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RESEARCH ARTICLE

Opportunity Cost: An Economic Concept That May Improve the Functioning of Federal Milk Marketing Orders and the U.S. Dairy Industry

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Abstract
In the United States, over 70% of milk production is priced under Federal Milk Marketing Orders (FMMOs). A primary purpose of FMMOs is to facilitate orderly allocation of milk as a limited, perishable resource among alternative uses. Fundamental to FMMOs are the regulatory prices applicable to milk used in cheese and whey (Class III), and nonfat dry milk and butter (Class IV). This work examines a novel milk pricing method based on the concept of opportunity cost for milk used in cheese and whey. This novel method may improve the functioning of FMMOs and the U.S. dairy industry.

Keywords: butter; cheese; dry whey; milk; nonfat dry milk; opportunity cost; price; protein

JEL classifications: L51; Q13; Q18

1. Introduction

U.S. milk production totaled 218 billion pounds in 2019, 99% of which was Grade A and eligible for fluid use (USDA, 2021d). The economics of a large part of U.S. Grade A milk production is influenced by the Federal Milk Marketing Order (FMMO) system. The FMMO system has evolved to facilitate orderly marketing of Grade A farm milk through classified pricing and revenue pooling (USDA, 2020a). In 2019, some 156 billion pounds of Grade A milk were pooled and priced under FMMOs, representing about 72% of U.S. production with a farmgate milk value exceeding $27.2 billion (USDA, 2020b). More than 50% of this value is typically represented by milk used in manufacturing, namely cheese, dry whey, nonfat dry milk, and butter.

FMMOs utilize classified pricing and revenue pooling to establish a single basic minimum uniform price for milk in a milkshed of a fluid (beverage) milk market. Each FMMO pool allows dairy farmers in a region to receive the uniform price regardless of how their milk was used (USDA, 2019a). Historically, the incentive to pool milk on an FMMO was the large differences between FMMO prices for fluid milk products (higher value) and milk used in manufactured products (lower value). Over time, per capita consumption of fluid milk products has declined (Stewart et al., 2021), and the margin by which FMMO values of fluid milk products exceed the value of milk used in manufactured products has decreased (USDA, 2021b). In addition, since the reduction in the support prices under the Dairy Product Price Support Program beginning in the late 1980s, the volatility of manufactured dairy product prices, particularly cheese, has increased significantly (Schnepf, 2014).

FMMOs define the value of milk used in cheese as Class III. The volatility of cheese prices has resulted in a Class III price that demonstrates a similar volatility. The volatility of the Class III

Table 1. FMMO classes, general product description, pricing elements

Class	General Product Description	Pricing Element	Estimated FMMO Value, 2019 (%)
Class I	Fluid, lower butterfat	Skim/butterfat	31
Class II	Soft, higher butterfat	Nonfat solids/butterfat	11
Class III	Cheese (Whey)/butter	Protein/other solids/butterfat	40
Class IV	Nonfat dry milk/butter	Nonfat solids/butterfat	18

FMMO—Federal Milk Marketing Order.
Source: USDA/AMS/Dairy Program.

price exists in contrast to a key criteria defined by USDA's Dairy Program at Federal Order Reform in 1999, that is, that, among other characteristics, class prices for manufacturing uses of milk be "stable" (USDA, 1999). Bozic and Wolf (2022) suggest that current FMMO price formulas may impair incentives for manufacturers "to quickly adjust product mix in response to demand shocks" and, by extension, exacerbate the volatility of cheese and Class III prices. In addition, Bozic and Wolf conclude that the price spread between cheese (Class III) and nonfat dry milk (Class IV) is the greatest contributor to depooling. Depooling occurs when a manufacturing price is out of alignment with other FMMO class prices and milk handlers of such uses choose to not participate in the pool. The result of depooling is that more than one basic price potentially exists in the milkshed of a FMMO, that is, the price paid for the depooled milk and the uniform price for the milk that remains in the pool. As noted previously, Federal orders were originally designed to establish a single basic minimum uniform price in a milkshed through regional pools. These developments have created challenges for how FMMO pools operate and relate to the U.S. dairy industry. A large part of these challenges is related to how FMMOs currently price milk used in manufacturing, specifically milk used in the manufacture of cheese.

Our research explores a novel approach to defining the FMMO Class III price that applies to milk used in cheese and whey. This novel approach is based on the economic concept of opportunity cost where the value of the use of a resource (milk used in cheese) is understood in terms of the value of an alternate use of the same resource (milk used in nonfat dry milk). A key aspect of this novel approach is that it is primarily based on existing assumptions implicit in the current Class III price, with a few additional assumptions. The primary objectives of this research are to define a regulatory price for milk used in cheese that: (1) better reflects the supply and demand for milk and is more stable than the current Class III price; (2) improves incentives to manufacturers to pool milk on FMMOs more consistently; and (3) reduces the institutional and programmatic costs of maintaining an economically relevant and appropriate regulatory price for Class III milk.

2. Abridged Primer on FMMOs

The goal of classified pricing and revenue pooling is to establish a single basic minimum uniform price of milk, a complex product with many uses, subject to certain defined adjustments. The concept of classified pricing and pooling has a long history dating to the late 1800s (Nourse, 1962, Erba and Novakovic, 1995, Manchester, 1983). The Agricultural Marketing Agreement Act (AMAA) is the legislative basis for the system of classified pricing and pooling embodied in FMMOs (AMAA of 1937). In 2000, a process commonly referred to as Federal Order Reform created the basic structure of FMMOs as they exist today (USDA, 1999).

In the FMMO system, dairy products are classified by dividing them into general categories defined by their physical and economic character. Economically relevant prices are used to establish the value of milk used in each class (See Table 1). The economic relevancy of prices for Class III and IV reflects the association of specific milk components and the yield and character of dairy

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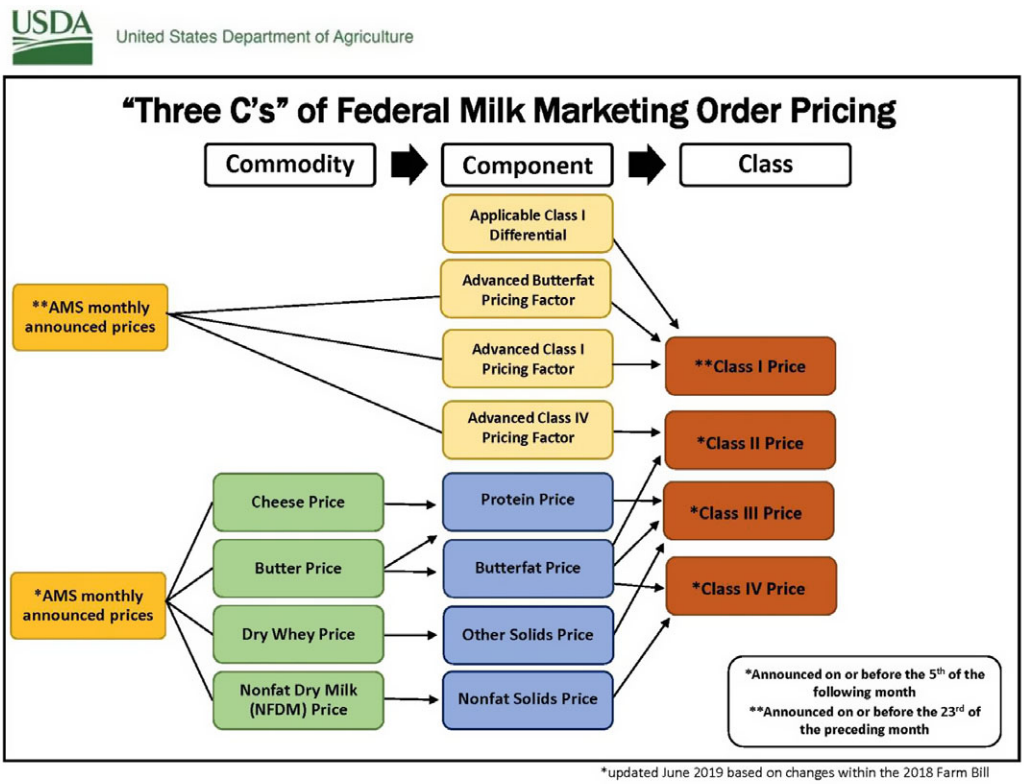

Figure 1. "Three C's" of Federal Milk Marketing Order pricing.

products in each class. The role of Class III and Class IV prices in FMMOs is to reflect the value of milk surplus to Class I, that is, milk used in the storable products of butter, nonfat dry milk, cheese, and dry whey. Class I and II prices include fixed, economic differentials that are added to Class III and/or Class IV price formulas. The economic differentials reflect costs associated with supplying plants that process Class I products, and, for Class II, cost relationships between two potential substitute ingredients (condensed milk and nonfat dry milk) used in Class II products. Class I prices and a subset of Class II prices are announced on an advanced basis but rely on the formulas applicable to Class III and/or IV. Figure 1 shows a rough schematic published by USDA of the relationships between dairy product prices and FMMO prices (USDA, 2019b). USDA also publishes information detailing the mathematical formulas for each class price applicable under FMMOs (Figure 2, USDA, 2022). The price formulas shown in Figure 2 for Class III and IV are further explored in subsequent sections.

In the early years of FMMOs, a variety of methods were tried to determine a surplus value of milk with varied results. All of these methods were intended to reflect the "supply and demand for milk or its products," a requirement of 608(c)(18) of the AMAA of 1937. Between the 1960s and 1990s, the M-W (Minnesota-Wisconsin) survey of Grade B milk prices paid by plants was used to set surplus values under FMMOs. One important characteristic of the M-W was that it included plants that manufactured "butter, cheese, and other products," theoretically incorporating competitive interactions between the surveyed plants (USDA, 1985). The "other products" included nonfat dry milk. Between the early 1990s and 2000, the pricing of surplus milk and its components transitioned to what is referred to as product price formulas that FMMOs use currently (USDA, 1999).

Marketing Order Statistics Price Formulas 2019

Announced milk prices are per 100 pounds (or cwt), rounded to the nearest cent. Component prices are per pound, rounded to nearest one-hundredth cent. Product prices and pricing factors are per pound, rounded to the nearest one-hundredth cent. For advanced cheese, dry whey, butter, and nonfat dry milk prices, the prices are two-week weighted averages of the weekly National Dairy Products Sales Report (NDPSR) prices, rounded to the nearest one-hundredth cent. For cheese, dry whey, butter, and nonfat dry milk prices, the prices are four- or five-week weighted averages of NDPSR prices, rounded to the nearest one-hundredth cent.

Class I:
- Base Class I Price = (Base Skim Milk Price for Class I x 0.965) + (Advanced Butterfat Pricing Factor x 3.5)
- Base Skim Milk Price for Class I = ((Advanced Class III Skim Milk Pricing Factor + Advanced Class IV Skim Milk Pricing Factor) / 2) + $0.74
- Advanced Class III Skim Milk Pricing Factor = (Advanced Protein Price x 3.1) + (Advanced Other Solids Price x 5.9)
- Advanced Protein Price = ((Advanced Cheese Price - 0.2003) x 1.383) + ((((Advanced Cheese Price – 0.2003) x 1.572) – Advanced Butterfat Pricing Factor x 0.9) x 1.17)
- Advanced Other Solids Price = (Advanced Dry Whey Price – 0.1991) x 1.03
- Advanced Class IV Skim Milk Pricing Factor = Advanced Nonfat Solids Price x 9
- Advanced Nonfat Solids Price = (Advanced Nonfat Dry Milk Price – 0.1678) x 0.99
- Advanced Butterfat Pricing Factor = (Advanced Butter Price - 0.1715) x 1.211
- Class II Skim Milk Price = Advanced Class IV Skim Milk Pricing Factor + 0.70
- Class II Nonfat Solids Price = Class II Skim Milk Price / 9

Class II:
- Class II Price = (Class II Skim Milk Price x 0.965) + (Class II Butterfat Price x 3.5)
- Class II Skim Milk Price = Advanced Class IV Skim Milk Pricing Factor + 0.70
- Class II Butterfat Price = Butterfat Price + 0.007
- Butterfat Price = (Butter Price – 0.1715) x 1.211

Class III:
- Class III Price = (Class III Skim Milk Price x 0.965) + (Butterfat Price x 3.5)
- Class III Skim Milk Price = (Protein Price x 3.1) + (Other Solids Price x 5.9)
- Protein Price = (Cheese Price-0.2003) x 1.383 + (Cheese Price-0.2003) x 1.572 - Butterfat Price x 0.9 x 1.17
- Other Solids Price = (Dry Whey Price – 0.1991) x 1.03

Class IV:
- Class IV Price = (Class IV Skim Milk Price x 0.965) + (Butterfat Price x 3.5)
- Class IV Skim Milk Price = Nonfat Solids Price x 9
- Nonfat Solids Price = (Nonfat Dry Milk Price – 0.1678) x 0.99

Source: USDA (https://www.ams.usda.gov/sites/default/files/media/PriceFormula2019.pdf)

Figure 2. FMMO price formulas.

Since 2000, Class III and IV milk prices in the FMMO system have been based on product price formulas that establish values for milk's primary components (butterfat, protein, and other solids) from surveyed wholesale prices for dairy commodities, namely cheddar cheese, dry whey, nonfat dry milk, and butter (USDA, 2009). As shown in Figure 1, cheese, dry whey, and butter define the value of milk used in Class III, while nonfat dry milk and butter define the value of milk used in Class IV. Since the value of butter defines the value of butterfat under both Class III and IV, the difference between Class III and IV prices is a function of differences between cheese/dry whey values and nonfat dry milk values.

Under FMMO component-based milk pricing, a manufacturer of the surveyed dairy commodities receives a stable gross margin (referred to as a "make allowance"), while changes in surveyed dairy product prices are passed to dairy producers as changes in the value of milk components.

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Consequently, for a manufacturer selling bulk dairy commodities (and participating in a FMMO pool), and whose manufacturing costs are similar to the respective FMMO make allowances, higher commodity prices do not lead to higher profit margins. In addition, by setting two independent prices for the surplus value of milk and its components, one based on cheese (Class III) and the other on nonfat dry milk (Class IV), when the storable dairy commodity prices diverge, it could be argued that they may reflect their own economics more than the supply and demand of milk in general.

The calculation of elasticities can provide a way to gauge the relative responsiveness of cheese and nonfat dry milk production to their surveyed wholesale prices. From 2009 through 2021, average price elasticities were calculated for cheese and nonfat dry milk.[1] The average price elasticity of U.S. cheese production is calculated to be about 0.4 (inelastic). In contrast, the price elasticity for nonfat dry milk production is calculated to be 1.5 (elastic). The price elasticity for nonfat dry milk suggests that it is responsive to and representative of "the supply and demand for milk or its products" in accordance with the AMAA of 1937. By extension, the relatively low cheese price elasticity suggests it is less responsive to "the supply and demand for milk or its products" than nonfat dry milk. By virtue of how FMMOs calculate component values for milk used in these products using fixed product price formulas and make allowances, these elasticities are similar to those calculated using FMMO prices for Class III and IV. This raises the question of whether the relationship between the cheese price and the price it implies for the value of milk used in cheese under FMMOs (Class III) can be improved to better reflect "the supply and demand for milk or its products." This question is in line with Bozic and Wolf's (2022) recommendation that "research should explore how product formulas may be altered to provide additional incentives to manufacturers to quickly adjust product mix in response to demand shocks."

3. Review of FMMO Product Price Formulas and Component Pricing

The primary purpose of the FMMO program is to facilitate efficient milk marketing by establishing a structure of classified, minimum pricing and pooling of raw milk for defined groups of milk handlers with business activity in a specific region. In the medium and long runs, supply and demand forces hold sway in defining the value of milk. When an FMMO is properly structured, each price in the classified pricing system is a minimum that is economically reasonable by itself and in relation to the other class prices and dairy product markets. In the medium and long terms, class prices should be less than the general economic value of the products into which the respective milk is made.

Since 2000, most of the milk in FMMOs has been priced using multiple component pricing. Milk in FMMOs not priced on a multiple component basis is priced on a skim and butterfat basis. FMMOs pricing milk on a skim and butterfat basis rely on the underlying component-based milk pricing formulas and standard milk component tests. Component-based milk pricing imputes a milk component value based on a survey of dairy commodity wholesale prices using product price formulas. These formulas create a direct, fixed relationship between a commodity price and its associated milk component price. The general functional form of a FMMO milk component price is provided in equation (1).

$$P_i = \left(P_j - \mathrm{MA}_j\right) \times Y_j \tag{1}$$

[1]Authors' calculations. Average price elasticities were calculated using monthly data from 2009 through 2021. Cheddar cheese and nonfat dry milk price data were drawn from USDA's Dairy Product Mandatory Reporting Program (USDA, 2021a). Dairy product production data were drawn from USDA's Commercial Disappearance for Dairy Product Categories (USDA, 2021c).

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where P_i denotes a component price, P_j is a commodity product price, MA_j is a commodity-specific make allowance, Y_j is a commodity-specific yield, i denotes the component, and j denotes the commodity.[2]

The value of butterfat in butter is calculated using the formula (1):

$$P_{BF} = (P_B - 0.1715) \times 1.211. \tag{2}$$

where P_{BF} is the butterfat price, P_B is the butter price, 0.1715 is the make allowance for butter, and 1.211 is the yield assumption for butter/butterfat. The butterfat price is the same for both Class III and IV and implies that the difference between the Class III and IV prices is limited to how each price values the nonfat portion of milk in the respective use.

Under FMMOs, the valuation of the nonfat portion of milk, skim milk, is more complex than that of butterfat. Skim milk is mostly water but contains nonfat components, referred to as nonfat solids. Nonfat solids include casein, whey proteins, lactose, and minerals. These nonfat solids are aggregated into two general categories: proteins (casein and whey proteins) and other solids (lactose and minerals). FMMOs use different aggregations of nonfat solids to value milk used in Class III and IV. Values for protein and other solids apply to milk used in Class III products (cheeses), while the value of total nonfat solids (protein plus other solids) applies to milk used in Class IV products (nonfat dry milk and similar products). The respective components are associated with the yield of the dairy products in each class.

When milk is used in the manufacturing of cheese and dry whey (Class III milk), nearly all casein remains with the cheese while nearly all whey proteins, lactose, and minerals are contained in liquid whey, the byproduct of cheese-making. For that reason, for the nonfat solids used in cheese and dry whey, separate prices are established for protein and other solids. For Class IV milk, nonfat solids are accounted for as nonfat dry milk (and similar products), and therefore, a single price is established for nonfat solids. The price formulas for other solids in Class III milk and nonfat solids in Class IV milk have the same basic form as equation(1). The other solids price is:

$$P_{OS} = (P_W - 0.1991) \times 1.03. \tag{3}$$

where P_{OS} is the other solids price, P_W is the dry whey price, 0.1991 is the make allowance, and 1.03 is the yield assumption for other solids/dry whey.

The nonfat solids price for Class IV is:

$$P_{NFS}^{IV} = (P_N - 0.1678) \times 0.99 \tag{4}$$

where P_{NFS}^{IV} is the Class IV nonfat solids price, P_N is the nonfat dry milk price, 0.1678 is the make allowance for nonfat dry milk, and 0.99 is the yield assumption for nonfat solids/nonfat dry milk.

Determining the price of protein in Class III milk is more complex and is based on the Van Slyke cheese yield formula. The original specification of the cheese yield formula was developed in the early 1900s by Lucius L. Van Slyke through basic research with the goal of identifying factors important to cheddar cheese yields (Van Slyke and Publow, 1918). The derivation of the Van Slyke cheese yield formula currently used by FMMOs is presented in a technical appendix (*Technical Appendix: Van Slyke Cheese Yield Formula*). The technical appendix can be used as an introduction to the assumptions currently used in setting Class III protein prices and that is the basis for the focus of this research, the concept of opportunity cost pricing.

[2]The derivation of the FMMO commodity-specific yield factors, other than those used for the Class III protein price, is not addressed in this paper. The derivation of the yield assumptions for the protein price is detailed in *Technical Appendix: Van Slyke Cheese Yield Formula*.

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4. Opportunity Cost-Based Milk Pricing

The concept of opportunity cost is basic to economics, and its roots reach back to Adam Smith (Smith, 1904). In effect, opportunity cost is the relationship between scarcity and choice. A common definition of opportunity cost is simply the value of the next-highest-valued alternative use of a resource (Buchanan, 2008). The value of milk in storable products is the opportunity cost of using the same milk in fresh fluid products. Similarly, after the demand for fresh fluid milk is fulfilled, economic forces in the market lead to decisions about what storable products are to be produced. Considering only more storable uses, the opportunity cost of using milk in cheese is the value of the same milk in nonfat dry milk and butter. The idea of opportunity cost, as used here, is simply the relationship between gross values of two different uses of the same resource. If the value of milk in one product can be determined with reasonable accuracy and appropriateness for its market and set of economic conditions, then it may be possible to establish its value in a second product by relationships between the component characteristics of milk and dairy products, dairy commodity product prices and simple algebra. The result defines the value of one product in terms of another. The algebraic calculations detailing how an opportunity cost value for Class III can be determined by component and price relationships between cheese and nonfat dry milk are shown in a technical appendix (*Technical Appendix: Opportunity Cost Pricing*).

The calculations in *Technical Appendix: Opportunity Cost Pricing* use assumptions in *Technical Appendix : Van Slyke Cheese Yield Formula* and monthly average price data for cheese, dry whey, nonfat dry milk, and butter as published by USDA's Dairy Product Mandatory Reporting Program (DPMRP) for January 2009 through December 2021 (USDA, 2021a). DPMRP dairy product prices are used in determining the current Class III and IV prices. The time period of 2009 through December 2021 is characterized by consistent dairy product price formulas associated with Class III and IV.

Two forms of opportunity cost pricing are calculated, Method A and Method B. Method A defines a Class III value based on a ratio of cheese and whey values relative to nonfat dry milk values. Method B defines a Class III value based on a ratio of cheese values relative to nonfat dry milk values. In Method B, the component value of dry whey is left at its current value as other solids.

Reduced forms of the Class III protein price using Method A and B as shown in *Technical Appendix: Opportunity Cost Pricing* are as follows:

$$P^{III}_{OCP,A} = 2.9895 \times P_{Ch} - 1.3057 \times P_B + 1.9634 \times P_W + 0.2239 - 0.5016 \times \frac{P_{Ch}}{P_N} + 0.2191 \times \frac{P_B}{P_N} - 0.3295 \times \frac{P_W}{P_N} - 0.0376 \times \frac{1}{P_N} \quad (5)$$

$$P^{III}_{OCP,B} = 2.9895 \times P_{Ch} - 1.1753 \times P_B + 0.2015 - 0.5016 \times \frac{P_{Ch}}{P_N} + 0.1972 \times \frac{P_B}{P_N} - 0.0338 \times \frac{1}{P_N} \quad (6)$$

where P_{Ch} is the cheese price, P_B is the butter price, P_W is the dry whey price and P_N is the nonfat dry milk price.

For ease of comparison, a reduced form of the current Class III protein price is:

$$P^{III}_{Pro} = 3.2222 \times P_{Ch} - 1.2752 \times P_B - 0.4267 \quad (7)$$

Comparing the coefficients of the reduced forms of the Class III protein prices in equations (5), (6), and (7) shows that opportunity cost Methods A and B have a lower coefficient for the cheese price (2.9895) than that of the current Class III protein price (3.2222). The lower cheese price coefficient for Methods A and B would suggest a dampening of the influence of the

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Table 2. Comparison of opportunity cost prices and current FMMO Class III prices ($/cwt): January 2009–December 2021

Statistic	FMMO Class III Price	Opportunity Cost Method A	Opportunity Cost Method B
Mean	16.58	16.71	16.48
Minimum	9.31	9.95	9.25
Maximum	24.6	24.18	24.39
Standard deviation	3.03	2.80	2.86
H_0: OC = FMMO Class III			
Paired t-test (2-tail)		−3.701*	2.971*
Pearson's correlation			
Class IV	0.77	0.84	0.84

FMMO—Federal Milk Marketing Order; OC—Opportunity Cost.
$N = 156$.
*$P < 0.005$.

cheese price on the protein price and implies a reduction in the volatility of the resulting Class III price. In addition, the negative coefficient on the ratio of the cheese price to the nonfat dry milk price implies a narrowing of the difference between the prices resulting from Method A and B and the Class IV price. A more extensive analysis of how opportunity cost pricing compares with the current Class III price can be found below.

5. Comparisons Between Current FMMO Class III Pricing and Opportunity Cost Pricing

In this section, we describe the character and behavior of the current FMMO Class III price and compare it with that of the prices generated using the concept of opportunity cost. In addition, regression analysis is used to discern how opportunity cost pricing may affect FMMO pools and the incentive to depool milk.

5.1. Simple Comparisons

To gauge the basic impact of using the opportunity cost protein price, we compare the Class III price under existing FMMO pricing with the calculated Class III price using opportunity cost pricing Methods A and B and measure their correlation with Class IV. As shown in Table 2, the mean difference between the opportunity cost Method A Class III price and the FMMO Class III price series is $0.13/cwt. In contrast, Method B results in a Class III price series with a mean $0.10/cwt lower than the current Class III. Figures 3 and 4 show monthly prices across the period analyzed. A general observation of both the data in Table 2, and Figures 3 and 4, is that the relationship between the price series changes depending on the relative level of commodity prices. When cheese prices are high relative to nonfat dry milk, the opportunity cost Class III price is lower than the current FMMO Class III price, and vice versa. While each opportunity cost method may result in prices different than the current Class III price in certain periods, the means of the three price series for the 2009 through 2021 period are not statistically different. In addition, each opportunity cost price has a higher correlation with Class IV (0.84) than the current Class III (0.77). A final measure of relative volatility is the standard deviation of month-to-month price changes. The standard deviation of month-to-month price changes for Class IV (0.93) is closer to those for the opportunity cost Class III prices (Method A: 0.94; Method B: 0.90) than the current Class III (1.64). Using the above measures, each opportunity cost Class III price is less volatile than the current Class III price and appears to better reflect the supply and demand for milk and its products.

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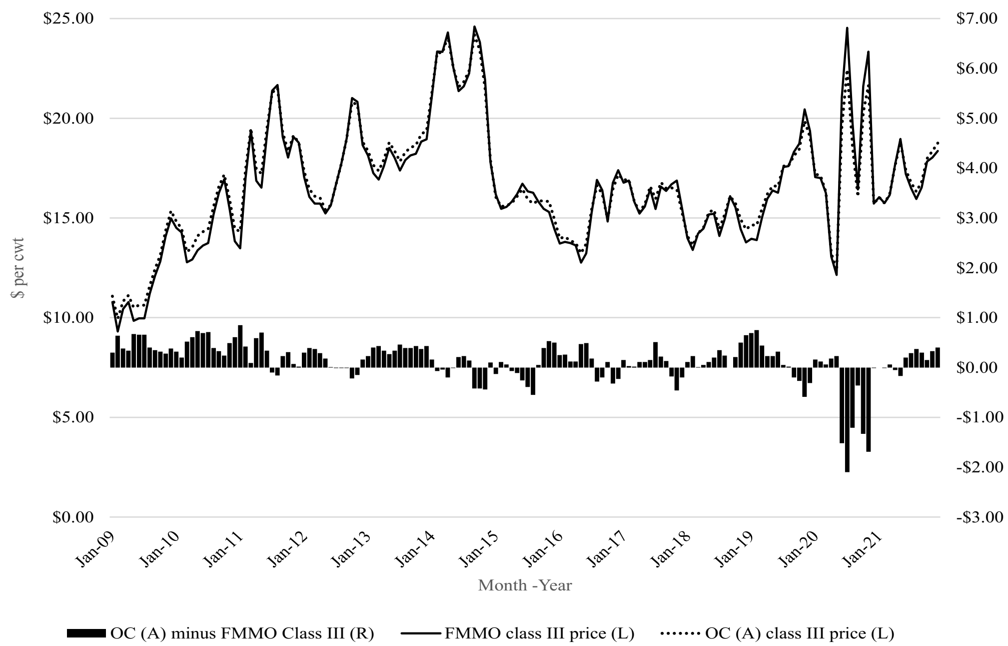
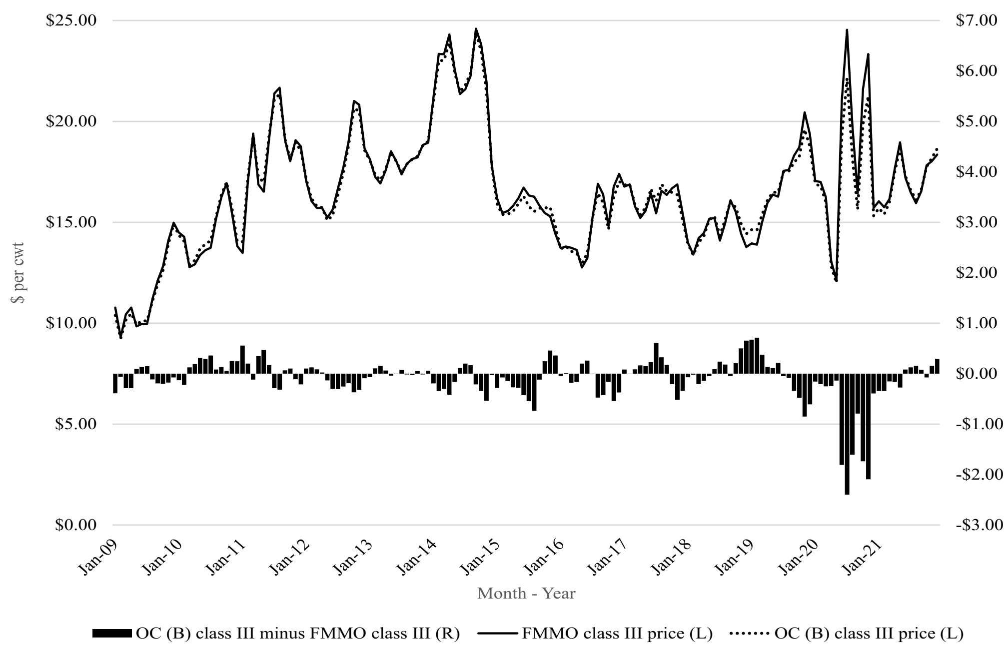


OC (A) – Opportunity Cost, Method A; FMMO – Federal Milk Marketing Order; (L) – Left hand axis; (R) – Right hand axis.

Figure 3. Comparison of Class III milk valuation methods: opportunity cost (OC, Method A) vs current FMMO pricing: January 2009–December 2021.



OC (B) – Opportunity Cost, Method B; FMMO – Federal Milk Marketing Order; (L) – Left hand axis; (R) – Right hand axis.

Figure 4. Comparison of Class III milk valuation methods: opportunity cost (OC, Method B) vs current FMMO pricing: January 2009–December 2021.

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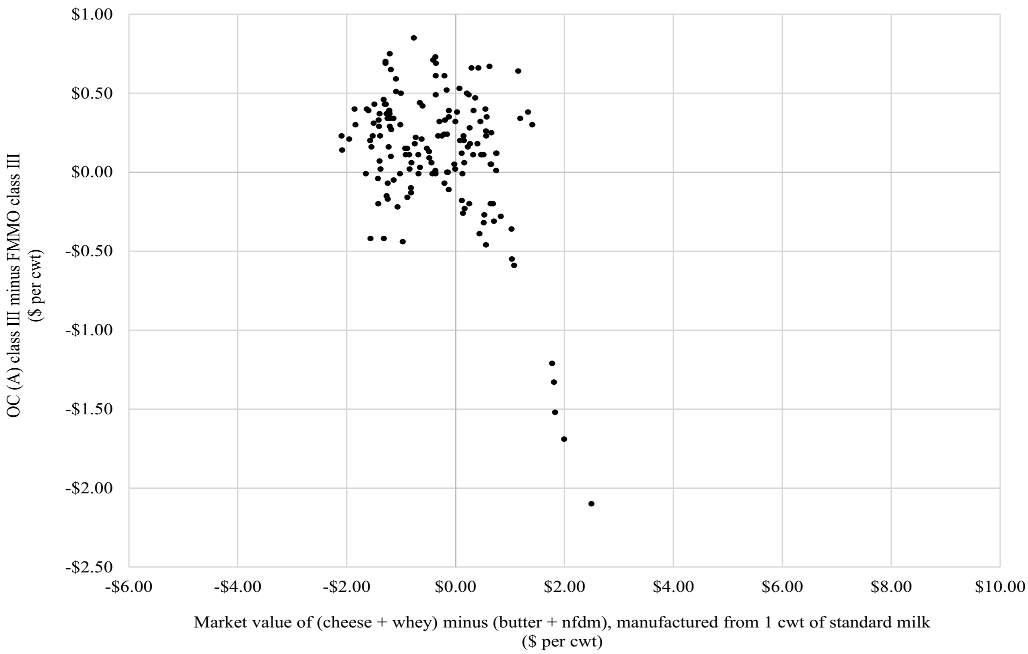

OC (A) – Opportunity Cost, Method A; FMMO – Federal Milk Marketing Order

Figure 5. Impact of relative commodity prices on the spread between opportunity cost (OC, Method A) and FMMO Class III price: January 2009–December 2021.

5.2. Relationships between Prices and Commodity Values

A more complex way to compare Method A and B opportunity cost prices to the current FMMO Class III price is to compare their difference to the difference in value of dairy products derived from one hundredweight of standard milk, that is, the value of cheese and dry whey minus the value of nonfat dry milk and butter.[3] Figures 5 and 6 present the respective difference between each opportunity cost Class III milk price and the FMMO Class III milk price relative to the difference in commodity values. For both opportunity cost pricing methods, when milk is more valuable to consumers as cheese and dry whey relative to nonfat dry milk and butter, a lower Class III price results (points below zero on the *y* axis). Manufacturers are thus rewarded for increasing the production of cheese and dry whey, as the gross margin of cheese and dry whey exceeds the gross margin of making nonfat dry milk and butter. The opposite also holds true. When cheese and dry whey are oversupplied, and the value of milk in cheese and dry whey declines relative to the value of milk in nonfat dry milk and butter, each opportunity cost method does not allow manufacturers to fully pass through that reduction in value to milk of pooled producers. Consequently, this implies an incentive to reduce production of cheese and dry whey which theoretically helps restore the market balance. However, Methods A and B are distinct in how they reflect the above relationships. Method A's observations show a circular pattern centered above and to the left of the zero point on the two axes. Method B's observations show a more ellipsoid pattern centered below and to the left of the zero point. The relationship between how the observations for Method A and B appear in Figures 5 and 6 suggests that Method B creates a more responsive relationship between the value of protein in cheese relative to nonfat dry milk than Method A.

[3]FMMO standard milk tests: 3.50% butterfat, 2.9915% protein; 5.6935% other solids; and 8.685% nonfat solids. The product yield assumptions for standard milk are as follows: 9.6373 for cheese; 5.9703 for dry whey; 9.2888 for nonfat dry milk; and 4.2385 for butter.

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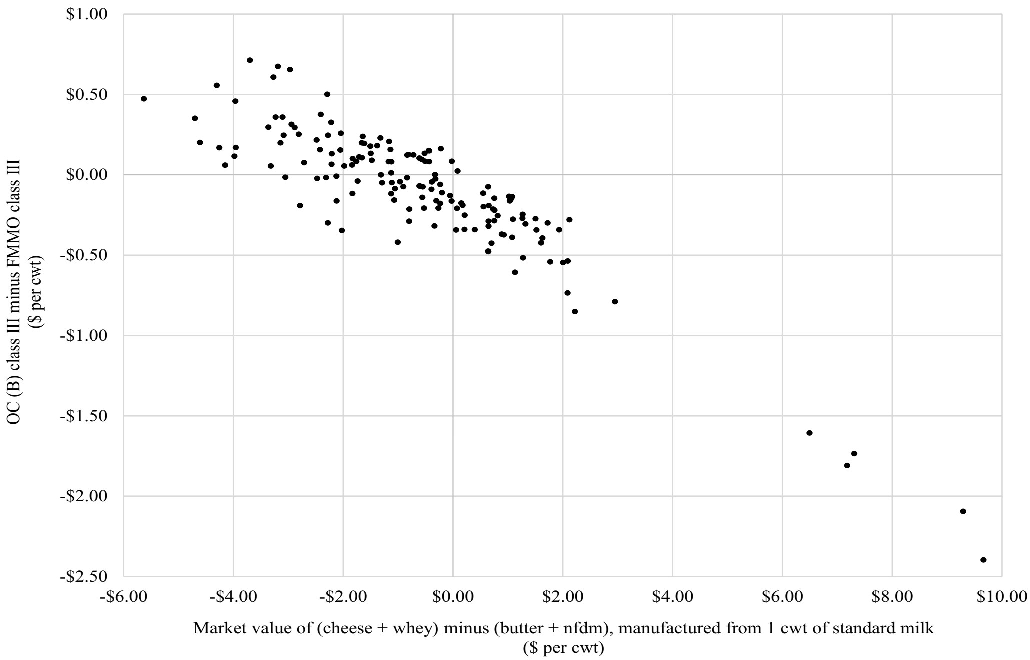

OC (B) – Opportunity Cost, Method B; FMMO – Federal Milk Marketing Order

Figure 6. Impact of relative commodity prices on the spread between opportunity cost (OC, Method B) and FMMO Class III price: January 2009–December 2021.

5.3. Price Relationships During Selected Time Periods

While the preceding provides some understanding of how the current Class III price compares to the two forms of opportunity cost pricing, examining how they compare over selected time periods may provide additional understanding.

During 2009 through 2021, a variety of price relationships existed between cheese, dry whey, nonfat dry milk, and butter. The 2009 through 2014 period is generally characterized by average prices for cheese ($1.71) and butter ($1.69) being near the same levels, with average nonfat dry milk ($1.40) prices somewhat lower than average cheese prices. The 2015 through 2019 period is generally characterized by average butter ($2.20) prices exceeding average cheese ($1.64) prices with average nonfat dry milk ($0.89) prices being significantly lower than average cheese prices. From 2020 through 2021, due to the COVID-19 pandemic and USDA's intervention in commodity markets, there were large differences between the average prices of cheese ($1.80) and nonfat dry milk ($1.16) and butter ($1.66). Extreme differences occurred between the cheese price and those for nonfat dry milk and butter between June and November 2020.

Table 3 shows the price relationships between the current Class III and IV prices and those for Methods A and B during the defined periods noted above. Class IV and its difference from Class III are shown for reference. These comparisons should be understood in the context of the fact that FMMO make allowances have not been updated since October 2008. For Method A, calculated prices are higher, on average, than the current Class III price for the 2009–2014 (+$0.28) and 2015–2019 (+$0.10) periods but by different margins. During 2020–2021, on average, Method A was $0.23 below the current Class III. Conversely, for Method B, calculated prices were consistently lower by similar amounts for 2009–2014 (−$0.03) and 2015–2019 (−$0.03), and lower by a greater margin for 2020–2021 (−$0.51) than Method A (−$0.23). The more consistent effect of Method B from 2009 through 2019 is indicative of the data as shown in Figures 5 and 6.

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Table 3. Comparisons between average Class III prices and opportunity cost prices for selected periods ($/cwt): 2009–2021

Product/Price	2009–21	2009–14	2015–19	2020–21
Class IV (IV–III)*	15.81 (−0.77)	17.03 (+0.05)	14.76 (−0.92)	14.79 (−2.83)
Class III*	16.58	16.98	15.68	17.62
Opportunity cost: Method A (Method A–III)	16.71 (+0.13)	17.26 (+0.28)	15.78 (+0.10)	17.39 (−0.23)
Method B (Method B–III)	16.48 (−0.10)	16.95 (−0.03)	15.65 (−0.03)	17.11 (−0.51)

*Current Federal Milk Marketing Order prices.

Table 4. Relationship between Pacific Northwest (PNW) Order producer price differential (PPD) and spread between Class III and IV skim prices ($/cwt): January 2009–December 2021

Variable	PPD_PNW
Intercept	0.4818*
Class III–IV skim price spread	−0.6128*
Adjusted R square	0.905
Observations	156

PPD—Producer Price Differential; PNW—Pacific Northwest Order.
*$P < 0.001$.

5.4. Depooling

As previously noted, the original intention of FMMO pools was to establish a single basic minimum uniform price in a milkshed of a fluid market. Depooling of milk from FMMO pools results in potentially two prices in a FMMO milkshed. Handlers of milk used in Class III and IV typically pool milk when it is financially advantageous, that is, when these use values are less than the uniform value and imply a payment from a FMMO pool. Incentives to depool milk primarily occur when the Class III and Class IV prices diverge as a result of differences in cheese (and dry whey) and nonfat dry milk prices.[4] When cheese and nonfat dry milk prices diverge, the average positive difference between Class III and Class IV prices is reduced for Method A and Method B relative to the current Class III formula. In the 2009–2014 period, the average positive difference between the current FMMO Class III and IV was $1.37; under Method A, the difference was reduced to $1.23. For the 2015–2019 period, the difference was reduced from $1.47 under the current Class III formula to $1.37 under Method A. For the 2020–2021 period, the difference was reduced from $1.92 to $1.79. Under Method B, the difference between Class III and IV was reduced to $1.17 for 2009–2014 to $1.26 for 2015–2019 and to $1.53 for 2020–2021.

While the significance of the difference between Class III and Class IV prices may not be obvious, this difference is a primary factor in determining the level of the FMMO uniform price and the producer price differential (PPD). The PPD is an accounting adjustment to reconcile the FMMO uniform value of milk, the weighted average value of all pooled milk, with its Class III component value. Low and negative PPDs generally indicate an incentive to depool milk classified as Class III. Table 4 shows the results of regressing the Pacific Northwest (PNW) Order's PPD on the spread between the Class III and Class IV skim prices. Table 5 shows a comparison of statistics of the PNW Order's published PPD and estimates of the PPDs associated with both Method A and B.

[4]Handlers of Class I milk with sales in the marketing area that meet certain criteria of a FMMO are regulated and do not have a choice in pooling.

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Table 5. Miscellaneous statistics: producer price differential (PPD), Pacific Northwest (PNW) Order: January 2009–December 2021

Statistic	Announced PPD_PNW	OC, Method A A_PPD_PNW*	OC, Method B B_PPD_PNW*
Minimum	−7.43	−5.03	−4.84
Maximum	2.50	2.44	2.58
Mean	−0.01	−0.09	0.06
Mean (≥0)	0.70	0.68	0.73
Mean (<0)	−1.13	−0.83	−0.81
Standard deviation	1.41	1.10	1.09

PPD—Producer Price Differential; PNW—Pacific Northwest Order.
*Estimated based on regression in Table 4 and the difference between the Class III skim calculated by the respective opportunity cost (OC) method and the announced Class IV skim price.

The estimates in Table 5 represent minimum effects as no adjustments are made to reflect increased incentives to pool Class III milk, whether as a function of price relationships or pooling standards that define what milk participates in a FMMO pool. The data suggest that the magnitude of the financial incentive to depool milk used in Class III (negative PPD) is reduced significantly in many months. Since the Class III price as defined using Method A or B is lower than the current Class III in periods of relatively higher cheese and dry whey prices, the financial incentive to depool Class III milk during these periods is also reduced.

In all three periods noted above, Method A and Method B would appear to demonstrate an enhanced ability of a cheese plant, relative to existing FMMO pricing structures, to bid milk away from a nonfat dry milk plant as price differences between cheese (and dry whey) and nonfat dry milk increase. As much as the dairy industry is able to respond to these incentives, reduced volatility of the Class III price and a reduction in differences between Class III and Class IV prices may further reduce incentives to depool milk, helping FMMOs to function more as they were intended.

6. Other Implications of Opportunity Cost Pricing: Make Allowances

Maintaining the current Class III pricing approach under FMMOs has certain costs for the industry in keeping it up to date through studies and administrative hearings, particularly in relation to the subject of making allowances. The most recent update of Class III and IV formulas occurred in October 2008, more than a decade year ago. Make allowances represent a particularly difficult subject as they can be viewed as a dividing line between revenue accruing to dairy farmers versus revenue for manufacturers. Method A and Method B represent a reduction in the number of make allowances needed to calculate Class III and IV prices. Opportunity cost pricing reduces the number of make allowances from four to two for Method A and to three for Method B. Reducing the number of make allowances may enable the industry to work through the updating process more easily and frequently.

7. Limitations of the Analysis

The concept of opportunity cost pricing as described above and in *Technical Appendix: Opportunity Cost Pricing* is a mathematical construct. This mathematical construct is novel and subject to review by the dairy industry for appropriateness. In addition, any description of the resulting prices and their behavior represents a static analysis. The static nature of this

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analysis is a significant shortcoming of this paper. However, the static analysis suggests the concept of opportunity cost pricing has promise and may benefit from further research.

Opportunity cost pricing may also affect the functioning of FMMOs, and the behavior of manufacturers and markets. A modeling of opportunity cost pricing relative to the current structure of FMMO pricing may lead to a better understanding of how manufacturers respond to changes in market demand for cheese and dry whey relative to nonfat dry milk and butter. Such a modeling effort would be in line with Bozic and Wolf's (2022) recommendation for research to explore how FMMO product price formulas may be altered to provide additional incentives to manufacturers to quickly adjust product mix in response to demand shocks.

8. Conclusion

Opportunity cost is a concept that is basic to economics and is currently used in many aspects of the pricing of milk in the dairy industry and FMMO milk pricing. This paper demonstrates that pricing of the nonfat portion of milk used in cheese and dry whey using the concept of opportunity cost may result in an improvement in how FMMOs and the U.S. dairy industry function. Based on our analysis, the incorporation of opportunity cost pricing in the FMMO system may result in (1) an FMMO Class III price that is more stable and better reflects the supply and demand for milk or its products; (2) more consistent incentives for manufacturers to pool milk on FMMOs; and (3) reduced institutional and programmatic costs of maintaining an economically relevant and appropriate regulatory price for Class III milk. Further research comparing the current form of FMMO pricing for Class III and opportunity cost pricing may provide additional information on how each form of pricing may influence the supply and demand for milk or its products.

Supplementary material. For supplementary material accompanying this paper visit https://doi.org/10.1017/aae.2022.29

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