calculated by expression (3.1); $DP_{sjk} \times DIS_{sjk}$ is the interaction term of diesel price and distance, shortly denoted by z_{sjk}; α_k, β_k and γ_k: unknown parameters to be estimated; c_{jk} is time-invariant unobserved effect; e_{sjk} is the error term that is assumed independent and identically distributed (iid).

The fixed effects model is applied to do panel regression. The reason we choose the fixed effects model is that it relaxes the strict assumption that the individual effect is independent of the included covariates as the random effects model does (McCarl, Villavicencio, and Wu 2008). Then fixed effect transformation is applied on equation (3.2) by firstly defining:

$$\bar{y}_{jk} = \frac{\sum_s y_{sjk}}{S}, \overline{DP}_{jk} = \frac{\sum_s DP_{sjk}}{S}, \overline{DIS}_{jk} = \frac{\sum_s DIS_{sjk}}{S}, \bar{z}_{jk} = \frac{\sum_s z_{sjk}}{S}, \bar{e}_{jk} = \frac{\sum_s e_{sjk}}{S} \quad (3.4)$$

Then subtracting the unit averages in (3.4) from each observation, and plugging the results into (3.2), we get:

$$\ddot{y}_{sjk} = \alpha_k \ddot{DP}_{sjk} + \beta_k \ddot{DIS}_{sjk} + \gamma_k \ddot{z}_{sjk} + \ddot{e}_{sjk} \quad (3.5)$$

where $\ddot{y}_{sjk} = y_{sjk} - \bar{y}_{jk}$, $\ddot{DP}_{sjk} = DIS_{sjk} - \overline{DP}_{jk}$, $\ddot{z}_{sjk} = z_{sjk} - \bar{z}_{jk}$, $\ddot{e}_{sjk} = e_{sjk} - \bar{e}_{jk}$. Under this transformation, time-invariant terms are not included in equation (3.5), and we will estimate equation (3.5) by pooled OLS.

3.4.2 Results

We treat the data as a standard panel data set and proceed to regress the model specification given in expression 3.2 in a fixed effects model. The estimates of the parameters for different classes of milk are presented in table 3-6, and most of the parameters are statistically significant at the 1 % level. The price differentials estimations show that the “diesel price” affects the differentials for all classes of milk through a significant positive coefficient, and the parameter of the interaction term between diesel price and assembling distance is also positive and significant at 1% level. This suggests that holding distance variable constant, a higher diesel price increases the ideal price differentials. To be specific, using the average assembling distance as an example, for Class I milk, the effect of one unit of higher diesel price could increase all price differentials on average by \$0.31/cwt.; while for Class II the increase would be \$0.25/cwt.; for Class III an increase of \$0.10/cwt.; for Class IV, \$0.16; and for Class IO, \$0.26. For the variable “distance”, its positive (negative) signs indicate an increasing (decreasing) effect on the differentials. Plus the effects of the interaction term, a shift toward longer distance would uniformly increase Class IO and IV price differentials; It will also increase Class I price differential if the diesel price is higher than \$1.50/gallon; decrease the Class II price differential if the diesel price is below \$3.00/gallon, and decrease the Class III price differential if the diesel price is below \$8.00/gallon. These regression results indicate that price differentials are significantly affected by diesel price and higher diesel price tends to increase the differentials.

Table 3-6. Panel Model Estimations for Price Differentials of Milk Classes

	Dependent Variable:				
Independent Variable:	ClassIO_Price	ClassI_Price	ClassII_Price	ClassIII_Price	ClassIV_Price
Diesel_Price	0.1926***	0.2807***	0.2317***	0.0910***	0.1541***
	(0.0084)	(0.0033)	(0.0038)	(0.0016)	(0.0050)
Distance	0.0025***	-0.0003*	-0.0006***	-0.0008***	0.0008**
	(0.0003)	(0.0001)	(0.0001)	(0.0000)	(0.0003)
Diesel_Price:Distance	0.0004***	0.0002***	0.0002***	0.0001***	0.0003***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
R-Squared	0.5554	0.8761	0.7901	0.7161	0.5131
Adjusted R-Squared	0.5145	0.8647	0.7708	0.6900	0.4683
F Statistic (df = 3; 1988)	827.824	4686.234	2494.234	1671.837	698.285

Significant level: * p<0.1, ** p<0.05, *** p<0.01

Table 3-7 shows the estimation results with the dependent variables being the milk component prices. The variable “diesel price” affects the prices for butterfat and other solids non-fat by a significant negative coefficient, and exhibits a positive coefficient for protein price; the estimate of the interaction term between diesel price and assembling distance is only significant for other solids non-fat price with a positive sign. This suggests that holding distance variable constant, a higher amount of diesel price on national average, decreases price differential of butterfat by \$0.37/cwt.; increase protein price differentials by \$0.21/cwt.; and decrease the price differentials for other solids non-fat if the milk moving distance is below 357.50 miles. The coefficient of the variable “distance” is positive for butterfat price indicating an increasing effect on its price differential, and negative for protein price differential. The results indicate that diesel price would exert important impacts on component price differentials and higher diesel price tends to decrease the price differential for butterfat and other solids non-fat, and increase the protein price differential.

Table 3-7. Panel Model Estimations for Price Differentials of Milk

	Dependent Variable:		
Independent Variable:	Butterfat_Price	Protein_Price	OtherSNF_Price
Diesel_Price	-0.3736***	0.2113***	-0.0716***
	(0.0352)	(0.0312)	(0.0158)
Distance	0.0040***	-0.0010**	-0.0002
	(0.0004)	(0.0003)	(0.0002)
Diesel_Price:Distance	0.00001	-0.00003	0.0002*
	(0.0002)	(0.0002)	(0.0001)
R-Squared	0.1896	0.0378	0.0098
Adjusted R-Squared	0.1843	0.0315	0.0033
F Statistic (df = 3; 1988)	167.1316	28.0670	7.0678

Significant level: * $p<0.1$, ** $p<0.05$, *** $p<0.01$

3.5 Conclusions and Discussion

This chapter reported on an examination of the effects of diesel price on idealized price differentials for classes of raw milk use and milk components (butterfat, protein and other solids non-fat). The ideal price differentials examined are those generated from the MilkOrdIII model described in section 2.

We first do an analysis comparing differentials generated under 2012 diesel prices with those generated under 2000 prices and find that diesel price changes exerts an significant impact on Class I price differentials with the ideal 2012 differentials being more than 26% higher than those under 2000 diesel prices.

We also investigate the quantitative relationship between the diesel price changes and the model generated price differentials. To do this the model was run with 12 alternative diesel prices with ideal differentials formed for each milk class and component. Then we pooled the data on the differentials, diesel prices and milk movement distances into a panel dataset for each class/component. Afterwards a fixed effects panel econometric model is applied to explore a relationship between differentials and diesel price. The estimation results show that price differentials are significantly affected by diesel price, and higher diesel prices increase the differentials for classes of raw milk; decrease the price differentials for butterfat and other solids non-fat, and increase the protein price differentials. The resultant function could possibly be used to update the differentials as diesel prices vary.

This study has several limitations: firstly, the price differentials for different classes of raw milk and milk components are generated from the MilkOrdIII model, and as stated in last section the model could be improved from some aspects, such as being updated with endogenous prices, and incorporating more on international trade.

Therefore, a further improved model would help the estimation of transportation cost effects on price differentials to reflect more realistic insights and provide informed suggestions for policy-makers. Next, due to the limit of data available, information about differences in the transportation routes, such as average speed, would help the model better represent the transportation situations.

4 U.S. AGRICULTURE UNDER CLIMATE: AN EXAMINATION OF CLIMATE CHANGE EFFECTS ON MILK PRODUCTION

4.1 Introduction

Climate influences agricultural production and is projected to change in the future with a likely global temperature increase of 0.3 - 4.8℃ by 2100, along with more frequent, intense and long-lasting extreme climate events plus more weather variability (IPCC 2013). Agriculture faces climate effects directly through changes in temperatures, rainfall, carbon dioxide, and extreme events, and indirectly through alterations in pest, pathogen, and weed incidence, plus shifts in product demand (Parry et al. 2007; IPCC 2013; Kumar 2016).

Livestock are an important part of agriculture, providing food and income (Rojas-Downing et al. 2017). Additionally population and income growth are expected to increase demand for livestock products. Alexandratos and Bruinsma (2012) project that world meat production will increase by more than 76% between 2006 and 2050 and milk production by 63%. Livestock value is also large with for example the cash value of US livestock commodities over $100 billion a year[38].

Understanding climate implications for livestock production is attracting attention from researchers (e.g., Goodland and Anhang 2009; Thornton et al. 2009). Climate impacts livestock performance though drought, floods and heat waves, which directly reduce yields and water availability, while increasing vulnerability to disease. Climate also affects quantity and quality of

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[38] Source: https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-agriculture-and-food-supply_.html

feed, and needed treatments for animal health, among other effects[39]. St-Pierre, Cobanov, and Schnitkey (2003) estimate that climate variation induces losses in the livestock industry with them amounting on average to about $2.02 billion per year, with the dairy industry being the most affected (about 60% of the total). In 2006, heat stress caused an estimated billion dollar economic loss for California dairy farmers (Nardone et al. 2010).

In this chapter, we estimate climate impacts on milk production using an econometric panel data approach. Panel data models have been commonly applied to analyze the impacts of climate on crop yields (Chen, McCarl, and Schimmelpfennig 2004; Schlenker, Hanemann, and Fisher 2006; Villavicencio et al. 2013; Attavanich and McCarl 2014). Blanc and Schlenker (2017) pointed out that panel models are good for such estimations as they have the advantage in accounting for omitted variables. For example, fixed effects models can avoid omitted variable bias caused by regionally specific time invariant factors (such as soil features and socio-economic status). However, time-varying regional characteristics could still bias fixed effects estimations. For example, omitting consideration of climate linked relative humidity and wind exposure could bias the estimation results (Hsiang and Narita 2012). In fact, Zhang, Zhang, and Chen (2017) indicate that ignoring wind speed can lead to underestimates of climate effects on crop yields. Since it's impossible to include all climate variables due to data limitations and we know climatic factors are usually correlated across regions, Auffhammer et al. (2013) argues that model estimations can be improved by taking spatial dependence into account.

This essay reports on a study using spatial panel models to estimate climate effects on milk yields. Several studies have already applied spatial panel models to explore the climate

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[39] https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-agriculture-and-food-supply_.html

effects on crop yields, such as Spatial Error Model (SEM) in the paper of Schlenker, Hanemann, and Fisher (2006), and Spatial Durbin Model (SDM) in Ortiz-Bobea (2015) and Wang, McCarl, and Wu (2017). Here we hypothesize that the use of spatial models will help alleviate biases due to spatially correlated omitted variables and test whether the spatial model improves goodness of fit.

4.2 Literature review

Climate change effects on agricultural productivity have been widely studied (Mendelsohn and Neumann 2004; Jones et al. 2007). changes in temperature, precipitation and carbon dioxide concentration can directly influence milk production and at the same time exert indirect effects by influencing such things as crop production, pasture availability, water supply, and animal health (Hill and Wall 2015). In this review, we will summarize related studies in two categories: first we will look at studies on the influence of heat stress and other climatic factors on productivity. Second we will review the methods used to estimate the quantitative effects of climate change.

4.2.1 The Effects of Heat Stress on Productivity

For livestock, the zone of thermal comfort (ZTC), which identifies optimal environmental conditions, plays an important role in production and reproduction (National Research Council 1981). When temperature exceeds the upper limit of that comfort range, livestock experience heat stress and degraded performance (Klinedinst et al. 1993). West (2003) pointed out that dairy cows are especially sensitive to heat stress exhibiting reduced feed intake, increased water intake (consequently threatening water supply), decreased meat and milk production, and altered birth rates (Lacetera et al. 2003). At the same time, high producing cows emit more metabolic heat than low-producing ones lowering production and potentially raising a need to alter breeds (Rojas-Downing et al. 2017). Ravagnolo, Misztal, and Hoogenboom (2000) suggested that one unit increase of heat stress index might lead to about 0.2 kg milk loss per day from a base of 26.3. Based on climate data between 1871 and 1932, although under the optimum heat abatement intensity[40], the annual average economic losses for dairy were simulated to be $897 million (St-Pierre, Cobanov, and Schnitkey 2003).

The majority of scientific studies indicate heat stress arises from the combination of temperature, air movement, and humidity (e.g., Bohmanova, Misztal, and Cole 2007). A number of indices for depicting heat stress this have been developed. The Temperature Humidity Index (THI), which takes air temperature and humidity into account, is the most commonly used index (e.g., Igono, Bjotvedt, and Sanford-Crane 1992; Mayer et al. 1999). There are several alternative formulas for calculating THI (Thom 1959; Bianca 1962; National Research Council 1971; Yousef 1985; Mader, Davis, and Brown-Brandl 2006; Gantner et al. 2011). The basic factors included are based follow Thom (1959)[41] and include dew point temperature, wet bulb temperature, relative humidity, wind speed, solar radiation and water vapor (Mader, Johnson, and Gaughan 2010). The major difference in the formulas involve the way that they integrate humidity. Beside the minimum and maximum values of THI, a U shaped curve is expected with the threshold level identifying the value above which heat stress starts to diminish productivity. This threshold has been identified to fall in the range from 64 to 86, with a THI value of 72 being the most common value (e.g., Reiczigel et al. 2009; Brügemann et al. 2009). Since high-producing cows are more sensitive, Renaudeau et al. (2012) argue milk yield might be

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[40] In the paper of St-Pierre, Cobanov, and Schnitkey (2003), the optimum heat abatement is defined as the greatest gain in revenues from heat abatement after subtracting the costs of that heat abatement system.

[41] An index for air humidity.

decreasing beginning at a THI threshold of 68 or lower. (Hammami et al. 2013) argue that THI has disadvantages as it 1) is an empirical index and should be adjusted with the changes of circumstance; 2) is not a uniform indicator of sensitivity for all breeds and that differential sensitivity needs to be explored; and 3) that other weather factors affecting dairy cows are not incorporated into this index.

Equivalent Temperature Index (ETI) is an alternative heat stress indicator and incorporates wind velocity, temperature, and humidity with come arguing that this is better in tropical regions (Baeta et al. 1987; Silva, Morais, and Guilhermino 2007). Gaughan et al. (2008) advance a heat load index (HLI), which adds more climate factors such as black globe temperature and wind speed, and they developed different thresholds for multiple genotypes.

Other indices exist, for example, the environmental stress index (ESI) combines fast response weather factors – ambient temperature, relative humidity, and solar radiation with Moran et al. (2001) arguing this is reliable and valid "especially in transient conditions". There is also the comprehensive climate index (CCI) that Mader, Johnson, and Gaughan (2010) argued fits a wide range of weather conditions.

4.2.2 Economic Analysis on Climate Effects

Economic approaches for climate change effect assessments have been categorized into structural and spatial analogue approaches (Adams et al. 1998). Structural modelling approaches incorporate models from different disciplines to simulate the implications of climate change. There are basically three steps for structural modelling: firstly, earth system models (ESMs) also known as global circulation models (GCMs) are applied to forecast changes in climate (such as temperature, precipitation, etc.) under different greenhouse gas concentration scenarios (e.g., Adams et al. 1995). Second one uses biophysical models to simulate the effects of climate projections on changes in agricultural production as done in the case of milk production by (West, 2003; and Mader, 2009). Third, the potential changes in production are integrated into economic models of agriculture to estimate the changes in welfare and market conditions. The economics models involved in this evaluation commonly aim to minimize costs (e.g., McCarl and Spreen 1997) or maximize social welfare of suppliers and consumers (Beach and McCarl 2010).

In contrast, a spatial analogue model relies on historical data for climate and production and then uses those data to examine the relationship between climate and production. Econometric approaches are then used (e.g., Tobey 1992; Mendelsohn and Neumann 2004). However, in doing this omitted variables can cause issues and generally results from limited data availability (Schlenker, Hanemann, and Fisher 2005). As a consequence panel models which to some extent deal with omitted variables, have commonly been used (Chen, McCarl, and Schimmelpfennig 2004; Villavicencio et al. 2013; Chen, McCarl, and Schimmelpfennig 2004; Schlenker and Roberts 2006; Deschênes and Greenstone 2007; McCarl, Villavicencio, and Wu 2008; Schlenker and Roberts 2009; Miao, Khanna, and Huang 2016; Blanc and Schlenker 2017).

As an additional refinement spatial panel models can be employed to deal with omitted variables that cause spatial correlation, as for example wind speed, drought incidence, humidity, and storm incidence are influenced by climate and have common effects over space (Auffhammer et al. 2013). A few spatial models have been applied in estimating climate change impacts. Schlenker, Hanemann, and Fisher (2006) estimated climate change effects on farmland value using a model that accounted for possible spatial correlation in the error terms under the assumption that the error terms were independent of the explanatory variables (that spatial error model (SEM)); Zouabi and Peridy (2015) used the spatial durbin model (SDM) that allowed correlation of the latent variables with the observed ones in a panel dataset on agricultural production finding the SDM model to perform the best. Wang, McCarl, and Wu (2017) compared performance across conventional panel, SEM and SDM models concluding that the SDM exhibited the best out of sample performance.

With respect to climate change and milk production, a few studies have used econometric analysis to examine productivity relationships with heat stress indicators. Mukherjee, Bravo-Ureta, and De Vries (2012) included the (THI or ETI) heat stress indices to explore the impacts of climate on south-eastern U.S. milk yield, and they found that both THI and ETI had a significant non-linear negative effect on milk yield. Key and Sneeringer (2014) did their work on the national level, and then predicted the future production change (in 2030) with potential climate change obtained from four versions of Global Circulation Models (GCMs) finding with no market adjustment, the nationally economic loss of heat stress induced for dairy industry in 2030 is \$79 to \$199 million (valued at 2010 prices).

4.3 Model and Data

4.3.1 Model Specification

A number of Models are employed in this paper to analyze the effects of climate on milk production. These include panel models without spatial interaction, which are the pooled OLS model, fixed effects model; and spatial panel models - Spatial Error Model (SEM) and Spatial Durbin Model (SDM).

A standard panel model without spatial correlation effects can be expressed as below[42]:

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[42] Refer to http://agecon2.tamu.edu/people/faculty/wu-ximing/agecon2/public/agec661/note9.pdf

$$y_{it} = x_{it}\beta + c_i + \mu_{it} \text{ (4.1)}$$

where y_{it} is the milk production per cow for year $t = 1, \dots, T$ in region $i = 1, \dots, N$; x_{it} is a vector of independent variables including climate elements that changes across region and year; c_i is unobserved state effect, which is assumed to be constant across time; μ_{it} is idiosyncratic error changing across time and regions, that are identically distributed disturbances (iid). Pooled OLS estimation is consistent if the region-specific effect c_i is not correlated with x_{it}. And another estimation method used in this paper is fixed effects estimation where the unobserved region effects can be correlated with x_{it} arbitrarily.

In panel modeling, omitted variables are a common issue of concern (LeSage 2008). In the context of climate change and agriculture, omitted variables tend to have spatial interactions, such as solar radiation and wind speed might affect milk production but are not generally available for the time and spatial dimensions needed and exert common influences across regions.

There are two representative cases to consider the spatial correlation for omitted variables (LeSage 2008; Cook, Hays, and Franzese 2015). Firstly, the omitted covariates are orthogonal to the independent variables but exhibit spatial dependence (SEM). That is, based on $y_{it} = x_{it}\beta + \mu_{it}$[43](4.2), the assumption is $\mu_{it} = \gamma W \mu_{it} + \varepsilon_{it} = (I_n - \gamma W)^{-1}\varepsilon_{it}$ (4.3), where γ is the spatial dependence parameter; $\boldsymbol{I}_n$ is an identity matrix; W is a spatial weight matrix; ε_{it} is an iid error term. And then equation (4.2) is changed to be: $y_{it} = x_{it}\beta + (I_n - \gamma W)^{-1}\varepsilon_{it}$ (4.4). Secondly, the omitted variables are correlated with the independent variables (SDM), so it assume $\varepsilon_{it} = x_{it}\xi + \nu_{it}$ (4.5), where ξ is the interrelationship coefficient; and ν_{it} is an iid error term. Then inserting (4.5) into (4.4), can obtain:

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[43] In order to simplify the deviation, c_i, the unobserved time-invariant state effect, is not included here.

$$y_{it} = x_{it}\beta + (I_n - \gamma W)^{-1}(x_{it}\xi + \nu_{it})$$

$$y_{it} = x_{it}\beta + (I_n - \gamma W)^{-1}x_{it}\xi + (I_n - \gamma W)^{-1}\nu_{it}$$

$$(I_n - \gamma W)y_{it} = x_{it}(\beta + \xi) + Wx_{it}(-\gamma\beta) + \nu_{it}$$

$$y_{it} = \gamma W y_{it} + x_{it}(\beta + \xi) + Wx_{it}(-\gamma\beta) + \nu_{it} \quad (4.6)$$

Let $\tau = \beta + \xi, \varphi = -\gamma\beta$

$$y_{it} = \gamma W y_{it} + x_{it}\tau + Wx_{it}\varphi + \nu_{it} \quad (4.7)$$

Equation (4.7) is the expression of SDM and it shows that the SDM includes both the spatially lagged dependent variable and the independent variables. When $\xi = 0$ in equation (4.5) SDM is converted to be SEM.

A unifying specification encompassing all of these cases is:

$$y_{it} = \alpha + \rho W y_{jt} + x_{it}\beta + Wx_{it}\theta + c_i + \mu_{it} \quad (4.8)$$

$$\mu_{it} = \lambda W \mu_{it} + \varepsilon_{it}$$

Where W is a spatial weight matrix; ρ, θ, λ are spatial correlation parameters; ε_{it} is idiosyncratic error. If ρ and θ are all equal zero, the model reduces to the SEM one and the spatial interaction across regions is only in the error term, noted by $\lambda W \mu_{it}$, which means that milk production in one region could also be affected by unobserved factors in neighboring regions. If $\lambda = 0$, the model is SDM and β and θ are coefficients implying the direct and indirect effects of the independent variables. If ρ, λ, and θ are all equal zero, equation (4.8) is reduced to be common panel model without spatial interaction.

The spatial weight matrix applied in this study reflects regional proximity with the elements being zero for non-neighboring states and having equal weight for each of the neighboring region (each of n neighboring regions has a weight of $1/n$). And we use queen criterion to figure out whether spatial units share a boundary or not[44]. As shown in figure 4-1, based on the queen criterion, for the region at the center (the dashed square cell in the figure below), its neighbors are the ones sharing a common edge with it, and also the square cells with common vertices.

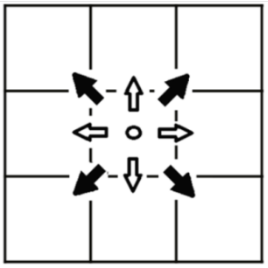

Figure 4-1. The Queen Criterion of Defining Neighborhood for Weight Matrix

4.3.2 Data

The influences of climate change on milk production will be analyzed with and without spatial interactions using state level data. This will be done through econometric estimation of panel models with the dependent variable being milk production per cow, and the explanatory variables being state level value of the palmer modified drought index (PMDI), annual precipitation (pcpn), and annual maximum and minimum THI. We use an annual data set for 48 contiguous US states for the years from 1924 to 2016. This results in a total of 4464 observations and a balanced panel dataset. Statistics computed over the data are in table 4-1.

Data sources and manipulations are as follows:

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[44] Refer to: https://spatial.uchicago.edu/geoda

Historical milk production: annual milk production per cow data used here are drawn from United States Department of Agriculture's National Agricultural Statistics Service (USDA NASS) Quick Stats database[45], measured in pounds per head during each year (lb/head) (figure 4-2).

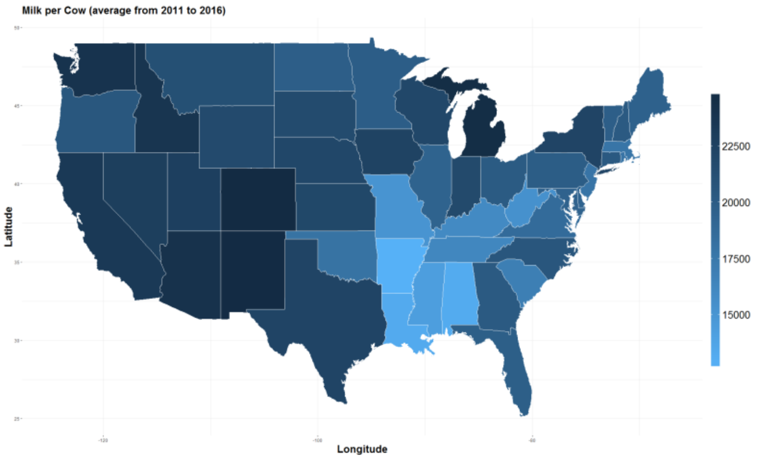

Figure 4-2. Milk per Cow (lb/head), average from 2011 to 2016

Historical climatic data: monthly palmer modified drought index (PMDI), precipitation, and maximum and minimum temperature by state are drawn from National Oceanic and Atmospheric Administration (NOAA), formerly the National Climatic Data Center (NCDC)[46]. These data are drawn seasonally (summer-June to August, spring-March to May, and winter-December to February). Taking the summer as an example, the summer PMDI and temperature are average values of June, July, and August; and summer precipitation data are the summation of the amounts across the summer months. The PMDI includes a weighted average of the wet and dry index terms, using the probability as the weighting factor (Heddinghaus and Sabol 1991). A PMDI value in the range 0 to -0.5 indicates normal; one in -0.5 to -1.0 indicates slight

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[45] Refer to: https://quickstats.nass.usda.gov/

[46] Refer to: https://www1.ncdc.noaa.gov/pub/data/cirs/climdiv/

drought; one in -1.0 to -2.0 denotes mild drought; in -2.0 to -3.0 denotes moderate drought; -3.0 to -4.0 denotes severe drought; and greater than -4.0 extreme drought. On the contrary, the higher the positive value of PMDI is, the wetter the climate is.

Seasonal maximum and minimum temperature data are used to calculated maximum and minimum THI[47] (Mayer et al. 1999; Mader 2003; Amundson et al. 2006), so temperature is not incorporated as an independent variable. Temperature is measured in degree Celsius, and precipitation is measured in inches. In this section, the models use the data from 1924-2010 to do the regression and reserve the data from 2011-2015 for out-of-sample forecasting.

Table 4-1. Statistical Summary for Historical Data (1924-2016)

Variable		Obs.	Minimum	Maximum	1.Quartile	3.Quartile	Mean	Median	Variance	Stdev
Logarithm of Milk per Cow	logmpc	4464	3.33	4.41	3.72	4.16	3.94	3.97	0.07	0.26
Summer PMDI	sm_pmdi	4464	-8.67	9.39	-1.55	1.70	0.04	0.10	5.62	2.37
Summer Precipitation	sm_pcpn	4464	0.14	28.79	6.70	13.27	10.18	10.48	23.72	4.87
Summer Max THI	sm_thimax	4464	64.54	92.49	71.18	78.88	75.21	74.80	23.26	4.82
Summer Min THI	sm_thimin	4464	50.71	68.11	55.94	61.52	58.77	58.56	13.79	3.71
Winter PMDI	wt_pmdi	4464	-6.53	7.93	-1.12	1.36	0.09	0.17	3.64	1.91
Winter Precipitation	wt_pcpn	4464	0.54	27.96	3.65	11.20	8.09	7.92	24.46	4.95
Winter Max THI	wt_thimax	4464	34.55	68.61	46.05	54.01	50.06	49.17	31.29	5.59
Winter Min THI	wt_thimin	4464	26.64	55.61	37.69	44.09	41.01	40.95	21.51	4.64
Spring PMDI	sp_pmdi	4464	-7.45	8.85	-1.41	1.44	0.00	-0.03	4.52	2.13
Spring Precipitation	sp_pcpn	4464	0.32	31.05	6.39	12.30	9.52	9.40	19.03	4.36
Spring Max THI	sp_thimax	4464	50.31	75.79	56.54	64.50	60.73	59.75	27.23	5.22
Spring Min THI	sp_thimin	4464	40.92	61.06	45.67	51.09	48.66	48.09	14.49	3.81

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[47] $THI = 0.8 \times T + [(\%\, RelativeHumidity/100) \times (T - 14.4)] + 46.4$

Where T is temperature in ℃, and $\%\, RelativeHumidity = 6.1121 \times \exp[\left(18.678 - \frac{T}{234.5}\right) \times \left(\frac{T}{257.14+T}\right)]$

Figure 4-3 below shows the national average distributions of seasonal climate factors and milk production per cow by year. From this figure, we could see that the climatic variables exhibit significant fluctuation with a general increasing trend in many. We also see milk per cow is increasing over time. Hence, a linear and a quadratic time trend are added into the model structure as independent variables. As stated by McCarl, Villavicencio, and Wu (2008), the time trend is added to capture "the effect of technological progress with the possibility of decreasing marginal returns". At the same time, the dependent variable – milk production per cow is transformed into logarithmic values (Mauldon 1962; Mosheim 2012), which may stabilize the variance of the data (Luetkepohl and Xu 2009). This means one unit of change in the independent variable results in a constant percentage change in milk production per cow holding all other independent variables constant.

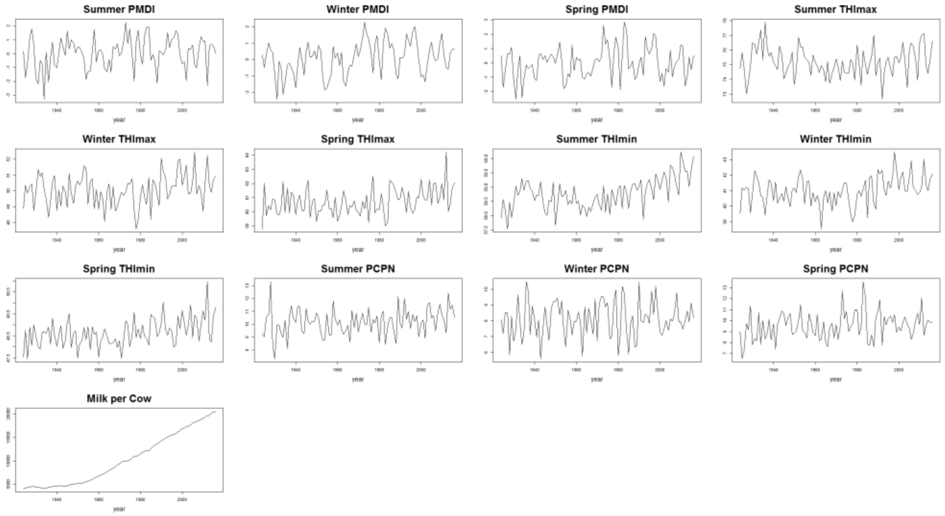

Figure 4-3. Data Plots cross Timeline

The projected climate conditions: the projected climate change in temperature and precipitation are drawn from Representative Concentration Pathway 8.5 (RCP 8.5) emission scenario[48] which is the worst case for climate change from runs of the Beijing Climate Center Climate System Model (BCC_CSM 1.1)[49] for 2030[50]. And table 4-2 calculates the statistics of the projected climatic data in 2030.

Table 4-2. Statistical Summary for Projected Climatic Data (2030)

Variable	Minimum	Mean	Maximum	1.Quartile	Median	3.Quartile	Stdev
Summer PMDI	-2.28	-0.61	0.94	-1.16	-0.53	-0.08	0.79
Summer Precipitation	1.00	7.05	13.87	4.92	7.17	9.20	3.09
Summer Max THI	72.25	80.79	91.13	76.14	80.85	84.74	4.98
Summer Min THI	52.22	60.93	67.62	58.18	61.01	64.13	4.21
Spring PMDI	-2.03	-0.18	1.11	-0.45	-0.10	0.13	0.64
Spring Precipitation	1.72	8.18	13.61	5.96	8.31	10.52	2.90
Spring Max THI	55.31	62.53	75.21	57.85	60.94	66.78	5.42
Spring Min THI	43.88	49.51	59.35	46.79	49.11	51.33	3.60
Winter PMDI	-1.81	0.09	2.41	-0.64	0.33	0.62	0.87
Winter Precipitation	0.74	7.84	17.86	3.10	8.32	10.14	4.55
Winter Max THI	41.01	52.16	69.92	47.64	50.98	55.95	6.14
Winter Min THI	32.51	42.41	56.44	38.79	42.52	45.33	5.18

4.4 Estimation Results

Estimations were done using a conventional OLS, a panel regression model and the SEM and SDM spatial panel models. We describe the results of the OLS model and panel fixed effects models first, then test for the existence of spatial correlation, and finally present the results from the spatial panel models.

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[48] RCP8.5 corresponds to the pathway with the highest greenhouse gas emissions, and refer to http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html

[49] Refer to http://forecast.bcccsm.ncc-cma.net/web/channel-43.htm

[50] Source: https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html

4.4.1 Panel Model Results without Spatial Interaction

The first step to estimate the climatic effects is to use regular panel models - the pooled OLS model and fixed effects model. All of the climatic variables and their quadratic terms are included in both of the models. The consequent fixed effects model results shows smaller absolute values for the climate effects than does the OLS approach, indicating not considering regional fixed effects overstates the impact of climate. This likely occurs since the fixed effects by state capture some of the effect differences. The results are summarized in table 4-3, and most of the terms for the climatic variables express a U shaped effect on milk production with a significant quadratic term. For example the summer maximum THI has an inverse U-shaped relationship with milk production, with a peak in the range of (68,72) meaning below or above that milk production increases. This is generally consistent with findings from previous research (e.g. Renaudeau et al. 2012).

In order to determine which model exhibits better performance, we use the standard F test[51] to examine whether there are significant state-specific effects. The hypothesis of no state-specific, fixed panel effect is rejected at the 1% level of significance. Thus the fixed effects model is preferred and there are fixed terms in each state likely from omitted variables.

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[51] Refer to: http://home.iitk.ac.in/~shalab/econometrics/Chapter12-Econometrics-TestsforStructuralChangeandStability.pdf

Table 4-3. Pooled OLS and Fixed Effects Model Results

Variable	Pooled OLS		Fixed Effects	
spring_pmdi	0.0023	*	-0.0034	***
	(-0.0012)		(-0.0011)	
spring_pmdi2	0.0015	***	0.0008	***
	(-0.0003)		(-0.0002)	
summer_pmdi	-0.0021	**	-0.0012	
	(-0.0008)		(-0.001)	
summer_pmdi2	-0.0007	***	0.0000	
	(-0.0002)		(-0.0002)	
winter_pmdi	0.0013		0.0054	***
	(-0.0012)		(-0.0011)	
winter_pmdi2	-0.0017	***	-0.0012	***
	(-0.0003)		(-0.0002)	
spring_pcpn	-0.012	***	-0.0079	***
	(-0.0013)		(-0.0014)	
spring_pcpn2	0.0003	***	0.0003	***
	(0.0000)		(0.0000)	
summer_pcpn	-0.0213	***	-0.0054	***
	(-0.0013		(-0.0017)	
summer_pcpn2	0.0007	***	0.0001	
	(0.0000)		(-0.0001)	
winter_pcpn	0.0029	***	-0.0045	***
	(-0.0009)		(-0.0011)	
winter_pcpn2	-0.0002	***	0.0001	***
	(0.0000)		(0.0000)	
spring_thimax	-0.1028	***	-0.0479	***
	(-0.0132)		(-0.0122)	
spring_thimax2	0.0008	***	0.0003	***
	(-0.0001)		(-0.0001)	
spring_thimin	0.1916	***	0.0713	***
	(-0.0198)		(-0.0199)	
spring_thimin2	-0.0018	***	-0.0007	***
	(-0.0002)		(-0.0002)	
summer_thimax	-0.0602	***	0.056	***
	(-0.0094)		(-0.011)	
summer_thimax2	0.0003	***	-0.0004	***
	(-0.0001)		(-0.0001)	
summer_thimin	0.2316	***	-0.0517	**
	(-0.016)		(-0.0261)	
summer_thimin2	-0.0019	***	0.0004	*
	(-0.0001)		(-0.0002)	

Table 4-3. Pooled OLS and Fixed Effects Model Results (Continued)

Variable	Pooled OLS		Fixed Effects	
winter_thimax	-0.0590	***	0.0271	**
	(-0.0112)		(-0.012)	
winter_thimax2	0.0006	***	-0.0003	**
	(-0.0001)		(-0.0001)	
winter_thimin	0.0665	***	-0.0236	**
	(-0.0114)		(-0.0117)	
winter_thimin2	-0.0008	***	0.0003	*
	(-0.0001)		(-0.0001)	
T1	0.0054	***	0.0051	***
	(-0.0003)		(-0.0002)	
T2	0.0000	***	0.0000	***
	(0.0000)		(0.0000)	
Constant	-2.0936	***	2.9803	***
	(-0.3082)		(-0.6512)	
R-squared	0.9323		0.9499	

The asterisks represents the probability that the coefficient differs from 0 and * notes significance at 10% level, ** at 5%, and *** at 1%.

4.4.2 Spatial Panel Model Results

Before showing the estimation results arising from the spatial panel models, we apply Pesaran's CD test (Pesaran 2004; 2015) to examine whether there is spatial dependence in the error terms. To do this we examine the cross-sectional dependence in residuals from the fixed effects model, which might arise from the spatial interaction of omitted climate factors. In particular if cross-state dependence is found this means, the estimators from the conventional panel models will be inefficient and that spatial models may be appropriate. This test operates under the null hypothesis of no cross-regional dependence and that hypothesis is rejected at the 1% significance level. Hence, it is appropriate to move on to use spatial panel models to estimate the climate effects on milk production.

Table 4-4 presents the estimation results using the SEM and SDM spatial models. Both models use the same basic set of independent variables. Spatially lagged independent variables are also included in the SDM and the results are reported.

The spatial parameter λ[52] estimated from SEM is 0.80 and significant at 1% level, which indicates strong and significant spatial dependence. This is reasonable evidence that the spatial model fits better than the conventional panel models in explaining climatic impacts on milk production. The possible reason for this finding might due to the spatial interaction effects of the omitted variables, and the effects of one state's climatic variables also could change the milk production of the states around.

The spatial effects that bleed over from other states could be quantified by multiplying λ with their corresponding weights. The coefficients generated from SEM are smaller than those from the fixed effects model, although the estimation for maximum THI in summer and its quadratic term exhibit a greater change.

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[52] The spatial parameter reported from SEM estimation is based on the notation in equation (4.8)

Table 4-4. SEM and SDM Estimation Results

Variable	SEM		SDM	
spring_pmdi	-0.0009		-0.0007	
	(-0.0010)		(-0.0010)	
spring_pmdi2	0.0000		-0.0001	
	(-0.0002)		(-0.0002)	
summer_pmdi	0.0008		0.0009	
	(-0.0008)		(-0.0008)	
summer_pmdi2	0.0000		0.0000	
	(-0.0001)		(-0.0001)	
winter_pmdi	-0.0001		-0.0005	
	(-0.0010)		(-0.0010)	
winter_pmdi2	-0.0002)		-0.0001	
	(-0.0002)		(-0.0002)	
spring_pcpn	-0.0033	***	-0.0026	**
	(-0.0011)		(-0.0011)	
spring_pcpn2	0.0001	***	0.0001	**
	(0.0000)		(0.0000)	
summer_pcpn	0.0007		0.0016	
	(-0.0012)		(-0.0012)	
summer_pcpn2	0.0000		0.0000	
	(0.0000)		(0.0000)	
winter_pcpn	-0.0015		-0.0012	
	(-0.0009)		(-0.0010)	
winter_pcpn2	0.0000		0.0000	
	(0.0000)		(0.0000)	
spring_thimax	-0.0212	**	-0.0160	
	(-0.0108)		(-0.0115)	
spring_thimax2	0.0002	*	0.0001	
	(-0.0001)		(-0.0001)	
spring_thimin	0.0093		0.0003	
	(-0.0180)		(-0.0196)	
spring_thimin2	-0.0001		0.0000	
	(-0.0002)		(-0.0002)	
summer_thimax	-0.0191	*	-0.0312	***
	(-0.0100)		(-0.0108)	
summer_thimax2	0.0001	**	0.0002	***
	(-0.0001)		(-0.0001)	
summer_thimin	0.0185		0.0428	*
	(-0.0240)		(-0.0253)	
summer_thimin2	-0.0002		-0.0004	**
	(-0.0002)		(-0.0002)	

Table 4-4. SEM and SDM Estimation Results (Continued)

Variable	SEM		SDM	
winter_thimax	-0.0172		-0.0283	**
	(-0.0111)		(-0.0120)	
winter_thimax2	0.0001		0.0002	**
	(-0.0001)		(-0.0001)	
winter_thimin	0.0217	**	0.0343	***
	(-0.0106)		(-0.0114)	
winter_thimin2	-0.0002	*	-0.0004	***
	(-0.0001)		(-0.0001)	
T1	0.0065	***	0.0012	***
	(-0.0006)		(-0.0001)	
T2	0.0000	***	0.0000	***
	(0.0000)		(0.0000)	
Spatial				
λ	0.7973	***		
	(-0.0083)			
ρ			0.7714	***
			(-0.0088)	
Wx				
spring_pmdi			-0.0005	
			(-0.0013)	
spring_pmdi2			0.0005	**
			(-0.0003)	
summer_pmdi			-0.0016	
			(-0.0011)	
summer_pmdi2			0.0000	
			(-0.0002)	
winter_pmdi			0.0025	**
			(-0.0013)	
winter_pmdi2			-0.0005	**
			(-0.0003)	
spring_pcpn			-0.0003	
			(-0.0016)	
spring_pcpn2			0.0000	
			(-0.0001)	
summer_pcpn			-0.0028	
			(-0.0019)	
summer_pcpn2			0.0000	
			(-0.0001)	

Table 4-4. SEM and SDM Estimation Results (Continued)

Variable	SEM	SDM	
winter_pcpn		-0.0013	
		(-0.0014)	
winter_pcpn2		0.0001	
		(0.0000)	
spring_thimax		-0.0012	
		(-0.016)	
spring_thimax2		0.0000	
		(-0.0001)	
spring_thimin		0.0373	
		(-0.0274)	
spring_thimin2		-0.0004	
		(-0.0003)	
summer_thimax		0.0777	***
		(-0.0143)	
summer_thimax2		-0.0005	***
		(-0.0001)	
summer_thimin		-0.0847	**
		(-0.0336)	
summer_thimin2		0.0008	***
		(-0.0003)	
winter_thimax		0.0486	***
		(-0.0163)	
winter_thimax2		-0.0004	***
		(-0.0002)	
winter_thimin		-0.0540	***
		(-0.0161)	
winter_thimin2		0.0006	***
		(-0.0002)	
R-squared	0.8983	0.9029	

The asterisks represents the probability that the coefficient differs from 0 and * notes significance at 10% level, ** at 5%, and *** at 1%.

Furthermore, the SDM as opposed to the SEM takes into account of the correlation between the omitted variables and the explanatory variables. This allows the estimated impacts of climatic variables on milk production to be decomposed into direct and indirect transmitted spatial effects (table 4-5). For a state, the direct effects come from the effects of independent variables in that state, and the indirect ones from the spatial spillover effects arising from adjacent states (Elhorst 2017). As described by (LeSage 2008), one of the important motivations to use spatial panel models is the existence of omitted variables. The inclusion of the direct and spatial indirect effects in essence, expands the panel model to include the effects from the neighboring regions. Following the derivation in (LeSage 2008) and Sarrias' lecture notes[53], $\boldsymbol{S}_r$ is used to denote the spatial effect matrix for the rth set of independent variables. The spatial direct effect is the averages from the diagonal elements of this matrix, and the total effect is the average of the summed effects across the row (or rows), and the indirect effect is equal to the total effect minus direct effect.

Compared to the SEM estimation results, more climatic variables are found to exert significant effects on milk production in the SDM estimation results. In particular the effects of the maximum summer THI and its quadratic term exhibit the same sign as in the fixed effects panel model but have greater absolute values. Similarly they are larger than those found when estimating with the SEM. This importantly implies a climate effect on milk production. Also summer maximum THI's estimation obtained from SDM verifies the finding in other literatures that there is a threshold of THI and after that milk production would decrease resulting from the increase of THI (Renaudeau et al. 2012; Hammami et al. 2013). In our estimated model this occurs at a THI level of 72. Furthermore, the indirect effect of summer maximum THI from the spatial omitted variables makes the effect even greater. However, the unobserved attribution of omitted variables prevent a proper explanation for indirect effect here (Wang, McCarl, and Wu 2017). Moreover, the figure 4-4 in the following draws effect curves of climate factors on milk production per cow using data falling in the range of historical observations.

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[53] Source: https://msarrias.weebly.com/uploads/3/7/7/8/37783629/lecture2.pdf .
Derivation is in Appendix B

The plot in the upper left of represents the total effects of summer maximum THI and its quadratic term on milk production per cow, assuming other independent variables are constant. And in order to display their relationship more intuitively, we use the volumes of milk production per cow as y-axis instead of its logarithm transformation applied in model estimation, and use the values of summer maximum THI starting from 72 as x-axis since a THI value of 72 is the mostly asserted common threshold value for the decline of milk production (Bohmanova, Misztal, and Cole 2007) and about 70% of the summer maximum THI in observed for all regions are greater than 72. The figure shows the inverse-U shape effect for summer maximum THI on milk production per cow. And after the value of 72, higher the THI is lower the milk production would be.

Meanwhile, the effects of other climatic factors on milk production per cow are also displayed in figure 4-4. The upper right plot shows the total effects of winter maximum THI and its quadratic term; the lower left is for spring precipitation; the lower right for winter PMDI. All these charts use values of milk yield per cow as y-axis, with assumption of other variables are constant. In detail, for winter maximum THI is again an important influencer of milk production. The relationship again shows a pattern of increasing and decreasing production levels with a threshold of around 55, and more than 75% of the data observed across regions are lower than 55. Hence the increase in winter maximum THI tends to increase milk production at an increasing rate. Spring precipitation effects also exhibit such an inverse shape, and the figure shows a threshold that occurs at 15 inches of precipitation, which is greater than the majority of the observations. Generally the spring precipitation exerts decreasing effect on milk production with the values below 15. And the study of Stull et al. (2008) found that precipitation negatively affected milk per cow in California, and this effect was stronger for farms that house cattle outside without shelter. The total effect of winter PMDI is positive meaning a move toward wetter conditions increases at a increasing rate. And as to the PMDI values (including 80% of the observations) lower than its critical value of 1.5, milk production per cow would increase with higher the PMDI value is (that is, wetter the climate is).

Table 4-5. Direct and Indirect Effects of Climate Variables from SDM

			SDM			
Variable	Direct		Indirect		Total	
spring_pmdi	-0.0010		-0.0039		-0.0050	
	(0.0010)		(0.0035)		(0.0037)	
spring_pmdi2	0.0001		0.0019	**	0.0019	**
	(0.0002)		(0.0008)		(0.0009)	
summer_pmdi	0.0006		-0.0035		-0.0029	
	(0.0008)		(0.0035)		(0.0038)	
summer_pmdi2	0.0001		0.0004		0.0005	
	(0.0001)		(0.0005)		(0.0006)	
winter_pmdi	0.0002		0.0082	***	0.0084	**
	(0.0009)		(0.0032)		(0.0033)	
winter_pmdi2	-0.0003		-0.0026	***	-0.0029	***
	(0.0002)		(0.0008)		(0.0008)	
spring_pcpn	-0.0035	***	-0.0092	*	-0.0127	**
	(0.0011)		(0.0050)		(0.0052)	
spring_pcpn2	0.0001	***	0.0003	**	0.0004	**
	(0.0000)		(0.0002)		(0.0002)	
summer_pcpn	0.0010		-0.0066		-0.0056	
	(0.0013)		(0.0062)		(0.0068)	
summer_pcpn2	0.0000		-0.0001		-0.0001	
	(0.0000)		(0.0002)		(0.0002)	
winter_pcpn	-0.0021	**	-0.0091	**	-0.0111	***
	(0.0009)		(0.0040)		(0.0043)	
winter_pcpn2	0.0001	**	0.0003	**	0.0004	**
	(0.0000)		(0.0002)		(0.0002)	
spring_thimax	-0.0214	*	-0.0525		-0.0740	
	(0.0110)		(0.0435)		(0.0455)	
spring_thimax2	0.0002	*	0.0004		0.0005	
	(0.0001)		(0.0004)		(0.0004)	
spring_thimin	0.0139		0.1464	**	0.1602	**
	(0.0178)		(0.0701)		(0.0725)	
spring_thimin2	-0.0001		-0.0015	**	-0.0016	**
	(0.0002)		(0.0007)		(0.0007)	

Table 4-5. Direct and Indirect Effects of Climate Variables from SDM (Continued)

	SDM					
Variable	Direct		Indirect		Total	
summer_thimax	-0.0099		0.2141	***	0.2043	***
	(-0.0102)		(-0.0359)		(-0.0377)	
summer_thimax2	0.0001		-0.0015	***	-0.0014	***
	(-0.0001)		(-0.0002)		(-0.0002)	
summer_thimin	0.0219		-0.2033	**	-0.1814	**
	(-0.0236)		(-0.0796)		(-0.0824)	
summer_thimin2	-0.0002		0.0018	***	0.0016	**
	(-0.0002)		(-0.0007)		(-0.0007)	
winter_thimax	-0.0190	*	0.1042	**	0.0852	**
	(-0.0115)		(-0.0421)		(-0.0427)	
winter_thimax2	0.0002		-0.0010	**	-0.0008	**
	(-0.0001)		(-0.0004)		(-0.0004)	
winter_thimin	0.0244	**	-0.1081	***	-0.0837	**
	(-0.0107)		(-0.0421)		(-0.0425)	
winter_thimin2	-0.0002	*	0.0012	**	0.0010	*
	(-0.0001)		(-0.0005)		(-0.0005)	
T1	0.0015	***	0.0037	***	0.0052	***
	(-0.0002)		(-0.0004)		(-0.0006)	
T2	0.0000	***	0.0000	***	0.0000	***
	(0.0000)		(0.0000)		(0.0000)	

The asterisks represents the probability that the coefficient differs from 0 and * notes significance at 10% level, ** at 5%, and *** at 1%.

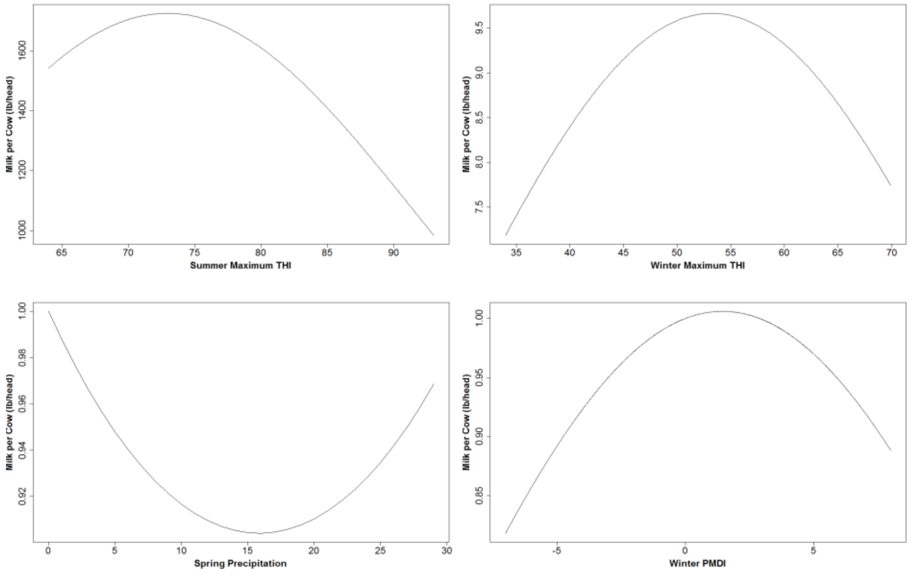

Figure 4-4. Relationship between Milk Production per Cow and Climatic Factors

Based on SDM estimation in table 4-4 and climatic projection of 2030, we will project the changes of milk production per cow across US. States. First of all, since there is no predicted PMDI data available, here we did a fixed effects panel regression of PMDI on precipitation, maximum temperature and minimum temperature using historical climate data. The results are reported in table 4-6, and we applied within transformation[54] to estimate fixed effects model and consequently time-invariant terms are not included. Then we do a projection of PMDI in 2030 using the estimated parameters in table 4-6. Secondly, integrating the predicted climate data in 2030 and SDM estimation in table 4-4, we project the milk production per cow in 2030. Then the growth rate[55] of milk production per cow is calculated by state based on the milk production in 2016. In figure 4-5, we can see the states in the West and Northeast would show increases of milk production, especially for Rhode Island (39.10%), New Jersey (36.50%), Washington (21.70%). On the other side, the decreasing states are concentrated in the Mid-west and South. And North Dakota (-28.30%), South Dakota (-24.30%), Nebraska (-26.30%) would experience relatively higher production declines

Table 4-6. Estimation Results for PMDI

	Dependent Variable: PMDI
Independent Variable:	
Precipitation	0.4686***
	(0.0059)
Max. Temperature	-0.1458***
	(0.0054)
Min. Temperature	0.1399***
	(0.0062)
R-Squared	0.152
F(47, 70221) = 125.760	

Significant level: * p<0.1, ** p<0.05, *** p<0.01

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[54] Refer to http://agecon2.tamu.edu/people/faculty/wu-ximing/agecon2/public/agec661/note10.pdf

[55] The growth rate is calculated by $\frac{Milk\ Prodcution\ per\ Cow\ in\ 2030 - Milk\ Production\ per\ Cow\ in\ 2016}{Milk\ Production\ per\ Cow\ in\ 2016}$ for each state

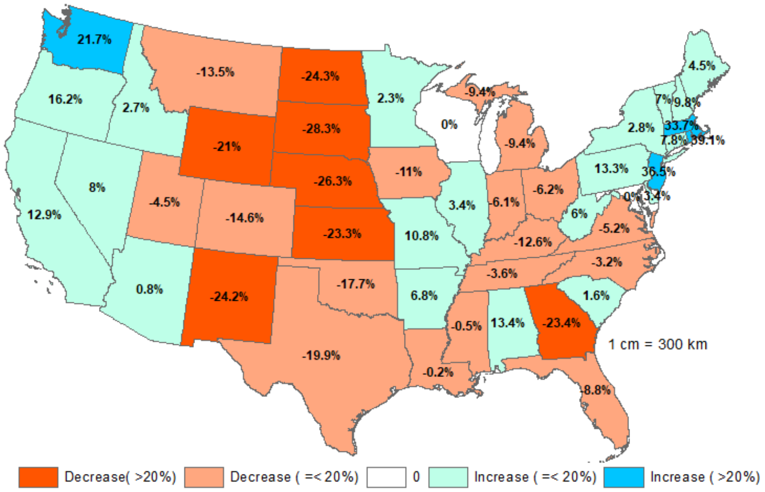

Figure 4-5. Annual Milk Production Growth Rate in U.S. States
(comparing 2030 projections with 2016 observations)

Now we turn to test the performance of the estimated models. To do this the data from 2011 to 2015 are used to do out-of-sample forecasting, and the resultant root-mean-square error (RMSE) is compared. The out-of-sample RMSEs for the fixed effects model, the SEM and the SDM are respectively 0.112, 0.085, and 0.086, which indicates that as to forecasting ability, SEM and SDM is more precise than fixed effects model with relatively smaller out-of-sample RMSEs.

Next, we statistically test the parameters which differentiate the panel, SEM and SDM models using the Wald test:

Firstly, test whether the spatial dependence (λ) factor in SEM is significantly different from zero, and if not the SEM will be equivalent to fixed effects model. The null hypothesis that spatial correlation factor is equal zero is rejected at 1% confidence level and SEM performs better than the fixed effects model;

Secondly, based on the equation 4.6 and 4.7 in model specification, we find that SDM is equal to SEM if $\xi = 0$ (not directly estimated), so equation $\varphi + \gamma\tau = 0$ is tested by the Wald test when $\xi = 0$ and then $\tau = \beta$. The null hypothesis is rejected at the 1% significance level, which indicates the SDM is preferred to the SEM model and that it is important to incorporate the correlation between the independent variables and the latent variables.

4.5 Conclusions and Discussion

This chapter reported on an effort to estimate the effects of climate on milk production econometrically using alternative econometric panel models including ones that include spatial considerations. In our study we found that the SDM model fits the best and will discuss climate results only for that model.

We find a number of things about climate effects on milk productivity. We find milk production is strongly influenced by summer maximum THI, an important measure of heat stress. The relationship shows an inverse U-shaped relationship with maximum THI values above a critical value of 72 leading to declining milk production and those below it showing increasing milk production as THI increases. This result also agrees with the findings of others in the literature, namely that there is a threshold of THI and after that milk production would decrease (Renaudeau et al. 2012). We also find winter maximum THI and a winter drought index (PMDI) also have an inverse-U shape effect on milk production with a threshold of 55 and 1.5 respectively. We find below these threshold values, the higher the winter maximum THI or the wetter the climate is, milk production increases while it declines above the thresholds. On the other hand, we find that spring precipitation shows a conventional U shape with more rain having a decreasing effect on milk production below a threshold of 15 inches and an increasing effect thereafter. However we note that we had few observations above 15 inches so are not confident in the estimation above the threshold.

We also examine future projected climate change effects on milk production, based on SDM estimation and an RCP 8.0 climatic projection in 2030. The result show that climate change would influence milk production with per cow rates in the West and Northeast increasing, but with decreases in the Mid-West and South.

On the methodological side we used several forms of panel models in an effort to improve model fit and projections. Examining the results of the estimations we find the fixed effects model is preferred to the pooled OLS as it captures the time-invariant fixed regional effects. We then find including spatial dependence via the Spatial Error Model (SEM) yet further improves performance indicating a strong effect across space of unobserved omitted but spatially correlated variables. Finally when we find that the Spatial Durbin Model (SDM) exhibits yet better performance indicating there is a degree of correlation between the omitted and independent variables. Additionally, we find the SDM model shows better forecasting accuracy with a smaller out-of-sample RMSE compared with the fixed effects and SEM models and thus feel use of spatial panel models is important in future work as in better inclusion of correlated omitted variables.

There are several limitations in this study: firstly, the spatial panel models used to investigate the effect of climate change on milk production could only reduce but can not eliminate the bias caused by spatial correlation of omitted variables. Therefore, in subsequent research, better model specifications including more of the omitted climate related variables needs to be explored. Secondly, due to the limitation of data availability, some important climatic factors, such as solar radiation which is strong correlated with temperature (Sheehy, Mitchell, and Ferrer 2006), in turn affecting milk production, have not been included in econometric models and perhaps richer data sets should be employed.

5 SUMMARY AND CONCLUSIONS

This dissertation investigates several economic issues regarding to the US dairy industry by examining three aspects:

- The match between the current FMMO price differentials and an ideal model generated set, plus the pattern exhibited by the model generated spatial price surfaces for butterfat, protein and other solids non-fat.
- The effects of shifting diesel price on price differentials of different milk classes and milk components and the possible development of a formula to update the differentials as diesel prices change.
- The effects of climate on milk production considering spatial correlation and the projected effect of future climate change.

5.1 Summary and Conclusions

Essay 1 examines how the present Class I price differentials under Federal Milk Marketing Orders compare to an idealized set generated from the MilkOrdIII model. Price surfaces are also explored for other milk classes (organic, Class II-IV) and raw milk components (butterfat, protein, and other solids non-fat). The MilkOrdIII model used in this essay is a spatial, mathematical programming model of the US dairy industry considering milk component differences for raw milk. At the same time, we also examine the effect of including raw milk components on the price differential surface relative to a model version that assumes all milk is homogeneous.

Results of our work show the idealized Class I price differentials generated from the MilkOrdIII model, are distributed in a pattern that is similar to the currently used Class I price differentials implemented by the FMMO. However, we find the range and variance of the model generated differentials are substantially larger than those under the current policy. These results suggest that the current Class I price differentials might be updated to better reflect the regional situations in dairy industry.

We find the idealized differentials from the model exhibit regional differences for organic- Class IO, and Class II to IV milk, with them being most significant for Class IO and Class II, IV. This implies that it may be desirable to also have regionalized differentials for Class IO, Class II and Class IV milk. On the other hand, we find the price differentials of Class III milk show are fairly uniform across the U.S. which is consistent with current uniform Class III price policy.

We also estimate price surfaces for butterfat, protein and other solids non-fat. To discover the surface we regress model generated milk values for raw milk of varying composition across space on their component makeup. This gives us estimates of the relative contribution to raw milk prices of marginal alterations in butterfat, protein, and other solids non-fat. Then for every region, we multiply the component prices obtained by their regional average percentages in one unit of milk across milk class and type to obtain a price for the component present in one unit of milk. The results show the butterfat price surface exhibits a relatively more diverse spatial pattern and that it might be ideal to set up different spatial-prices for butterfat. For protein, most of the agricultural districts have a similar price as do those for solids non-fat, prices, implying a uniform price by region would be suitable.

Essay 2 explores the effects of diesel prices on ideal model generated price differentials of raw milk and milk components. We find the shift in diesel prices from 2012 to 2000 level has significantly increased the ideal differentials namely with them increasing by an average of 26%. We then proceed to develop a formula relating diesel prices to ideal price differentials. We do this by solving the MilkOrdIII model under 12 diesel price scenarios and forming a data set of differentials then using that data set in a regression exercise to see how diesel price changes influence the differentials. This is done using a fixed effects panel model. The results show that price differentials are significantly affected by diesel price, and higher diesel price tends to increase the differentials for raw milk; but decrease those for butterfat and other solids non-fat, while increasing protein differentials. We feel the resultant formula could possibly be used to update the differentials.

Essay 3 examines climate impacts on milk production to both get an estimate of the size of current climate impacts and enable future climate change related projections. The relationship between climate and milk production is examined using panel models.

We find a number of things about climate effects on milk productivity. We find milk production is strongly influenced by summer maximum THI, an important measure of heat stress. The relationship shows an inverse U-shaped relationship with maximum THI values above a critical value of 72 leading to declining milk production and those below it showing increasing milk production as THI increases. This result also agrees with the findings of others in the literature, namely that there is a threshold of THI and after that milk production would decrease (Renaudeau et al. 2012). We also find winter maximum THI and a winter drought index (PMDI) also have an inverse-U shape effect on milk production with a threshold of 55 and 1.5 respectively. We find below these threshold values, the higher the winter maximum THI or the wetter the climate is, milk production increases while it declines above the thresholds. On the other hand, we find that spring precipitation shows a conventional U shape with more rain having a decreasing effect on milk production below a threshold of 15 inches and an increasing effect thereafter. However we note that we had few observations above 15 inches so are not confident in the estimation above the threshold.

We also examine future projected climate change effects on milk production, based on SDM estimation and an RCP 8.0 climatic projection in 2030. The result show that climate change would influence milk production with per cow rates in the West and Northeast increasing, but with decreases in the Mid-West and South.

On the methodological side we find that more complex models fit better with the fixed effects model preferred to the pooled OLS and the Spatial Error Model (SEM) yet further improving performance with the Spatial Durbin Model (SDM) being the best yet. Thus we feel use of spatial panel models is important in future work as in better inclusion of correlated omitted variables.

5.2 Limitations and Future Research

There are several limitations in this dissertation that could be improved in future research.

In essay 1, we assume that capacity volumes of the processing plants and per capita consumption of dairy products are constant nationally and seasonally and we set up the MilkOrderIII model fixed production and consumption volumes. Hence, future study might alter capacity seasonally and use supply and demand curves for raw milk and products.

In essay 2, the price differentials used in the econometric estimation are generated from the MilkOrdIII model. However, the model could be enhanced, in turn resulting in better estimates of the effects of diesel prices on price differentials. Moreover, the econometric model does not take account of information about transportation routes, such as different geographic characteristics, and this should be considered in future studies.

In essay 3, the spatial panel models used to investigate the effect of climate change on milk production can only reduce but not eliminate the bias caused by spatial correlation of omitted variables. Therefore, in subsequent research, better model specifications need to be explored and tested. Secondly, due to data availability, some important climatic factors affecting milk production, such as solar radiation which are strongly correlated with temperature (Sheehy, Mitchell, and Ferrer 2006), were not included in econometric model. In future studies a richer set of climatic data could be included.

REFERENCES

Adams, R. M., B. H. Hurd, S. Lenhart, and N. Leary. 1998. “Effects of Global Climate Change on Agriculture: An Interpretative Review.” *Climate Research* 11 (1): 19–30.

Alexandratos, N., and J. Bruinsma. 2012. “World Agriculture towards 2030/2050: The 2012 Revision.” ESA Working paper Rome, FAO.

Ahn, B.I. and D.A. Sumner. 2009. “Political Market Power Reflected in Milk Pricing Regulations.” *American Journal of Agricultural Economics* 91(3): 723–737.

Amundson, J. L., T. L. Mader, R. J. Rasby, and Q. S. Hu. 2006. “Environmental Effects on Pregnancy Rate in Beef Cattle 1.” *Journal of Animal Science* 84 (12): 3415–3420.

Attavanich, W., and B. A. McCarl. 2014. “How Is CO 2 Affecting Yields and Technological Progress? A Statistical Analysis.” *Climatic Change* 124 (4): 747–762.

Auffhammer, M., S. M. Hsiang, W. Schlenker, and A. Sobel. 2013. “Using Weather Data and Climate Model Output in Economic Analyses of Climate Change.” *Review of Environmental Economics and Policy* 7 (2): 181–98. https://doi.org/10.1093/reep/ret016.

Balagtas, J.V., A. Smith, and D.A. Sumner. 2007. “Effects of Milk Marketing Order Regulation on the Share of Fluid-grade Milk in the United States.” *American Journal of Agricultural Economics* 89(4): 839–851.

Baker, T.G., P. Dixit, and B.A. McCarl. 1981. “Documentation and Use of a Computer Software Package for Simulation of Optimal Investment in Dairy Processing.” Purdue University Agr. Exp. Sta. Bull. No. 345.

Beach, R. H., and B. A. McCarl. 2010. “US Agricultural and Forestry Impacts of the Energy Independence and Security Act: FASOM Results and Model Description.” *Research Triangle Park, NC: RTI International*.

Bianca, W. 1962. “Relative Importance of Dry-and Wet-Bulb Temperatures in Causing Heat Stress in Cattle.” *Nature* 195: 251–252.

Blanc, E., and W. Schlenker. 2017. “The Use of Panel Models in Assessments of Climate Impacts on Agriculture.” *Review of Environmental Economics and Policy* 11 (2): 258–279.

Bohmanova, J., I. Misztal, and J. B. Cole. 2007. “Temperature-Humidity Indices as Indicators of Milk Production Losses Due to Heat Stress.” *Journal of Dairy Science* 90 (4): 1947–56. https://doi.org/10.3168/jds.2006-513.

Capps, Jr., O., and P. Sherwell. 2007. “Alternative Approaches in Detecting Asymmetry in Farm-Retail Price Transmission of Fluid Milk.” *Agribusiness* 23(3): 313–331.

Chen, C.C., B.A. McCarl, and D.E. Schimmelpfennig. 2004. “Yield Variability as Influenced by Climate: A Statistical Investigation.” *Climatic Change* 66 (1): 239–261.

Chen, C. C., B. A. McCarl, and D. E. Schimmelpfennig. 2004. “Yield Variability as Influenced by Climate: A Statistical Investigation.” *Climatic Change* 66 (1): 239–261.

Chouinard, H. H., D. E. Davis, J. T. LaFrance, and J. M. Perloff. 2010. “Milk Marketing Order Winners and Losers.” *Applied Economic Perspectives and Policy* 32 (1): 59–76.

Christ, P.G. 1980. “An Appraisal of the U.S. Government’ Role in Milk Pricing.” *American Journal of Agricultural Economics* 62(2): 279–287.

Cook, S. J., J. C. Hays, and R. J. Franzese. 2015. “Model Specification and Spatial Interdependence.”

Cox, T.L. and E.V. Jesse. 1995. “Regional Effects of Selected Dairy Options: Dairy IRCM Simulations.” Staff papers 52, Department of Agricultural and Applied Economics, University of Wisconsin-Madison.

Cox, T.L. and J.P. Chavas. 2001. “An Interregional Analysis of Price Discrimination and Domestic Policy Reform in the U.S. Dairy Sector.” *American Journal of Agricultural Economics* 83(1): 89–106.

Dantzig, G.B. 1948. “Programming in a Linear Structure.” Comptroller, USAF, Washington, D.C.

Depetris de Guiguet, E., and J. E. Pratt. 1996. “A Comparative Assessment of the Milk Hauling Sector in the US and Argentina.” *E.B. (USA)*. http://agris.fao.org/agris-search/search.do?recordID=US9711968.

Deschênes, O., and M. Greenstone. 2007. “The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather.” *American Economic Review* 97 (1): 354–85. https://doi.org/10.1257/aer.97.1.354.

Dobson, W.D., and L. Salathe. 1979. "The Effects of Federal Milk Orders on the Economic Performance of U.S. Milk Markets." *American Journal of Agricultural Economics* 61: 213–27.

Elhorst, J. P. 2017. "Spatial Panel Data Analysis." https://spatial-panels.com/wp-content/uploads/2017/07/Elhorst-Spatial-Panel-Data-Analysis-Encyclopedia-GIS-2nd-ed_Working-Paper-Version.pdf.

Enke, S. 1951. “Equilibrium among Spatially Separated Markets: Solution by Electric Analogue.” *Econometrica* 19: 40–47.

French, C.E. and E.W. Kehrberg. 1960. “The Midwest-Eastern Seaboard Conflict of Interest in the Production and Distribution of Milk: The Comparative Advantage Aspects.” *Journal of Farm Economics* 42(5): 1297–1309.

Gallagher, E. W., C. S. Thraen, and G. D. Schnitkey. 1993. “Milk Assembly Costs in the Greater Ohio Area: A Multiproduct Analysis.” *Applied Economic Perspectives and Policy* 15 (1): 75–88. https://doi.org/10.2307/1349713.

Gantner, V., P. Mijić, K. Kuterovac, D. Solić, and R. Gantner. 2011. “Temperature-Humidity Index Values and Their Significance on the Daily Production of Dairy Cattle.” *Mljekarstvo* 61 (1): 56–63.

Gaughan, J. B., T. L. Mader, S. M. Holt, and A. Lisle. 2008. “A New Heat Load Index for Feedlot Cattle.” *Faculty Papers and Publications in Animal Science*, 613.

Goodland, R., and J. Anhang. 2009. “Livestock and Climate Change: What If the Key Actors in Climate Change Are... Cows, Pigs, and Chickens?” *Livestock and Climate Change: What If the Key Actors in Climate Change Are Cows, Pigs, and Chickens?* https://www.cabdirect.org/cabdirect/abstract/20093312389.

Gould, B.W., T.L. Cox, and F. Perali. 1990. “The Demand for Fluid Milk Products in the U.S.: A Demand Systems Approach.” *Western Journal of Agricultural Economics* 15(1):1–12.

Hallberg, M.C., D.E. Hahn, R.W. Stammer, G.J. Elterick, and C.E. Fife. 1978. "Impact of Alternative Federal Milk Order Pricing Policies on the U.S. Dairy Industry." Pennsylvania State Agr. Exp. Sta. Bull. No. 818.

Hamby, D. M. 1994. “A Review of Techniques for Parameter Sensitivity Analysis of Environmental Models.” *Environmental Monitoring and Assessment* 32 (2): 135–54. https://doi.org/10.1007/BF00547132.

Hammami, H., J. Bormann, N. M’hamdi, H. H. Montaldo, and N. Gengler. 2013. “Evaluation of Heat Stress Effects on Production Traits and Somatic Cell Score of Holsteins in a Temperate Environment.” *Journal of Dairy Science* 96 (3): 1844–55. https://doi.org/10.3168/jds.2012-5947.

Heddinghaus, T. R., and P. Sabol. 1991. “A Review of the Palmer Drought Severity Index and Where Do We Go From Here.” In *Proc. 7th Conf. On Applied Climatol, American Meteorological Society*.

Hill, D. L., and E. Wall. 2015. “Dairy Cattle in a Temperate Climate: The Effects of Weather on Milk Yield and Composition Depend on Management.” *Animal* 9 (1): 138–149.

Hsiang, S. M., and D. Narita. 2012. “Adaptation to Cyclone Risk: Evidence from the Global Cross-Section.” *Climate Change Economics* 03 (02): 1250011. https://doi.org/10.1142/S201000781250011X.

IPCC. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. TF Stocker, D. Qin, GK Plattner, et al.Cambridge, NY, Cambridge University Press.

Ippolito, R. A. and R.T. Masson. 1978. “The Social Cost of Government Regulation of Milk.” *Journal of Law and Economics* 21: 33–65.

Jacobson, R. E., and G. F. Fairchild. 1969. “Hauling Costs and Rates in Bulk Milk Assembly.”

Jess, E., and B. Cropp. 2008. “Basic Milk Pricing Concepts for Dairy Farmers.” *Publication A3379, University of Wisconsin-Extension*. http://future.aae.wisc.edu/publications/basic_milk_pricing.pdf.

Jones, P. D., K. E. Trenberth, P. Ambenje, R. Bojariu, D. Easterling, T. Klein, D. Parker, J. Renwick, M. Rusticucci, and B. Soden. 2007. “Observations: Surface and Atmospheric Climate Change.” *Climate Change*, 235–336.

Kawaguchi, T., N. Suzuki, and H.M. Kaiser. 1997. “A Spatial Equilibrium Model for Imperfectly Competitive Milk Market.” *American Journal of Agricultural Economics* 79(3): 851–859.

———. 2001. “Evaluating Class I Differentials in the New Federal Milk Marketing Order System.” *Agribusiness* 17(4): 527–538.

Klinedinst, P. L., D. A. Wilhite, G. L. Hahn, and K. G. Hubbard. 1993. “The Potential Effects of Climate Change on Summer Season Dairy Cattle Milk Production and Reproduction.” *Climatic Change* 23 (1): 21–36. https://doi.org/10.1007/BF01092679.

Kumar, M. 2016. “Impact of Climate Change on Crop Yield and Role of Model for Achieving Food Security.” *Environmental Monitoring and Assessment* 188 (8): 1–14.

Lacetera, N., U. Bernabucci, B. Ronchi, and A. Nardone. 2003. “Physiological and Productive Consequences of Heat Stress. The Case of Dairy Ruminants.” In *Proceedings of the Symposium on Interaction between Climate and Animal Production: EAAP Technical Series*, 7:45–60.

LeSage, J. P. 2008. “An Introduction to Spatial Econometrics.” *Revue d’économie Industrielle,* no. 3: 19–44.

Luetkepohl, H., and F. Xu. 2009. “The Role of the Log Transformation in Forecasting Economic Variables.” CESifo Working Paper Series 2591. CESifo Group Munich. https://econpapers.repec.org/paper/cesceswps/_5f2591.htm.

MacDonald, J., E. O'Donoghue, W. McBride, R. Nehring, C. Sandretto, and R. Mosheim. 2007. Profits, Costs, and the Changing Structure of Dairy Farming. Washington DC: U.S. Department of Agriculture, ERR. 47.

Mader, T. L., L. J. Johnson, and J. B. Gaughan. 2010. “A Comprehensive Index for Assessing Environmental Stress in Animals.” *Journal of Animal Science* 88 (6): 2153–2165.

Mader, T. L. 2003. “Environmental Stress in Confined Beef Cattle.” *Journal of Animal Science* 81 (14_suppl_2): E110–E119.

Mader, T. L., M. S. Davis, and Tami Brown-Brandl. 2006. “Environmental Factors Influencing Heat Stress in Feedlot Cattle.” *Journal of Animal Science* 84 (3): 712–719.

Mauldon, R. G. 1962. “An Econometric Analysis of the Supply of Livestock Products and Demand for Feed Grains.” ISU General Staff Paper 196201010800003000. Iowa State University, Department of Economics. https://econpapers.repec.org/paper/isugenstf/196201010800003012.htm.

Mayer, D. G., T. M. Davison, M. R. McGowan, B. A. Young, A. L. Matschoss, A. B. Hall, P. J. Goodwin, N. N. Jonsson, and J. B. Gaughan. 1999. “Extent and Economic Effect of Heat Loads on Dairy Cattle Production in Australia.” *Australian Veterinary Journal* 77 (12): 804–808.

McCarl, B.A., R.B. Schwart Jr., and J.W. Siebert. 1996. “Converting DAMPS into GAMS.”

McCarl, B.A., X. Villavicencio, and X.M. Wu. 2008. “Climate Change and Future Analysis: Is Stationarity Dying?” *American Journal of Agricultural Economics* 90 (5): 1241–47. https://doi.org/10.1111/j.1467-8276.2008.01211.x.

McCarl, B. A., and T. H. Spreen. 1997. “Applied Mathematical Programming Using Algebraic Systems.” *Cambridge, MA*.

McCarl, B. A., X. Villavicencio, and X. Wu. 2008. “Climate Change and Future Analysis: Is Stationarity Dying?” *American Journal of Agricultural Economics* 90 (5): 1241–1247.

McCarl, B.A., T.H. Spreen. 2011. Applied Mathematical Programming Using Algebraic Systems. Texas: Texas A&M University.

McCarthy, J. J., O. F. Canziani, N. A. Leary, D. J. Dokken, and K. S. White. 2014. *Climate Change 2014–Impacts, Adaptation and Vulnerability: Regional Aspects*. Cambridge University Press.

McDowell, H., A.M. Fleming, and R.E Fallert. 1988. Federal Milk Marketing Orders: An Analysis of Alternative Policies. Wasington DC: U.S. Department of Agriculture, ERS, Agr. Econ. Rep. 598.

McDowell, H., A.M. Fleming, and E Spinelli. 1995. U.S. Milk Markets under Alternative Federal Order Pricing Policies. Washington DC: U.S. Department of Agriculture, ERS, Staff Rep. AGES. 9068.

Mendelsohn, R., and J. E. Neumann. 2004. *The Impact of Climate Change on the United States Economy*. Cambridge University Press.

Miao, R., M. Khanna, and H. Huang. 2016. “Responsiveness of Crop Yield and Acreage to Prices and Climate.” *American Journal of Agricultural Economics* 98 (1): 191–211. https://doi.org/10.1093/ajae/aav025.

Moneta, A., D. Entner, P.O. Hoyer, and A. Coad. 2013. “Causal inference by independent component analysis: theory and applications.” *Oxford Bulletin of Economics and Statistics* 75(5), 705–730.

Moran, D. S., K. B. Pandolf, Y. Shapiro, Y. Heled, Y. Shani, W. T. Mathew, and R. R. Gonzalez. 2001. “An Environmental Stress Index (ESI) as a Substitute for the Wet Bulb Globe Temperature (WBGT).” *Journal of Thermal Biology* 26 (4): 427–431.

Mosheim, R.. 2012. “A Quarterly Econometric Model for Short-Term Forecasting of the U.S. Dairy Industry.” 184305. Technical Bulletins. United States Department of Agriculture, Economic Research Service. https://ideas.repec.org/p/ags/uerstb/184305.html.

Nardone, A., B. Ronchi, N. Lacetera, M. S. Ranieri, and U. Bernabucci. 2010. “Effects of Climate Changes on Animal Production and Sustainability of Livestock Systems.” *Livestock Science* 130 (1): 57–69.

National Research Council. 1971. *A Guide to Environmental Research on Animals*. National Academies.

Newton, J. 2009. “Transportation Analysis for Producer Milk Associated with the Mideast Order (Staff Paper 08-02). 2008: US Dept of Agriculture.” *Agricultural Marketing Service, Dairy Programs, Mideast Marketing Area*.

Novakovic, A.M. 1979. “A Approach to a Model for Analyzing the Spatial Organization of the Northeast Dairy Industry.” Department of Agricultural Economics, Cornell University.

Novakovic, A.M. and J.E. Pratt. 1991. “Geographic Price Relationships under Federal Milk Marketing Orders.” Staff paper 91–8, Department of Agricultural Economics, Cornell University.

Novakovic, A.M. 2009. “Economic History of Dairy Markets.” Paper presented at the 16th Annual National Workshop for Dairy Economists and Policy Analysts, Washington, DC, 24 April.

Ortiz-Bobea, A.. 2015. “The Impacts of Climate Change on US Agriculture: Accounting for Omitted Spatial Dependence in the Hedonic Approach.”

Pesaran, M. H. 2004. “General Diagnostic Tests for Cross Section Dependence in Panels.”

———. 2015. “Testing Weak Cross-Sectional Dependence in Large Panels.” *Econometric Reviews* 34 (6–10): 1089–1117.

Renaudeau, D., A. Collin, S. Yahav, V. De Basilio, J. L. Gourdine, and R. J. Collier. 2012. “Adaptation to Hot Climate and Strategies to Alleviate Heat Stress in Livestock Production.” *Animal* 6 (5): 707–728.

Pratt, J.E., P.M. Bishop, E.M. Erba, A.M. Novakovic, and M.W. Stephenson. 1997. “A Description of the Methods and Data Employed in the U.S. Dairy Sector Simulator, Version 97.3.” Dept. Agr. Econ. Bull. No. 97–9, Cornell University.

Rojas-Downing, M. M., A. P. Nejadhashemi, T. H., and S. A. Woznicki. 2017. “Climate Change and Livestock: Impacts, Adaptation, and Mitigation.” *Climate Risk Management* 16 (Supplement C): 145–63. https://doi.org/10.1016/j.crm.2017.02.001.

Saltelli, A.. 2002. “Sensitivity Analysis for Importance Assessment.” *Risk Analysis* 22 (3): 579–590.

Samuelson, P.A. 1952. “Spatial Price Equilibrium and Linear Programming.” *The American Economic Review* 42(3): 283–303.

Seo, H.S. 2015. “Agricultural Policy Analysis: Considering Policy Measure Updating in Milk Pricing and Crop Insurance.” Ph.D. thesis, Texas A&M University.

Schiek, W.A. 1994. "Regional Impacts of Federal Milk Marketing Order Policy Alternatives." *Agricultural and Resource Economics Review* (23): 207–217.

Schlenker, W., W. M. Hanemann, and A. C. Fisher. 2005. “Will US Agriculture Really Benefit from Global Warming? Accounting for Irrigation in the Hedonic Approach.” *The American Economic Review* 95 (1): 395–406.

———. 2006. “The Impact of Global Warming on US Agriculture: An Econometric Analysis of Optimal Growing Conditions.” *Review of Economics and Statistics* 88 (1): 113–125.

Schlenker, W., and M. J. Roberts. 2006. “Nonlinear Effects of Weather on Corn Yields.” *Applied Economic Perspectives and Policy* 28 (3): 391–98. https://doi.org/10.1111/j.1467-9353.2006.00304.x.

———. 2009. “Nonlinear Temperature Effects Indicate Severe Damages to U.S. Crop Yields under Climate Change.” *Proceedings of the National Academy of Sciences* 106 (37): 15594–98. https://doi.org/10.1073/pnas.0906865106.

Schwarz, G. 1978. "Estimating the Dimension of a Model." The Annals of Statistics 6: 461–464.

Sheehy, J. E., P. L. Mitchell, and A. B. Ferrer. 2006. “Decline in Rice Grain Yields with Temperature: Models and Correlations Can Give Different Estimates.” *Field Crops Research* 98 (2–3): 151–156.

Shields, D.A. 2010. Consolidation and Concentration in the U.S. Dairy Industry. Washington DC: Congressional Research Service Report R41224. Available online at http://nationalaglawcenter.org/wp-content/uploads/assets/crs/R41224.pdf.

Silva, R. G., D. A. E. F. Morais, and M. M. Guilhermino. 2007. “Evaluation of Thermal Stress Indexes for Dairy Cows in Tropical Regions.” *Revista Brasileira de Zootecnia* 36 (4): 1192–1198.

Sims, C. A. 1980. “Macroeconomics and Reality.” *Econometrica: Journal of the Econometric Society* (48): 1–48.

St-Pierre, N. R., B. Cobanov, and G. Schnitkey. 2003. “Economic Losses from Heat Stress by US Livestock Industries.” *Journal of Dairy Science* 86: E52–E77.

Stollsteimer, J.F. 1963. “Fixed Production-Fixed Consumption Models with Processing Introduced.” Interregional Competition Research Methods, Agricultural Policy Institute, North Carolina State University.

Stull, C. L., LL McV Messam, C. A. Collar, N. G. Peterson, A. R. Castillo, B. A. Reed, K. L. Andersen, and W. R. VerBoort. 2008. “Precipitation and Temperature Effects on Mortality and Lactation Parameters of Dairy Cattle in California.” *Journal of Dairy Science* 91 (12): 4579–4591.

Sumner, D.A., J. Medellín-Azuara, and E. Coughlin, 2015. Contributions of the California Dairy Industry to the California Economy. University of California Agricultural Issues Center.

Takayama, T. and G.G. Judge. 1964. “Spatial Equilibrium and Quadratic Programming.” *Journal of Farm Economics* 46(1): 67–93.

Testuri, C.E., R.L. Kilmer, and T. Spreen. 2001. “Seasonality of Class I Price Differential Estimates for the Southeastern United States.” *Journal of Agricultural and Applied Economics* 33(3): 591–604.

Thom, E. C. 1959. “The Discomfort Index.” *Weatherwise* 12 (2): 57–61. https://doi.org/10.1080/00431672.1959.9926960.

Thornton, P. K., J. V. Steeg, A. Notenbaert, and M. Herrero. 2009. “The Impacts of Climate Change on Livestock and Livestock Systems in Developing Countries: A Review of What We Know and What We Need to Know.” *Agricultural Systems* 101 (3): 113–127.

USDA, AMS. “Producer Milk Utilization by Class and by Order - January 2000 - July 2015” https://www.ams.usda.gov/sites/default/files/media/DYFMMOCA%20Table%2011%20Class%20Usage%20by%20Order.pdf

Villavicencio, X., B. A. McCarl, X. Wu, and W. E. Huffman. 2013. “Climate Change Influences on Agricultural Research Productivity.” *Climatic Change* 119 (3–4): 815–824.

Wang, Z., B. A. McCarl, and X. Wu. 2017. “The Impact of Climate Change on Corn Yield: Incorporating Spatial Interrelationships.” *Working Paper*.

Yavuz, F., C. Zulauf, G. Schnitkey, and M. Miranda. 1996. “A Spatial Equilibrium Analysis of Regional Structural Change in the U.S. Dairy Industry.” *Agricultural and Resource Economics Review* 18(4): 693–703.

Yousef, M. K. 1985. *Stress Physiology in Livestock. Volume I. Basic Principles.* CRC press.

Zhang, P., J. Zhang, and M. Chen. 2017. “Economic Impacts of Climate Change on Agriculture: The Importance of Additional Climatic Variables Other than Temperature and

Precipitation.” *Journal of Environmental Economics and Management* 83 (May): 8–31. https://doi.org/10.1016/j.jeem.2016.12.001.

Zouabi, O., and N. Peridy. 2015. “Direct and Indirect Effects of Climate on Agriculture: An Application of a Spatial Panel Data Analysis to Tunisia.” *Climatic Change* 133 (2): 301–320.

APPENDIX A

INPUT-OUTPUT FORMULAS

The input-output formulas depend on the components of raw milk (butterfat, protein, and other solids non-fat). These formulas calculate how many units of raw milk needed to produce one unit of final dairy products, and the volume balance is used to figure out the units of the byproducts produced in their corresponding processes.

Fluid Milk (or Yogurt) Plant

Input: $the\ unit\ of\ raw\ milk = \frac{\%\ butterfat\ of\ cream - \%\ butterfat\ of\ fluid\ milk}{\%\ butterfat\ of\ cream - \%\ butterfat\ of\ raw\ milk}$

Output: 1 unit of fluid milk (or yogurt)

$$the\ units\ of\ cream = the\ units\ of\ raw\ milk - 1$$

Sour Cream Plant

Input: 0.60 unit of raw milk and 0.40 unit of cream

Output: 1 unit of sour cream

Ice Cream Plant

Input:1 unit of ice cream mix[56]

Output: 1 unit of ice cream

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[56] Ice cream mix is the mixture of Class II milk, skim milk, cream, non-fat dry, condense skim powder, dried cheddar cheese whey, dried cottage cheese whey, dried Italian cheese whey, and butter whey, balanced by their components.

Cottage Cheese Plant

Process 1: Make Cottage Cheese

Input: $the\ units\ of\ raw\ milk = \frac{\%fat\ of\ cream - \%fat\ of\ fluid\ milk}{(\%fat\ of\ cream - \%fat\ of raw\ milk)*0.15}$

0.50 unit of cottage cheese dressing[57]

Output: 1 unit of cottage cheese

$$the\ units\ of\ cream = \left[1 - \frac{(\%fat\ of\ cream - \%fat\ of\ fluid\ milk)}{(\%fat\ of\ cream - \%fat\ of raw\ milk)}\right]/0.15$$

$$the\ units\ of\ cottage\ cheese\ whey = the\ units\ of\ raw\ milk - the\ units\ of\ cream - 1$$

Process 2: Dry Whey

Input: $the\ units\ of\ cottage\ cheese\ whey = \frac{\%\ solid\ non{-}fat\ of\ dried\ cottage\ cheese\ whey}{\%\ solid\ non{-}fat\ of\ cottage\ cheese\ whey}$

Output: 1 unit of Dried cottage cheese whey

Cheddar Cheese Plant

Process 1: Make Cheddar Cheese

One unit of milk produces

$$the\ units\ of\ cheese = \frac{(0.93*\%\ butterfat\ of\ raw\ milk + 0.82*\%\ protein\ of\ raw\ milk \times 0.96)\times 1.09}{1 - moisture\ of\ cheese}$$

Input: $\frac{1}{the\ units\ of\ cheese}$ units of raw milk

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[57] Cottage cheese dressing is the mixture of Class II milk, skim milk, cream, non-fat dry, condense skim powder, and butter whey, balanced by their components.

Output: 1 unit of Cheddar Cheese

$$the\ units\ of\ butter\ whey = \frac{(1-0.93)*\%\ butterfat\ of\ raw\ milk}{0.8*\ the\ units\ of\ cheese}$$

$$the\ units\ of\ cheddar\ cheese\ whey = the\ units\ of\ raw\ milk - the\ unit\ of\ butter\ whey - 1$$

Process 2: Dry Whey

Input: $the\ units\ of\ cheddar\ cheese\ whey = \frac{\%\ solid\ non\text{-}fat\ of\ dried\ cheddar\ cheese\ whey}{\%\ solid\ non\text{-}fat\ of\ cheddar\ cheese\ whey}$

Output: 1 unit of dried cheddar cheese whey

Italian Cheese Plant

Process 1: Make Italian Cheese

The units of raw milk are used to produce 1 unit of milk with 2.80% butterfat

$$the\ units\ ofraw\ milk = \frac{\%\ butterfat\ of\ cream - 2.80\%}{(\%\ butterfat\ of\ cream - \%\ butterfat\ ofraw\ milk)}$$

$$the\ unit\ of\ cheese = \frac{(0.82*2.80\%+0.82\times the\ units\ of\ raw\ milk*\%\ protein\ of\ raw\ milk\times 0.95)\times 1.12}{1-moisture\ of\ cheese}$$

Input: $the\ units\ of\ raw\ milk = \frac{the\ units\ ofraw\ milk}{the\ units\ of\ cheese}$

Output: 1 unit of Italian cheese

$$the\ units\ of\ cream = \frac{the\ units\ ofraw\ milk-1}{the\ units\ of\ cheese}$$

$$the\ units\ of\ butter\ whey\ = \frac{(1-0.93)*0.028}{0.8*the\ units\ of\ cheese}$$

$$the\ units\ of\ Italian\ cheese\ whey$$

$$= the\ units\ of\ raw\ milk - the\ units\ of\ butter\ whey - the\ units\ of\ cream - 1$$

Process 2: Dry Whey

Input: $the\ units\ of\ Italian\ cheese\ whey = \frac{\%\ solid\ non{-}fat\ of\ dried\ Italian\ cheese\ whey}{\%\ solid\ non{-}fat\ of\ Italian\ cheese\ whey}$

Output: 1 unit of dried Italian cheese whey

Butter Plant

Process 1: Separate

Input: 1 unit of raw milk

Output: $the\ units\ of\ cream = \frac{\%\ butterfat\ of\ cream}{\%\ butterfat\ of\ raw\ milk}$

$$the\ units\ of\ skim\ milk = 1 - the\ units\ of\ cream$$

Process 2: Make Butter

Input: the units of cream $= \frac{\%\ butterfat\ of\ butter}{\%\ butterfat\ of\ cream} * 1.024,$

Output: 1 unit of butter

$$the\ units\ of\ butter\ milk = the\ units\ of\ cream - 1$$

Process 3: Dry Whey

Input: $the\ units\ of\ butter\ milk\ = \frac{\%\ solid\ non{-}fat\ of\ dried\ butter\ milk}{\%\ solid\ non{-}fat\ of\ butter\ milk}$

Output: 1 unit of dried butter milk

Powder Plant

Process 1: Separate

Input: 1 unit of raw milk

Output: $the\ units\ of\ cream = \frac{\%\ butterfat\ of\ cream}{\%\ butterfat\ of\ raw\ milk}$

$$the\ units\ of\ skim\ milk = 1 - the\ units\ of\ cream$$

Process 2:

Output: 1 unit of condense whole milk

Input: $the\ units\ of\ raw\ milk = \frac{\%\ solid\ non{-}fat\ \ of\ condese\ whole\ milk}{\%\ solid\ non{-}fat\ of\ raw\ milk}$

Output: 1 unit of condense skim milk

Input: $the\ units\ of\ skim\ milk = \frac{\%\ solid\ non{-}fat\ of\ condese\ skim\ milk}{\%\ solid\ non{-}fat\ of\ raw\ milk}$

Output: 1 unit of non-fat dry

Input: $the\ units\ of\ condense\ skim\ milk = \frac{\%\ solid\ non{-}fat\ of\ non{-}fat\ dry}{\%\ solid\ non{-}fat\ of\ condense\ skim\ milk}$

Output: 1 unit of whole powder

Input: $the\ units\ of\ condense\ whole\ milk = \frac{\%\ solid\ non{-}fat\ of\ condese\ whole\ milk}{\%\ solid\ non{-}fat\ of\ whole\ powder}$

APPENDIX B

THE DERIVATION OF DIRECT AND INDIRECT EFFECTS FOR SPATIAL DURBIN MODEL

The following derivation is based on the study of (LeSage 2008) and Sarrias' lecture note[58]. The basic panel model could be $Y = X\beta + \mu = \sum_{r=1}^{K} x_r \beta_r + \mu$, where $x_r = (x_{1r}, x_{2r}, \dots, x_{nr})^T$. And the SEM assumes that the spatial information comes from the unobserved term and it's not correlated with explanatory variables: $\mu = \rho W \mu + \varepsilon$, re-written to be $\mu = (I_n - \rho W)^{-1}\varepsilon$, where I_n identity matrix; ε is error term and $\varepsilon \sim N(0, \sigma_\varepsilon^2 I_n)$; W is spatial weight matrix; ρ is spatial correlation parameter and $\rho \in (0,1)$. Then the model is written to be: $Y = X\beta + (I_n - \rho W)^{-1}\varepsilon$. Based on that, SDM also assumes that the unobserved effect is related with independent variables, $\varepsilon = X\gamma + \vartheta$, where $\vartheta \sim N(0, \sigma_\vartheta^2 I_n)$. We obtain:

$$Y = X\beta + (I_n - \rho W)^{-1}(X\gamma + \vartheta)$$

$$(I_n - \rho W)Y = X\beta + WX(-\rho\beta) + X\gamma + \vartheta$$

$$(I_n - \rho W)Y = X(\beta + \gamma) + WX(-\rho\beta) + \vartheta$$

Let $\tau = \beta + \gamma$ and $\varphi = -\rho\beta$ and then

$$(I_n - \rho W)Y = X\tau + WX\varphi + \vartheta$$

$$\begin{aligned} Y &= (I_n - \rho W)^{-1}(X\tau + WX\varphi) + (I_n - \rho W)^{-1}\vartheta \\ &= \sum_{r=1}^{K} (I_n - \rho W)^{-1} (I_n \tau_r + W\varphi_r) x_r + (I_n - \rho W)^{-1}\vartheta \end{aligned}$$

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[58] Source: https://msarrias.weebly.com/uploads/3/7/7/8/37783629/lecture2.pdf

$$\boldsymbol{S}_r = \frac{\partial Y}{\partial x_r} = (\boldsymbol{I}_n - \rho \boldsymbol{W})^{-1}(\boldsymbol{I}_n \tau_r + \boldsymbol{W}\varphi_r) = (\boldsymbol{I}_n - \rho \boldsymbol{W})^{-1} \begin{bmatrix} \tau_r & w_{12}\varphi_r & \cdots & w_{1n}\varphi_r \\ w_{21}\varphi_r & \tau_r & & w_{2n}\varphi_r \\ \vdots & & \ddots & \vdots \\ w_{n1}\varphi_r & w_{n2}\varphi_r & \cdots & \tau_r \end{bmatrix}$$

Where $i = 1, \dots, n$ denotes state; $r = 1, .., K$ is the set of independent variables; $\mathrm{S_r}$ is $n \times n$ spatial effect matrix. Assume $Y = (y_1, y_2, \dots, y_n)^T$, and then

$$y_i = \sum_{r=1}^{K} [\boldsymbol{S}_r(W)_{i1} x_{1r} + \boldsymbol{S}_r(W)_{i2} x_{2r} +, \dots, + \boldsymbol{S}_r(W)_{in} x_{nr}] + (\boldsymbol{I}_n - \rho \boldsymbol{W})^{-1}{}_i \vartheta$$

$$\frac{\partial y_i}{\partial x_{jr}} = \boldsymbol{S}_r(W)_{ij}$$

Where $\boldsymbol{S}_r(W)_{ij}$ is the i, jth element of $\boldsymbol{S}_r$; $(\boldsymbol{I}_n - \rho \boldsymbol{W})^{-1}{}_i$ is the ith row. And the diagonal elements of the matrix $\boldsymbol{S}_r$ measure the direct impacts and off-diagonal elements is the indirect impacts.