Analyses of Selected Dairy Programs Proposed to Reduce Variability in Milk Prices and Farm Income

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Executive Summary

Motivated by concerns about low and variable milk prices and farm incomes, a number of dairy industry groups have expressed interest in programs to manage growth in US milk production. This study evaluated the impacts of two types of programs to manage growth in US milk supplies:

1) A program that specified an allowable annual growth in production with "market access fees" paid by farms that exceeded that growth. This is similar to programs proposed by the Holstein Association and the Growth Management Program (GMP) promoted by the Milk Producers' Council in 2009, except that market access fees now differ by farm size. Two versions of this program were analyzed, one with fixed allowable growth and market access fees, and another that linked these to the milk-feed price ratio;
2) A program that paid a low value for milk produced above an allowable amount based on percentage reductions required given threshold values of a margin of milk price less feed costs. This is similar to the Dairy Market Stabilization Program (DMSP) initially proposed by the National Milk Producers' Federation (NMPF) as a part of their Foundation for the Future (FFTF) initiative, except that the marginal milk is non-zero for farms with less than 500 cows.

We assessed the potential impact of the implementation of these programs with different assumptions about their operation, assuming that the programs would have been implemented in January 2014. We evaluated a variety of farm-level and dairy market outcomes during 2014 to 2020 using a detailed dynamic simulation model of the global dairy supply chain.

Our key findings are:

- The programs would generally reduce variation in milk prices, enhance average milk prices and margin over feed costs to varying degrees, and increase net farm operating income (NFOI) for all farm sizes compared to a Baseline scenario with existing policies. Average annual milk prices were increased with MAF-based programs up to between \$0.40/cwt and \$1.10/cwt depending on the assumed restrictiveness of the program. Including refund payments for farms within allowable growth limits, milk revenue increases \$1.19/cwt to \$2.98/cwt. Reduction in the average variation in milk prices generally ranged from \$0.01/cwt to \$0.25/cwt;
- Compared to the Baseline scenario, the programs would generally decrease average annual US milk production, the overall value of US dairy product exports, domestic dairy product sales and US government expenditures. These decreases are larger when the programs are assumed to be more restrictive.

Introduction and Objectives

Previous analysis[1] provided evidence that programs to manage growth in milk supplies such as those proposed in the late 2000s by the Holstein Association (later modified and introduced in Congress by Representative Costa and Senator Sanders as the Dairy Price Stabilization Program) and as an initial component of Foundation for the Future program proposed by the National Milk Producers Federation could reduce milk price variability, make farm incomes more stable and mitigate to some extent the low-price periods of the dairy price cycle. Other previous work[2] has also suggested that the milk price cycles arise primarily due to the supply decisions by dairy farms and related time delays, that is, due to a lack of supply chain coordination matching milk supply and demand. Although the magnitude of the variations in milk prices during the cycle vary[3], the cycle continues to influence milk prices to a notable extent. US dairy farms are now entering their fourth year of lower-than-average milk prices, posing significant management challenges to many of operations due to low profitability.

Although previous analyses suggested these programs could be effective in the market environment of the early 2010s, a number of changes have occurred since the time, including a) increasing US participation in export markets (more closely integrating US milk prices with those in other exporting regions, b) a smaller number of US dairy farms and greater milk production from larger operations, c) modifications to federal dairy programs (replacing price supports with risk management tools under MPP-Dairy (now Dairy Margin Coverage), and d) reductions in per capita fluid milk demand. Although cyclical variation in milk prices has been less since 2015, this has accompanied by four years of margins frequently below $10/cwt, resulting in ongoing profitability challenges for many dairy farms. These challenges and changes in the market environment provide a motivation to re-visit the effectiveness of programs that propose to limit supply responses with the objective of reducing variability in prices and farm profitability.

With this background, our objective is to analyze likely market and income impacts of selected[4] programs to address price volatility in the U.S. dairy industry—if they had been in operation beginning in 2014. Our focus is on how the programs would have affected the level and variability in the All-Milk price, but we also consider a variety of other impacts, including net farm operating income, government expenditures and the value of US dairy exports. In keeping with our view of our obligations as academic professionals, we have no intention to promote or recommend any specific program (or any form of government intervention) to address the issues of supply chain instability and low margins[5]. We believe that the merits and potential drawbacks of these programs should be assessed and discussed by those most likely to be affected—dairy industry stakeholders.

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[1] Nicholson, C. F. and M. W. Stephenson. 2010. Analysis of Proposed Programs to Mitigate Price Volatility in the U.S. Dairy Industry. Project report for consortium of dairy industry organizations administered by the Milk Producers Council. September. (http://dairy.wisc.com)

[2] Nicholson, C. F. and M. W Stephenson. 2015. Price Cycles in the U.S. Dairy Supply Chain and their Management Implications. *Agribusiness: An International Journal*, 31:507-520.

[3] For example, an analysis of price cycles indicates that the price "peaks" in 2011 and 2017 were small compared to the price peaks in 2008 and 2014.

[4] The selection of programs in this case was primarily done by the study funders, the Wisconsin Farmers Union, with input from the authors. Other programs have been suggested but are beyond the scope of this study.

[5] In particular, when analysis suggests that the program may have what are viewed as positive effects, this should not imply that we support the implementation of the program.

Specific Objectives:

Given the above, will assessed the impact on various farm-level and dairy market outcomes for the following programs:

1) A continuously-operated program that specifies an allowable annual growth in milk production per farm (an "allowable percentage increase"), assesses a payment on milk production on farms that exceed that allowable growth (a "market access fee") and distributes the collected funds to farms that grow milk production less than the allowable amount. This is similar to the program proposed by the Holstein Association in 2009, except that the market access fees vary by farm size;
2) A program operated similar to that above, but program operation is conditioned on values of the milk-feed price ratio. This is similar to legislation introduced by Representatives Costa and Sanders in 2009, except that the market access fees differ by farm size;
3) A supply-reduction program that is activated when a margin above feed costs is below specified trigger values for one or two months. When activated, the program would facilitate specific percentage reductions in milk marketed by paying a much lower "marginal milk price" for milk above the amounts indicated by the percentage reduction. Farms marketing milk above the allowed amount would be paid lower "marginal" milk price, but milk buyers would pay a typical market price. This difference would create a pool of funds that would be used to purchase dairy products for domestic distribution in non-competitive channels (such as food donation programs) and for facilitation of US dairy product exports. This program is similar to that proposed as the Dairy Market Stabilization Program of the Foundation for the Future (FFTF) program proposed by the National Milk Producers Federation (NMPF), except that the marginal milk price differs by farm size.

Outcomes Examined

A variety of potential impacts of these proposed programs are of interest to dairy industry stakeholders. We examine those previously included in the report by Nicholson and Stephenson in 2010, doing so for the period 2014 to 2020.

- *Prices:* Average All-milk price, Federal Milk Marketing Order (FMMO) class prices and product prices for American cheese, dry whey, butter and NDM;
- *Farm price variability:* Average absolute deviation from average All-milk price;
- *Farm profitability:* Net farm operating income, $/farm/year, for eight types of farms based on four size categories and two locations (CA and rest of US);
- *Milk production:* Total milk produced and marketed;
- *US dairy product exports:* The total value of US dairy product exports;
- *Government impacts:* Cumulative government program expenditures;
- *Dairy product sales:* Total product sales for cheese, dry whey, butter and NDM.

Description of Programs Analyzed

Program with Allowable Annual Growth Limits and Market Access Fees (Growth Management Program)

The principal elements of the original program included an allowable percentage growth in milk production per year, and a market access fee per hundredweight to be paid on either all milk or marginal milk at the producer's choice if the producer does not limit milk production to within the program-allowable annual rate. This program can be implemented continuously with fixed values of allowable growth and the market access fee (as in the program proposed by the Holstein Association) or allowable growth and market access fees can be determined with specific schedules based on the milk-feed price ratio[6], as in the legislation proposed by Costa and Sanders.

For the purposes of analyzing this proposed program, we separate the decision-making of farms that will limit production to stay within the allowable growth in a given year from those that will increase production by more than the allowable growth. The proportion of farms in each group is determined based on a distribution of farms centered on the average annual amount of growth in milk per farm for each size category (1.1, 1.4, 1.7 and 2.4% per year, respectively), adjusted based on the difference in NFOI between farms limiting production and those not limiting production. That is, larger market access fees would encourage a greater number of farms to limit production, because their NFOI would be reduced by the market access fee payments.

Because in a given year many farms will not be expanding milk production by a significant amount, many farms will "limit" production to be within the allowable growth without the need for reductions. Farms that must actively limit production to stay within the growth allowed by the program are assumed to adjust culling rates (cow numbers) to stay within the allowable amounts but continue to increase milk production per cow consistent with average annual milk per cow growth rates. Farms increasing production above the allowable growth are assumed to pay the market access fee on all milk, which is the lower-cost alternative for milk production increases above about 25% given the 5:1 ratio for market access fees on marginal and all milk in the original legislation. Consistent with the original legislation, the model accounts for the process of observing the milk-feed price ratio in a given quarter, 30 days' notice provided by the Secretary of Agriculture and the subsequent quarterly periods for measuring milk production and making or receiving payments.

The Holstein Association originally proposed allowable annual growth values ranging from 1 to 2%, with Market Access fees paid on amounts above that growth of $2 to $3 per cwt. For the purposes of this report, we analyzed two options, each with smaller allowable growth but lower average market access fees (Table 1). In addition, we specified different values of allowable growth and market access fees by farm size. Both versions of the continuously operated program allowed growth of 1.0% per year. For one program version, a market access fee for production above that amount of growth ranged from $0.25/cwt for farms with less than 100 cows to $1.00/cwt for farms with more than 2000 cows. A second more restrictive option allowed

[6] The use of the milk:feed price ratio has been criticized as a measure of farm profitability, and a margin over feed cost may be preferable. In principle, either could be used to determine allowable growth and market access fees under this type of program.

growth of 1% per year but would charge larger market access fees for farms exceeding that growth with more than 500 cows (Table 1).

Table 1. Assumed Allowable Annual Growth in Milk Production and Market Access Fees by Farm Size for Two Programs with Continuous Operation

Assumption	Continuous MAF 1	Continuous MAF 2
Allowable growth, %/year	1%	1%
Market Access Fee, $/cwt		
1-99 cows	0.25	0.25
100-499 cows	0.50	0.50
500-1999 cows	0.75	2.00
2000+ cows	1.00	3.00

The legislation proposed by Costa and Sanders in 2009 linked the allowable annual growth and the market access fee to value of the milk-feed price ratio with specific schedules (rather than fixed values in the Holstein Association proposal). The intention of this linkage was to make the program more responsive to changing market conditions, that is, allowing more growth and lowering market access fees when the milk-feed price ratio was high (above 2 in their original proposal), and being more restrictive when the milk-feed price ratio was low. We evaluated the initial schedule (Figure 1) proposed by Costa and Sanders and determined that a program using it would have very limited impacts in the market environment that characterized the period since 2014. This is because the milk feed price ratio was often above the threshold value of 2, which thus would have allowed 3% annual growth and low market access fees during the period 2014 to 2018. As a result, for two scenarios implementing this program we modified the schedules linking the milk-feed price ratio to the allowable growth and market access fees to be more consistent with market conditions observed in the past five years (Table 2). The schedules used a milk-feed price ratio of 2.5 rather than 2 as a “neutral” (no growth) threshold and specified market access that differed by farm size.

Table 2. Assumed Allowable Annual Growth in Milk Production and Market Access Fees by Farm Size for Two Programs Conditioned on the Milk:Feed Price Ratio

Assumption	Non-Continuous MAF 1	Non-Continuous MAF 2
Allowable growth, %/year		
Milk:Feed Price Ratio < 1.75	-3%	-3%
Milk:Feed Price Ratio > 1.75 & < 2.5	0%	0%
Milk:Feed Price Ratio > 2.5	+3%	+3%
Market Access Fee, $/cwt		
Milk:Feed Price Ratio < 2.5		
1-99 cows	0.25	0.25
100-499 cows	0.50	0.50
500-1999 cows	0.75	2.00
2000+ cows	1.00	3.00
Milk:Feed Price Ratio > 2.5 & < 3.0		
1-99 cows	0.065	0.065
100-499 cows	0.13	0.13
500-1999 cows	0.195	0.52
2000+ cows	0.26	0.78
Milk:Feed Price Ratio > 3.0		
1-99 cows	0.015	0.015
100-499 cows	0.03	0.03
500-1999 cows	0.045	0.12
2000+ cows	0.06	0.18

Marginal Milk Pricing Above Allowed Milk Production with Funding of Domestic Purchases and Supporting Export Sales (Dairy Market Stabilization Program)

This program proposal consists of a marginal milk pricing component, where farms receive a low price on any milk marketed exceeding the amount allowed when a milk-feed margin value is below certain trigger values. We assume that the margin over feed cost used for the Dairy Margin Coverage (DMC) is used as a program trigger. This margin is calculated based on the difference between the All-Milk price and the value of a ration based on alfalfa hay prices, soybean meal prices and corn prices (adjusted to the Chicago Mercantile Exchange values). In the original program milk all producers would receive a marginal milk price (set to $0/cwt) for all milk marketed above a required production decrease linked to the value of the margin with a schedule that increased reductions for lower margins. This is similar in concept to the use of a schedule associated with the milk-feed price ratio described above, where lower margins would be associated with larger reductions in the amount of milk that would receive the market price for milk rather than the marginal value. In one version of the proposed DMSP program, the program was triggered when margins fell below $4/cwt for one month or $6/cwt for two consecutive months. Reductions of milk marketing ceased when the margin increased above $6/cwt for two consecutive months, or when the US price of cheddar cheese or NDM some percentage above the "world" market price for two consecutive months.

Other dairy industry analysts have pointed out that this program with its original structure as described above would not have been triggered during 2014 to 2018 because the margin conditions for activation were not met. Moreover, with the passage of the 2018 Farm Bill and the implementation of the Dairy Margin Coverage (DMC) with $9.50 maximum margin coverage (and a $5/cwt "catastrophic" margin coverage), the trigger values of $4/cwt and $6/cwt seem too low for the program to have substantive impact in the future. Thus, we modified the trigger to be an average margin of either $8.00/cwt for one month or $9.50/cwt for two months, with de-activation of the program is the average margin was above $9.50 for two consecutive months. We developed two scenarios that modified the schedule linking require marketed milk reductions to the margin value. The first scenario required of all farms a 3% reduction when the $8.00/cwt margin condition is met, or a or 2% reduction when the margin falls below $9.50/cwt. The second scenario used the same triggers but allowed farms with less than 500 cows to reduce milk production by 1.5% and 2.25% instead of 2% and 3%. We used the average of prices for American cheese and NDM in the European Union and Oceania as the comparison price, and the program would be de-activated if the US prices for these products was 20% above that average for two consecutive months. As in the original program, we set the value of "marginal milk" equal to $0/cwt for farms with more than 500 cows. For farms with less than 500 cows, marginal milk prices would be low but non-zero, ranging from $2/cwt to $8/cwt (Table 3)

Table 3. Assumed Required Percentage Milk Marketing Reductions and Marginal Milk Prices by Farm Size for Analysis of Two Marginal Milk Pricing Programs

Assumption	Marginal Milk Pricing 1	Marginal Milk Pricing 2
Required Percentage Marketings Reduction		
Margin below $8/cwt for 1 month		
1 – 499 Cows	-3%	-2.25%
500+ Cows	-3%	-3%
Margin below $9.50/cwt for 2 months		
1 – 499 Cows	-2%	-1.5%
500+ Cows	-2%	-2%
Marginal Milk Price, $/cwt		
1-99 cows	$8.00	$4.00
100-499 cows	$4.00	$2.00
500-1999 cows	$0	$0
2000+ cows	$0	$0

Buyers would be required to pay at least the current classified prices for all milk marketed (including marginal milk), which would create a pool of dollars that can be spent on purchase of dairy products for distribution outside of commercial channels (such as school or other feeding programs) or for facilitation of export sales. For domestic purchasing programs, we assume all funds are allocated to purchase of American cheese based on previous work (Nicholson and Kaiser, 2008[7]) that indicates allocating funds to promotion of cheese provides larger returns. For facilitated export sales, we assume that funds collected would be spent to bridge any price gap between the US price and the average of EU and Oceania prices, with 80% of the funds allocated exports of American Cheese, 10% for NDM and 10% for butter. Funds are assumed spent at a rate proportional to the funds available (the accumulated difference between funds received and funds expended on product purchases). The rate is set so that if no further funds were collected, all money would be spent within approximately 12 months.[8]

Uncertainty exists about how dairy farmers would respond in aggregate to required milk marketing reductions under such as marginal milk pricing plant, in part because dairy producers face a relatively complicated set of incentives under this program, particularly when combined with the DMC program. Our previous work identified three possible behavioral options: 1)

[7] Nicholson, C. F. and H. M. Kaiser. 2008. Dynamic Impacts of Generic Dairy Advertising. *Journal of Business Research*, 61:1125-1135.

[8] As a product, cheese is readily used in food donations. In practice, NDM may be bartered or swapped for other dairy containing products such as yogurt, soups, etc.

dairy farmers continue to respond to long-term profitability to determine the desired level of cow assets (numbers) which is affected by the program but not fully in the short term, 2) dairy farmers respond to long-term profitability with regard to milk production, but find alternative uses for marginal milk (such as calf feeding, or disposal) so as to reduce marketings by an amount sufficient to avoid receiving the marginal milk price on at least some of their milk, and 3) dairy farmers respond immediately and fully to reduce milk production (and thus, marketed) to a level that avoids receiving the marginal milk price on a significant proportion of their milk. Consistent with our 2010 analysis, we assume a "compliance rate" with required reductions of 65%, which means that milk marketed would be larger than that indicated by the required reductions. We discuss the importance of this assumption below.

Assumptions Regarding Other Programs and Market Impacts

For both programs, our analysis assumes operation of the MPP-Dairy/Dairy Margin Coverage program as implemented from 2014 to 2018 (MPP-Dairy) and re-structured in the 2018 Farm Bill (DMC). We assumed relatively low participation in MPP-Dairy prior to 2018, with the largest proportion of producers in all four size categories and both regions (California and the rest of US) signing up for catastrophic margin coverage at the $4/cwt level, and small amounts of sign-up at the $6.50/cwt and $8/cwt margin values. For the more generous DMC program, we assumed that 75% of producers would sign up for $9.50/cwt margin coverage, and another 20% would sign up at the $5/cwt margin level. We also incorporated changes to the definition of the Class I Mover under Federal Milk Marketing Orders (FMMO) in January 2019 from the provisions of 2018 Farm Bill and the transition of California from state marketing order regulation to a FMMO in November 2018. The model scenarios do not include other authorized risk management programs currently (such as the Livestock Growth Margin-Dairy and the Dairy Revenue Protection program) because these and (other risk management programs) are likely to have limited impact on price variability.

With regard to developments due to trade disputes or new trade agreements, we retained NAFTA provisions for trade with Mexico and Canada (given relatively small differences between them and the USMCA). We used actual NASS-reported corn and soybean prices through October 2018 for the calculation of the margin values, and trend projections from the Chicago Mercantile Exchange (CME) through various months in 2020. Alfalfa prices were assumed to increase at a rate of 1% per year from October 2018 values. We represented other effects of the ongoing trade dispute with China via a 25% initial reduction in US exports of all tradable dairy products to China beginning in June 2018. Direct payments to dairy farmers to compensate for trade losses were modeled for December 2018 with $0.04/cwt paid on total milk production during June to December 2018.

It is also important to note that we do not consider the administrative arrangements and specific program provisions appropriate to enforce the analyzed programs. Rather, we assume that these can be developed and implemented in a manner that will allow the programs to be effective.

Results

Our analyses indicate that many of the programs can reduce the degree of price variation, but generally only to a moderate degree, in part because of the lower degree of variability during 2014 to 2018 and in part because the programs have price-enhancing effects that can tend to increase variability compared to the Baseline. All of the Market Access Fee programs had price-enhancing (and margin-enhancing) effects, and the magnitude of these effects was associated with the size of the fees. The marginal milk pricing program resulted in average milk prices very close to the Baseline value but will a good deal less variation. However, both the variation in prices relative to the baseline and price enhancement effects varied over time (Figures 3 to 11). Variation and price enhancement tended to be shortly after the assumed program implementation time, January 2014. After the initial implementation, it was more common that prices were lower than they would have been under the Baseline, but the overall average price and margin over feed costs were increased under the assumed program provisions. Table 1 provides detailed results for analyzed outcomes, and Tables 2 and 3 report differences and percentage differences between the Baseline and program outcomes.

Key specific results include:

- MAF-based Programs increased the average all-milk price during 2014 to 2020 by $0.40 to $1.10/cwt. Larger and more consistent increases result from continuous operation of an allowable growth and market access fee program (like that proposed by the Holstein Association) than for a program triggered by a milk-feed price ratio of 2.5. A program triggered by margins of $8.00 and $9.50/cwt tended to have smaller and less consistent price enhancement effects, in part because the program would be switched on and off frequently, sometimes due US NDM and cheese prices more than 20% higher than the average of the EU and Oceania.
- Under a MAF program, the changes in the milk price would be accompanied by refund payments averaging between $0.78/cwt and $.88/cwt, increasing the total revenue per cwt (from price and refunds combined) by $1.19/cwt to $2.98/cwt.
- Price variation would decrease under most programs, between $0.01/cwt and $0.25/cwt. For example, the deviation from the average all-milk price during 2014 to 2020 in the Baseline scenario was $0.88/cwt[9], whereas this was reduced to $0.66/cwt for the continuously-operated MAF-type program with allowable growth of 1% per year and a Market Access Fee ranging from $0.25/cwt to $1.00/cwt.
- The programs generally increased the average Net Farm Operating Income (NFOI) for all size farms, often by substantial percentages. However, under the MAF-based programs farms that increased producer by more than the allowable annual percentage—those who paid market access fee on all milk—saw decreased average incomes compared the Baseline. However, an individual expanding farm would see this decrease only in the year of expansion[10], and the market access fee would be offset to some extent by higher milk prices.
- Total average annual milk marketed in the US during 2014 to 2020 decreased under the MAF-based programs compared the Baseline, by 2.9% to 6.6%. Average annual milk marketed increased under the MMP program, in part because initially higher prices

[9] This is value comes from calculating the average all-milk price for the Baseline scenario and calculating the average of the absolute value (making negative values positive) of the all of the difference from that average during 2014 to 2020.

[10] For example, a farm expanding from 500 to 1000 cows with production of 20,000 lbs per cow per year in 2015 would pay a $2/cwt MAF on the larger production amoun but would also benefit from a milk price $1.10/cwt higher, for a net payment of $0.90/cwt or $180,000. The additional revenues from the higher milk price during 2016-2020 for an assumed constant milk production would be $1.1 million, and the higher revenues in 2016 would be larger than the MAF paid during 2015.

facilitated increased production later the program was sometimes terminated due to NDM and cheese prices more than 20% higher than in EU and Oceania.

- Consistent with the impact on farm milk prices, the MAF-based programs increase FMMO class prices and product prices, with larger impacts on Class IV and Class II prices (due to larger impacts on NDM and butter prices, as these are assumed to be the uses of skim and cream that balance supply and demand in a current month). MMP-based programs, which lower average annual milk prices, result in lower average Class II and IV prices, but higher Class I and Class III prices.
- MAF-based programs reduce the average annual value of US dairy product exports by 8 to 18%, depending on the degree of price enhancement. MMP-based programs, because they lower milk and NDM and butter prices, result in larger US dairy product exports.
- Government expenditures (net of MPP-Dairy/DMC premium payments) during 2014-2020 under the Baseline are projected to be $1,676 million, much of which is due to indemnity payments under the DMC program during 2019-2020. All of the programs reduce government expenditures, by $329 million to $1,245 million.
- US domestic dairy product sales are generally decreased by both types of program, from very small amounts to 3% for the programs with the largest price-enhancing effects. The MMP-based programs would decrease American cheese sales by 7% increase US sales of cheese other than American styles, NDM, butter and dry whey.
- The program would reduce the rate of farm exits during the 2014-2020 period, primarily due to decreases in the rate of business failures. Although this affects all farm sizes, more small (1-99 cows) and medium (100-499 cows) farms are retained as a result of these policy initiatives. Although the simulation outcomes suggest retaining as many as 7,000 more farms by 2020, we believe this estimate is likely too high[11].

Comments on the Differences in Outcomes between the MAF and MMP-based Programs

There is a contrast in the outcomes between the two types of programs, most notably that a MAF-based program would enhance average milk prices during 2014 to 2020 and a MMP-based program would reduce them. It is worth exploring further why these differences occur, and how they are related to program structure and the interaction with market conditions.

The differences arise in part because of how the triggers interact with market conditions induced by the program, and in part because of the nature of the reduction in milk produced or marketed. Under the MAF-based program, the use of a schedule of allowable growth linked to the milk-feed price ratio with a value of 2.5 means that the program would be active very frequently, with a zero or negative values of allowable growth in all but nine months during the 84 months from January 2014 through December 2020. In contrast, reductions are not required under the MMP-based program for 27 of the 84 months, and their timing differs somewhat from that under the MAF-based programs—being more directly linked to previous required reductions. The more consistent application of the restrictions under the assumed implementation of the MAF program

[11] The model is calibrated to replicate the number of farms in 2017 (the latest reported value) but the exit functions may not sufficiently accurately reflect farm financial incentives and thus may overstate the impact of the programs. Nevertheless, we find it plausible that the programs could have a notable effect on farm exits.

implies greater price stability and price enhancement than for MMP programs, at least as both programs are assumed to be implemented.

Another substantive difference between the two programs (again, as assumed implemented) is the nature and extent of their milk supply control elements. The MAF-based programs specify allowable *growth* in *milk production*, whereas the MMP program specifies *reductions* in *milk marketed*—and assumes only partial compliance with the required reductions. Thus, the MAF-based program is assumed to result in the *culling of cows* when necessary to stay within allowable production growth limits (and the growth limits are often 0% per year). In addition, farms that are expanding production above the amount of allowable growth are required to pay the market access fee, which lowers their profitability compared to farms that comply with the allowable production growth and also compared to farms in the Baseline. This has the effect of slowing the growth in milk production on *all* farms, not just those that stay within the amount of allowable growth. The combination of requiring culling of cows and slowing milk production growth on all farms has a longer-lasting effect on milk production and allows for increased stability and enhanced milk prices.

The MMP-based program requires reductions in the milk marketed, not in milk production, so our analysis assumes that farmers will maintain the cow numbers that are indicated by current levels of profitability, while finding other uses for marginal milk when reductions in marketed milk are required. This means that milk marketed can come back quite quickly after when reductions are no longer required (which as noted above occurs more frequently under this type of program than the allowing of positive growth under MAF-based programs) because the underlying production base is still in place. In addition, the enhanced profitability that initially occurs under the MMP program actually encourages farms to have more cows, partly in expectation of a time when reductions will not be required. Thus, unlike the MAF-based program, a MPP program (as assumed implemented) provides incentives for *additional milk production capacity* even when the program is *restricting milk marketings*. In addition, based on discussions with industry analysts prior to our 2010 study, we assumed a 65% "compliance rate" with the provisions of the marketing limitation. Specifically, this means that the amount of milk marketed per farm was equal to the allowable marketings (amount of milk marketed 12 months earlier multiplied by one minus the required percentage reduction, resulting in a value like 97% of previous-year *marketings*) times the compliance rate of 65%, plus 35% (100%-65%) of the amount of milk currently *produced*—and as noted above, production can actually increase given the profitability incentives for additional cows. Thus, the supply-control components of the MPP program (as assumed implemented) are substantively less restrictive than those under the MAF-based program.

We also assessed the impact of a 95% compliance rate, and this was much more effective at controlling supply increases and increased average milk prices by about $0.15/cwt, although it increased variability in milk prices compared the Baseline. Greater variability compared to the Baseline occurred because the MMP program with high compliance resulted in a series of high-amplitude cycles primarily driven by the switching on and off of the program.

The key conclusion from the above is that programs that operate more consistently and provide greater restrictions on milk production growth will result in larger reductions in price variability and (potentially) larger farm milk price and NFOI enhancement. A MMP program structured to restrict milk production rather than marketings could be developed and would likely be more effective at managing milk production growth than the current program structure.

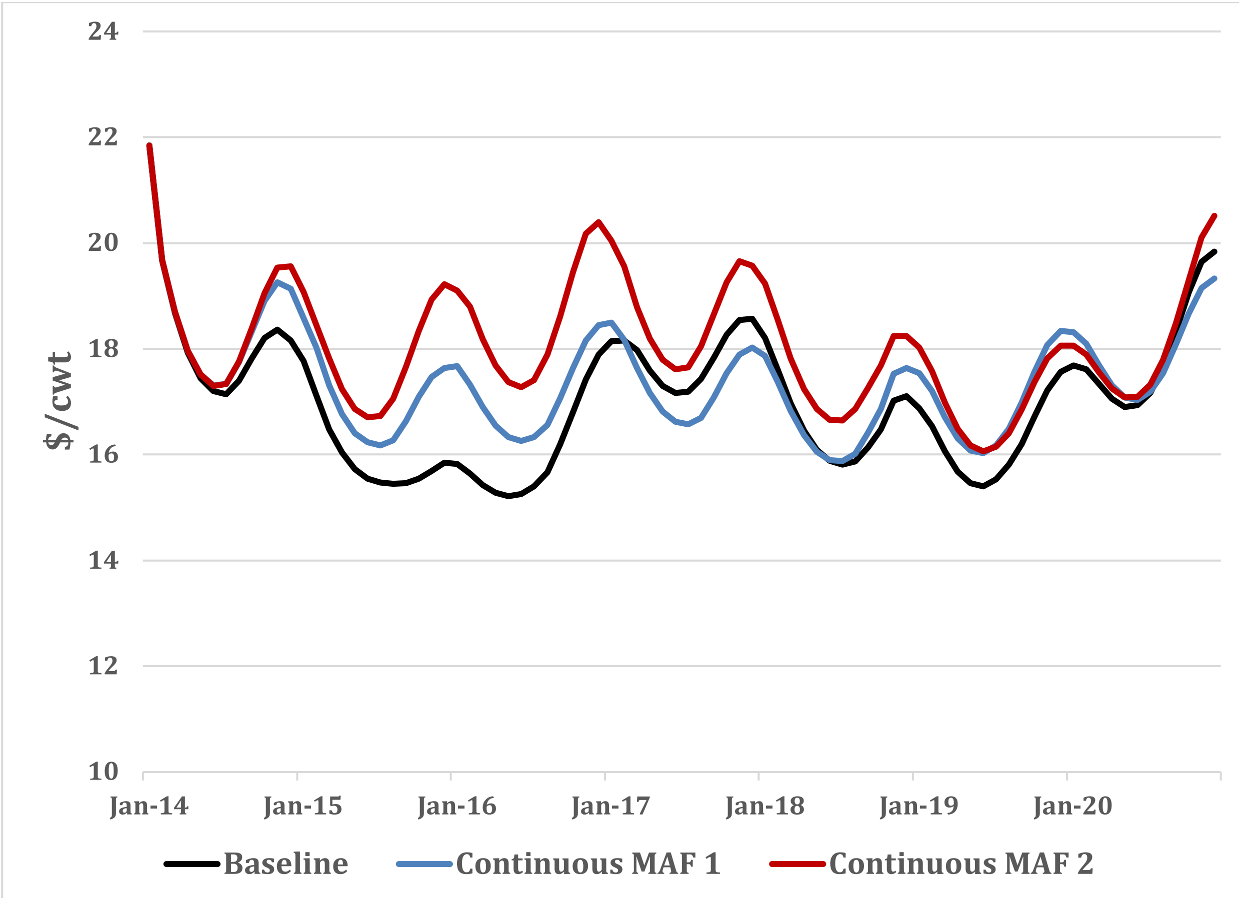

Figure 1. Simulated All Milk Prices for Baseline and Two Continuous Allowable Growth and Market Access Fee Programs, 2014-2020

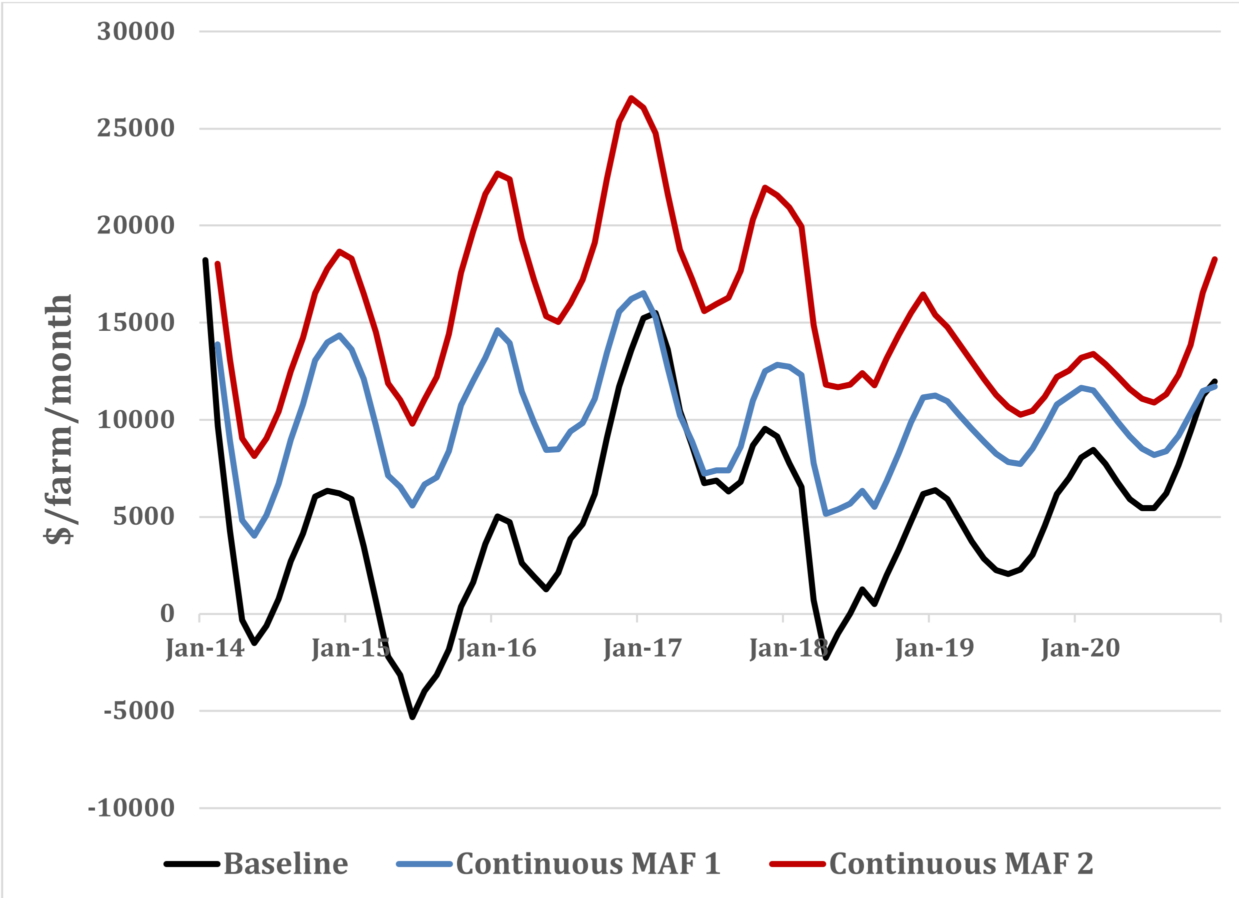

Figure 2. Simulated Net Farm Operating Income ($/Month) for a Farm with Approximately 200 Cows, Baseline and Two Continuous Allowable Growth and Market Access Fee Programs, 2014-2020

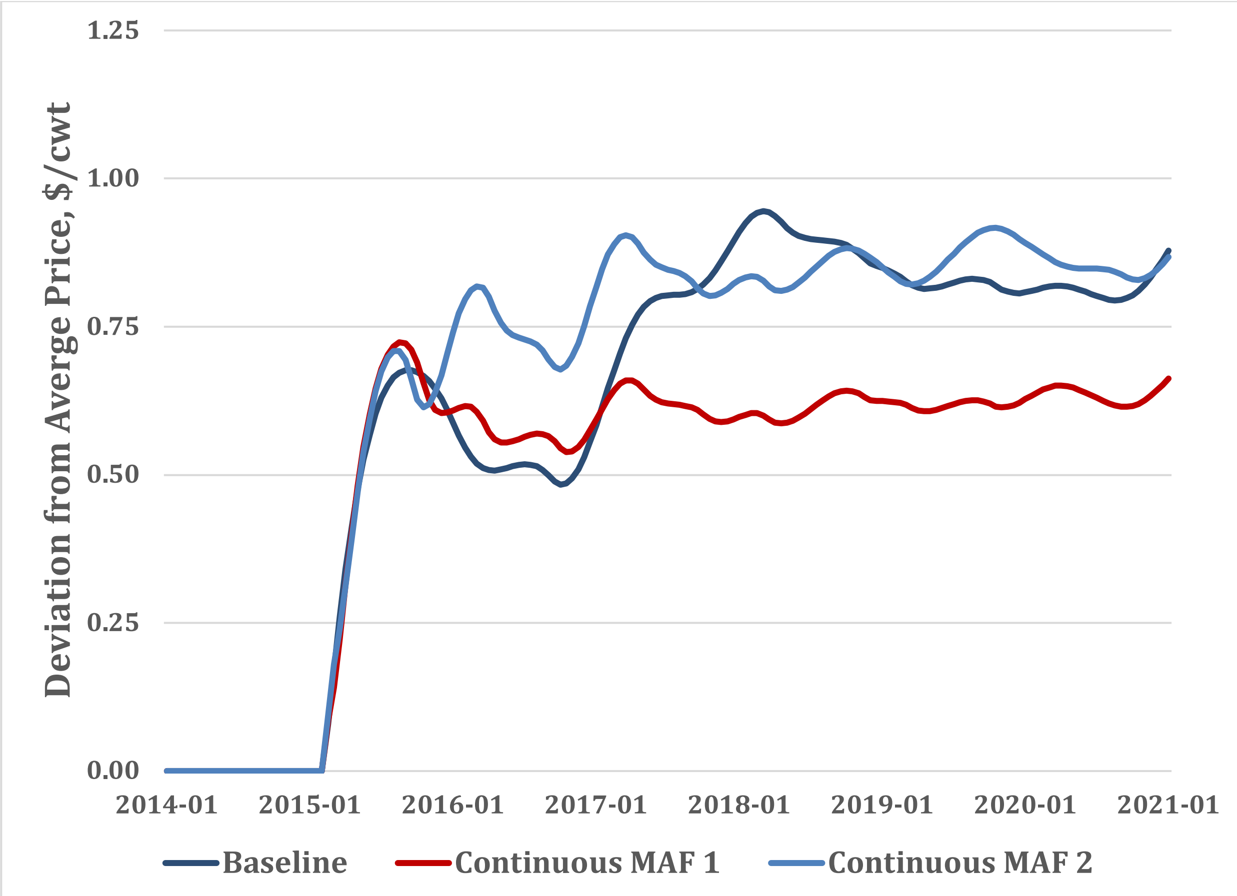

Figure 3. Simulated Average Price Deviation for Baseline and Two Continuous Allowable Growth and Market Access Fee Programs, 2014-2020

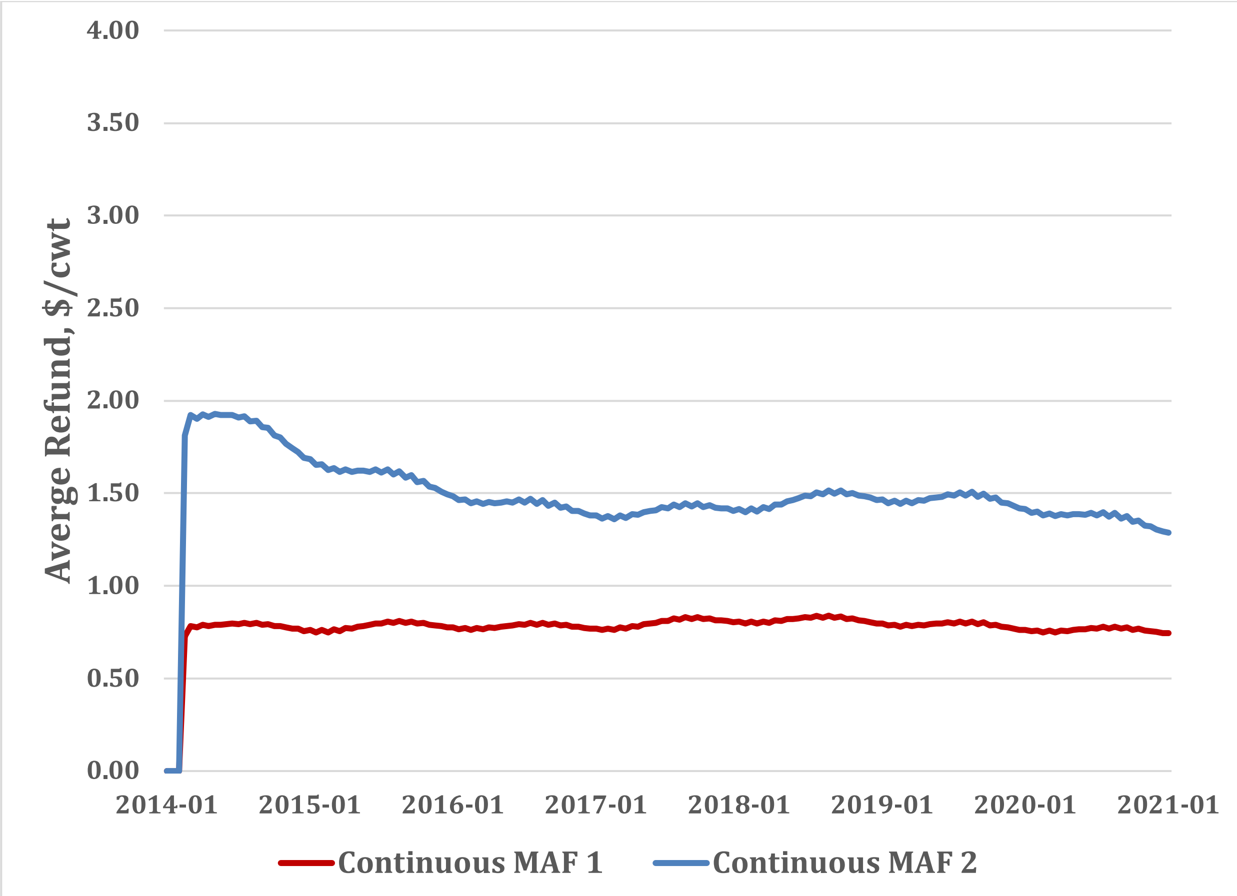

Figure 4. Simulated Refund Per Hundredweight for Farms Within Allowable Growth, Two Continuous Allowable Growth and Market Access Fee Programs, 2014-2020

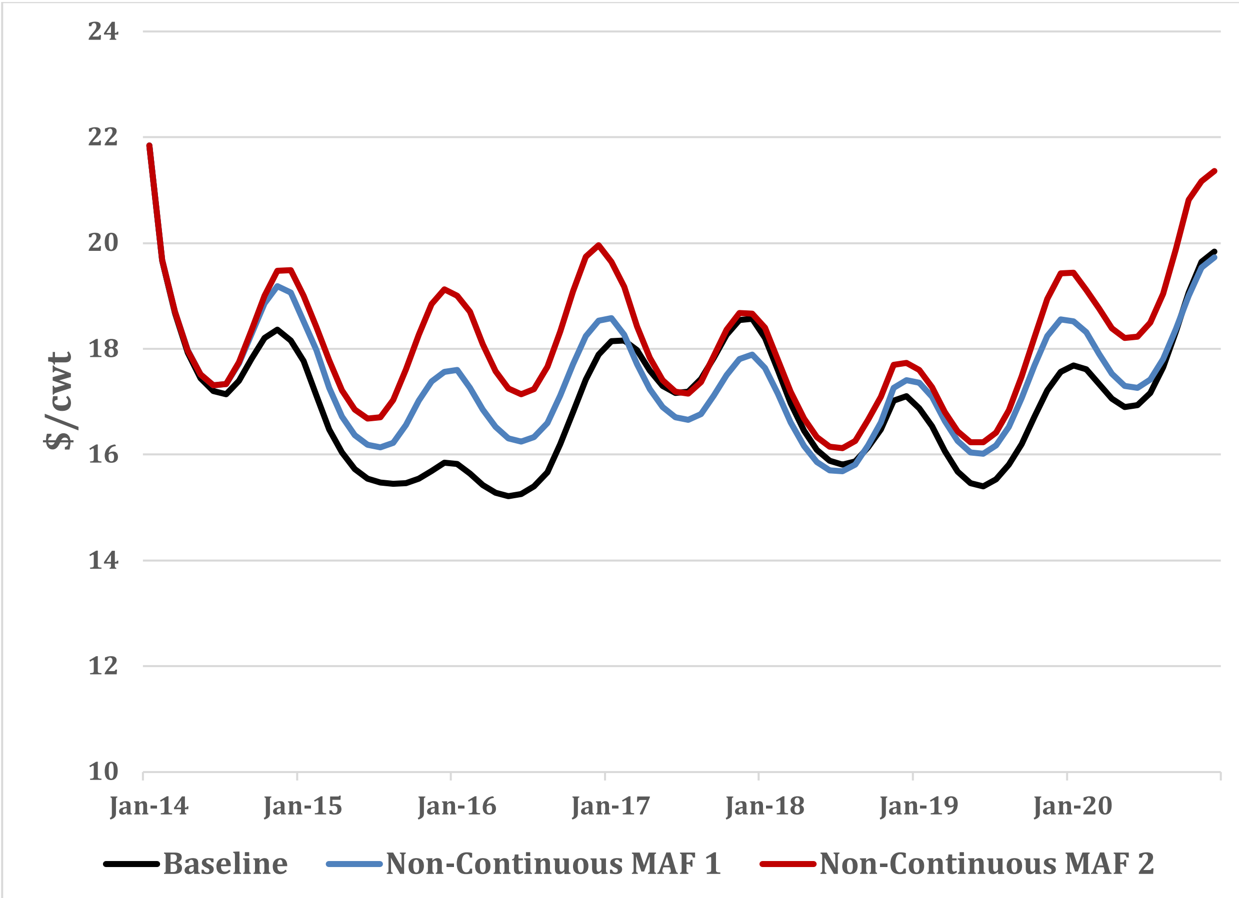

Figure 5. Simulated All Milk Prices for Baseline and Two Allowable Growth and Market Access Fee Programs Linked to the Milk-Feed Price Ratio, 2014-2020

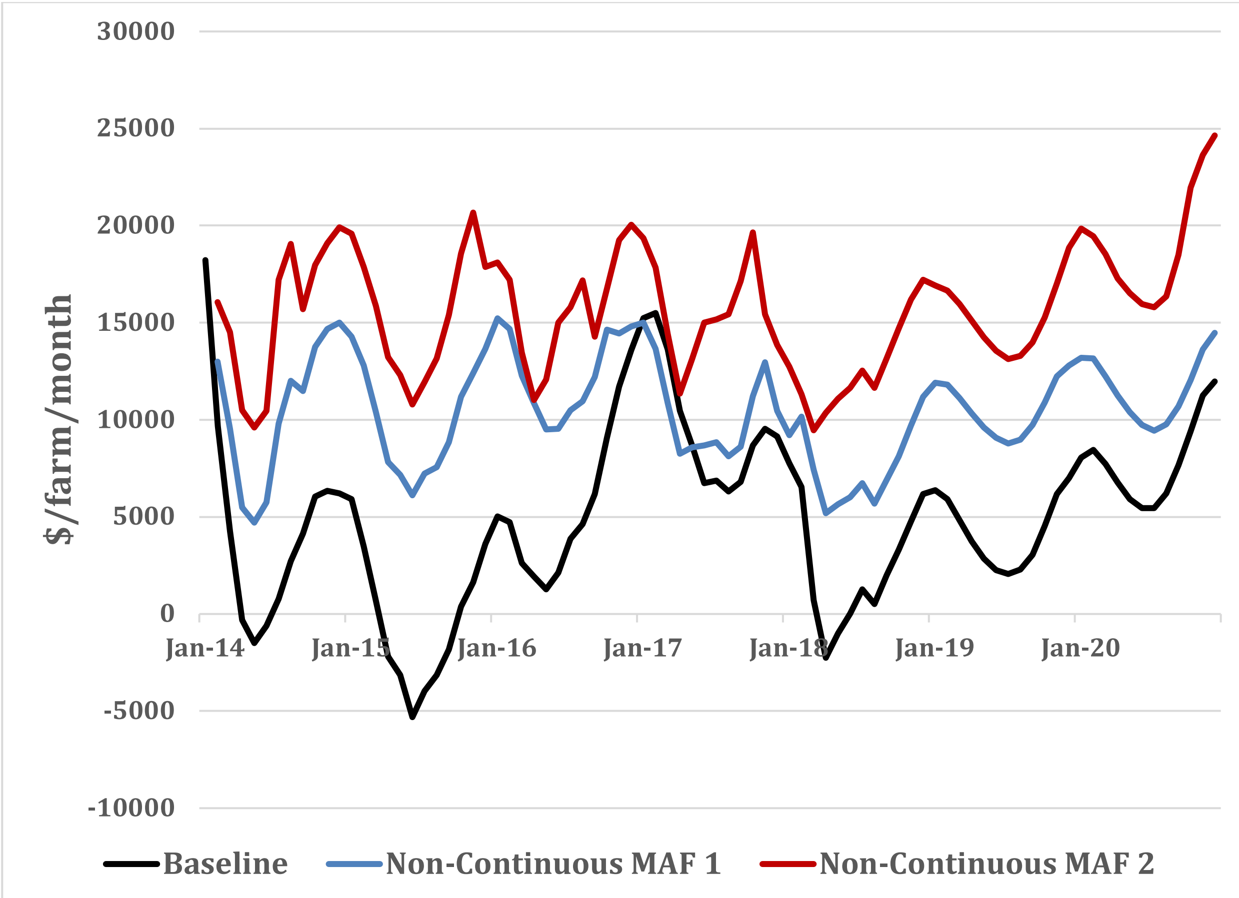

Figure 6. Simulated Net Farm Operating Income ($/Month) for a Farm with Approximately 200 Cows, Baseline and Two Allowable Growth and Market Access Fee Programs Linked to the Milk-Feed Price Ratio, 2014-2020

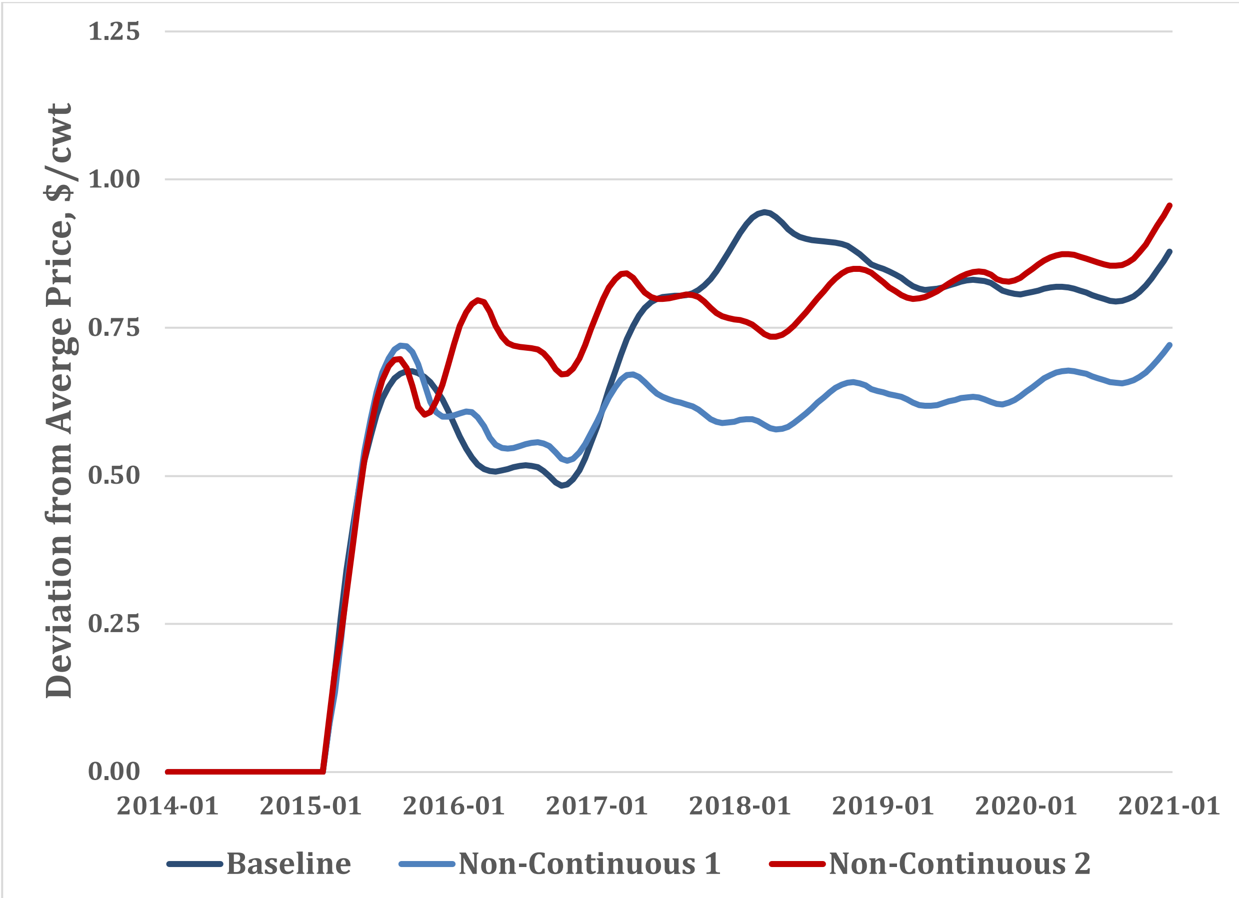

Figure 7. Simulated Average Price Deviation for Baseline and Two Allowable Growth and Market Access Fee Programs Linked to the Milk-Feed Price Ratio, 2014-2020

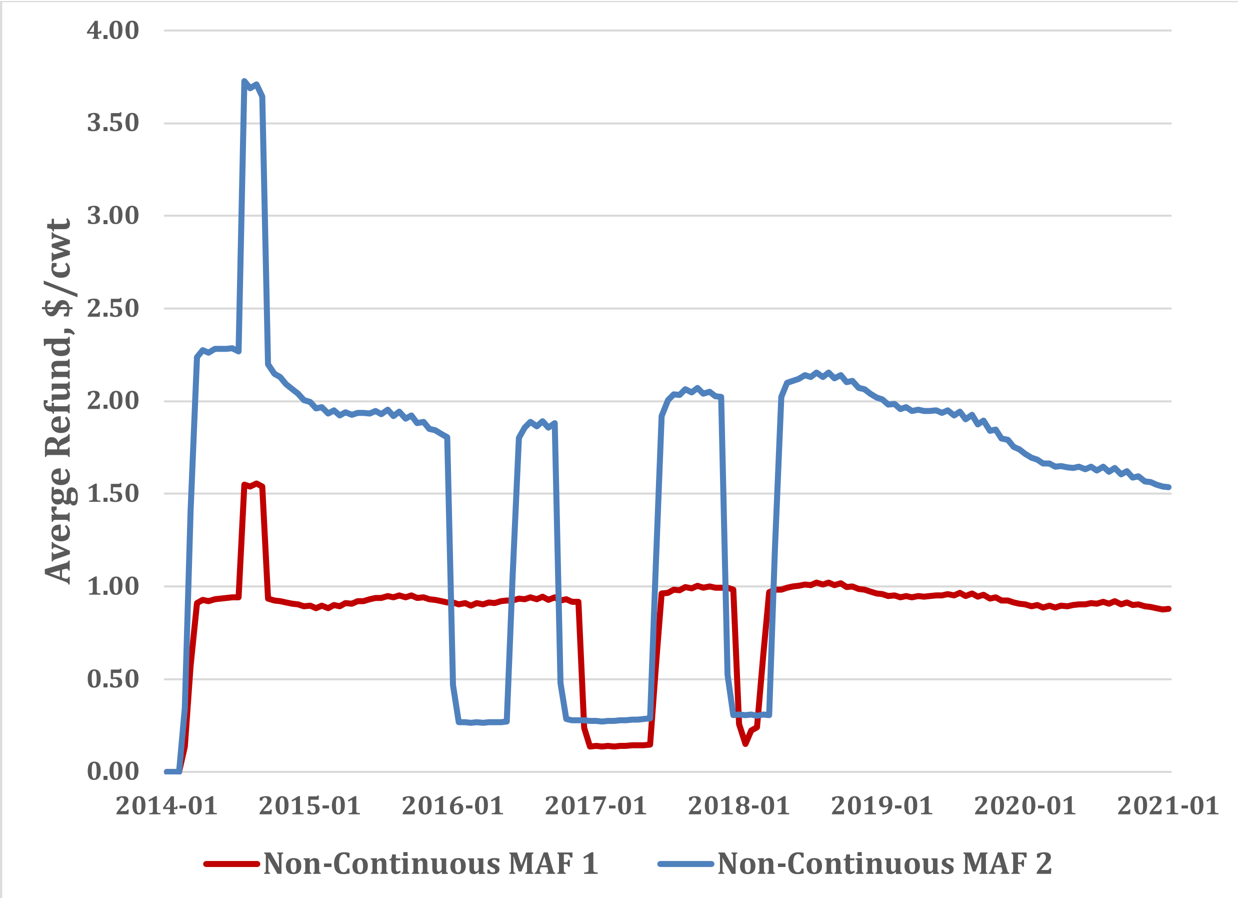

Figure 8. Simulated Refund Per Hundredweight for Farms Within Allowable Growth, Two Allowable Growth and Market Access Fee Programs Linked to the Milk-Feed Price Ratio, 2014-2020

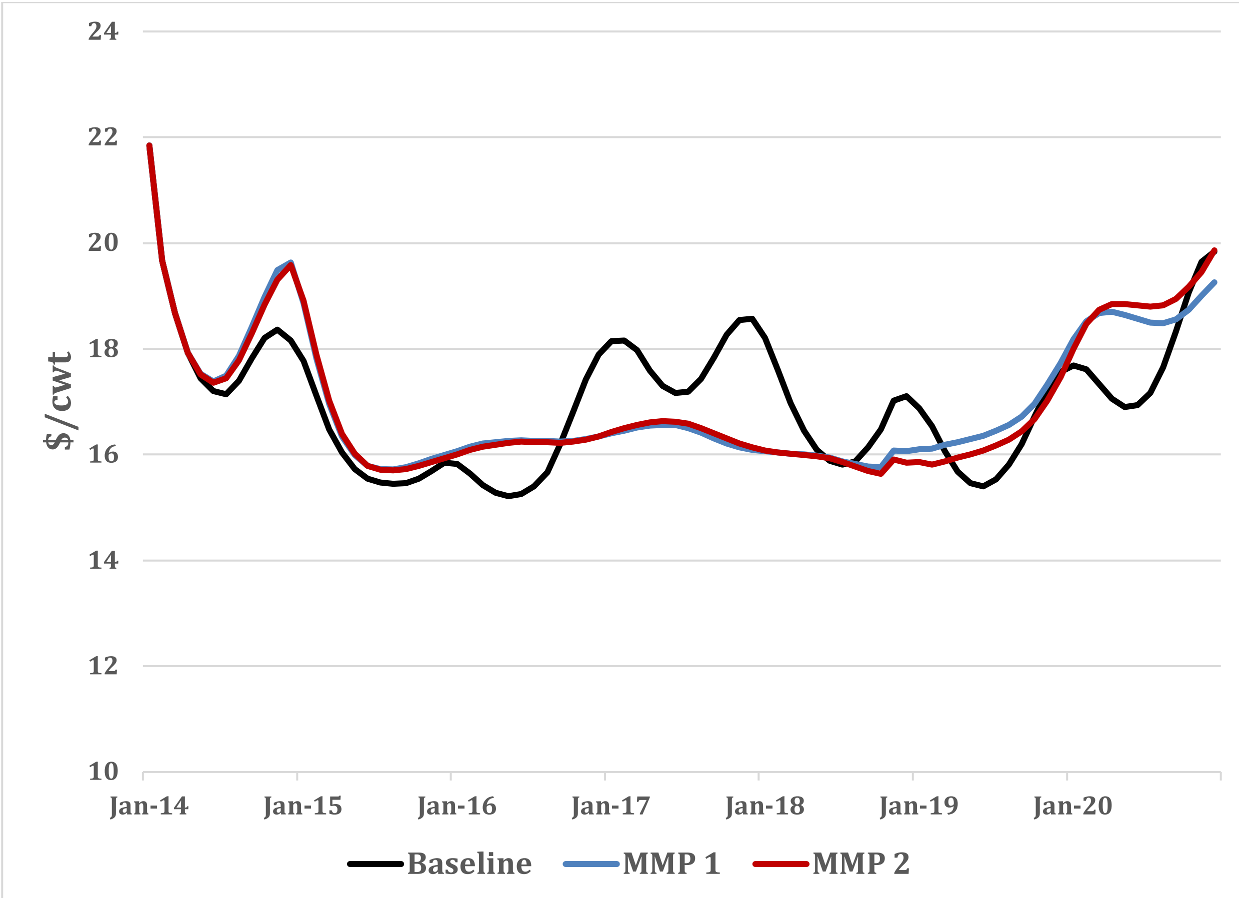

Figure 9. Simulated All-Milk Price for Baseline and Two Marginal Milk Pricing Programs Linked to the Margin Above Feed Costs, 2014-2020

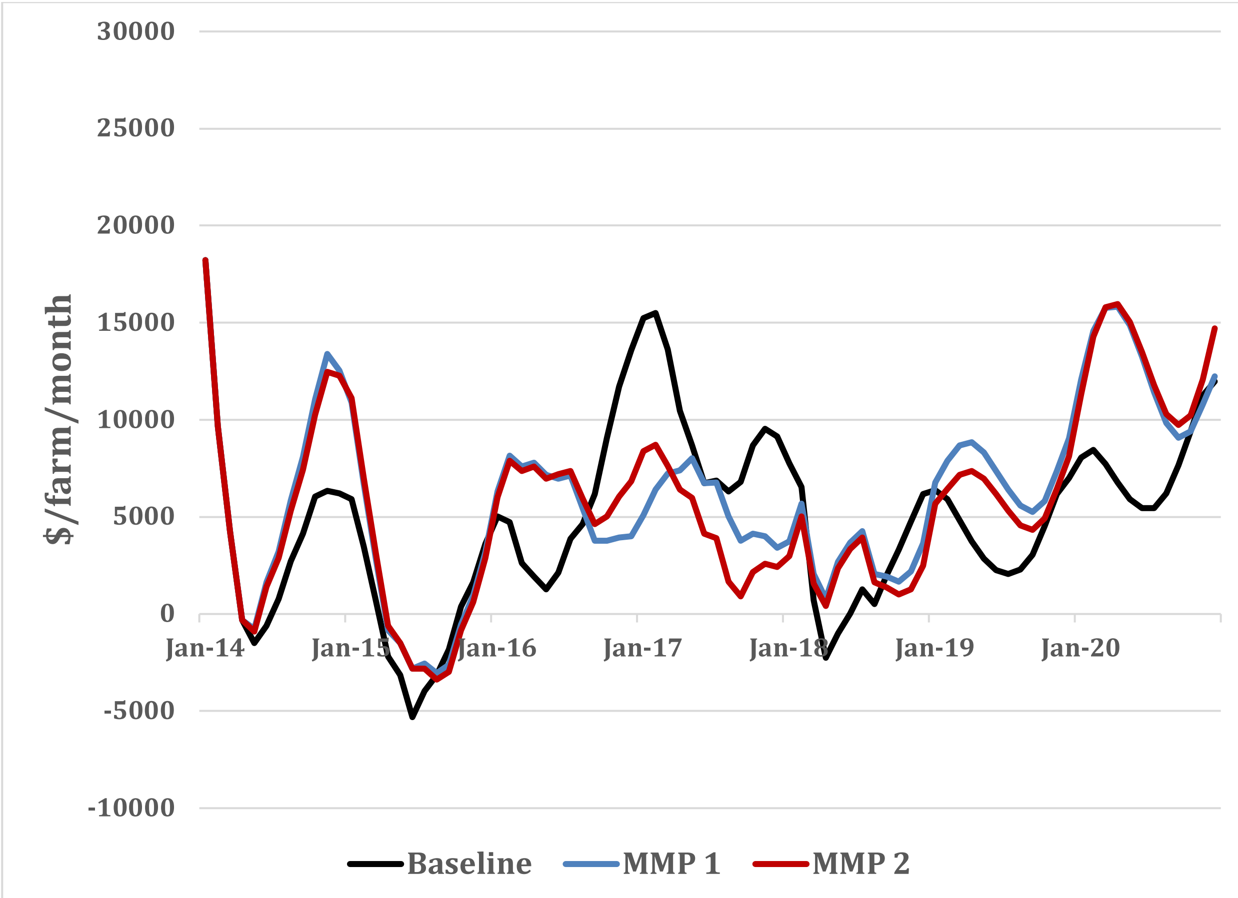

Figure 10. Simulated Net Farm Operating Income ($/Month) for a Farm with Approximately 200 Cows, Baseline and Two Marginal Milk Pricing Programs Linked to the Margin Above Feed Costs, 2014-2020

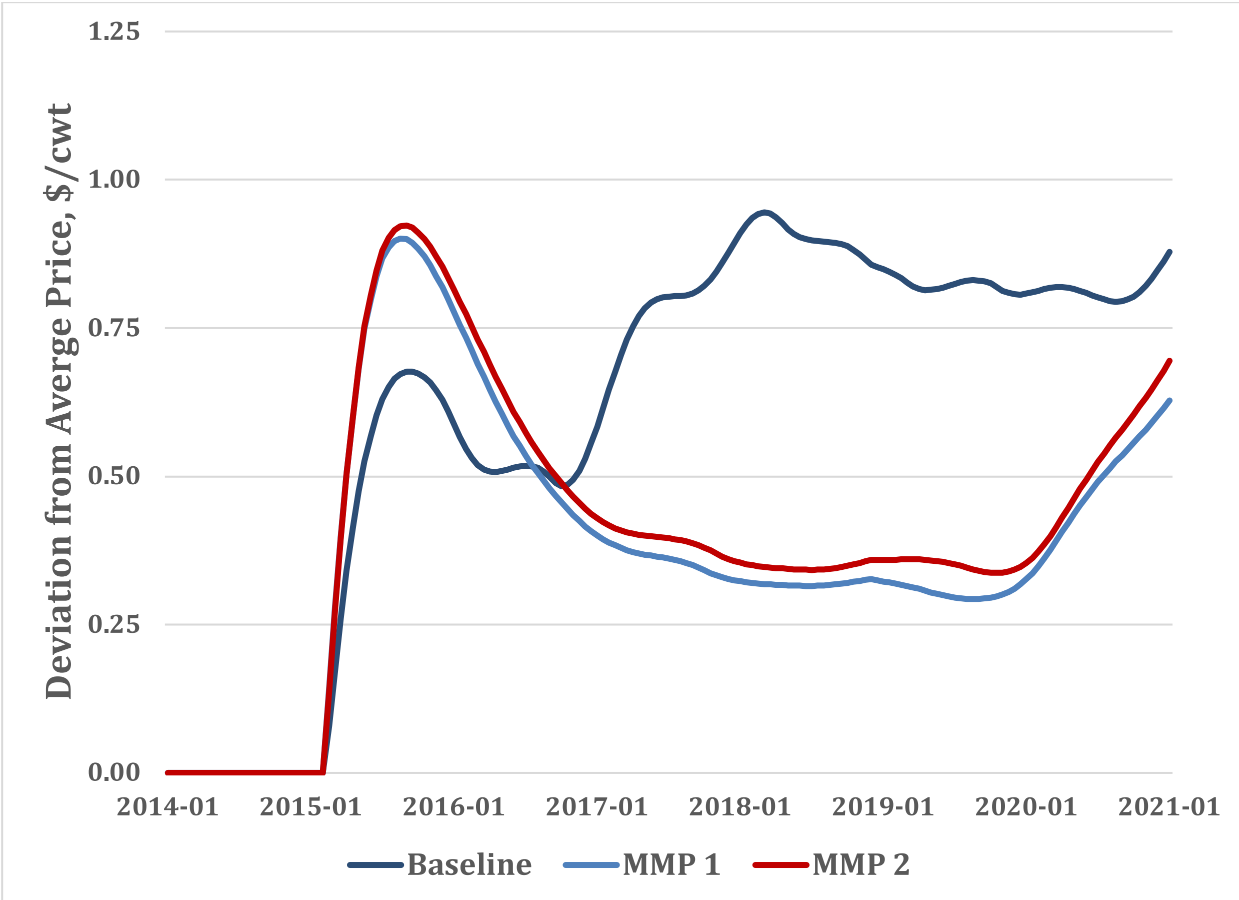

Figure 11. Simulated Average Price Deviation for Baseline and Two Marginal Milk Pricing Programs Linked to the Margin Above Feed Costs, 2014-2020

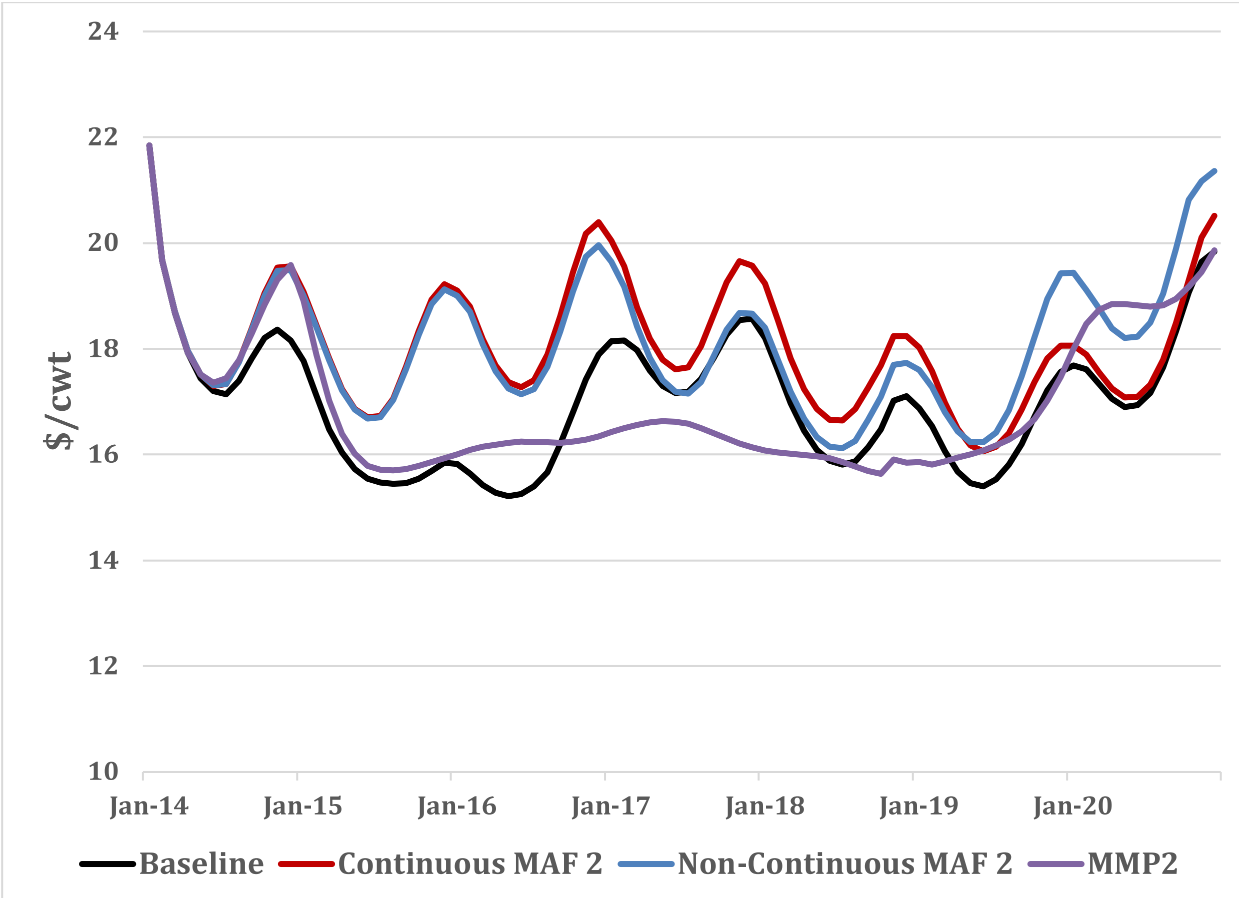

Figure 12. Simulated All Milk Price for Baseline and Most Restrictive of Each of Three Types of Programs, 2014-2020

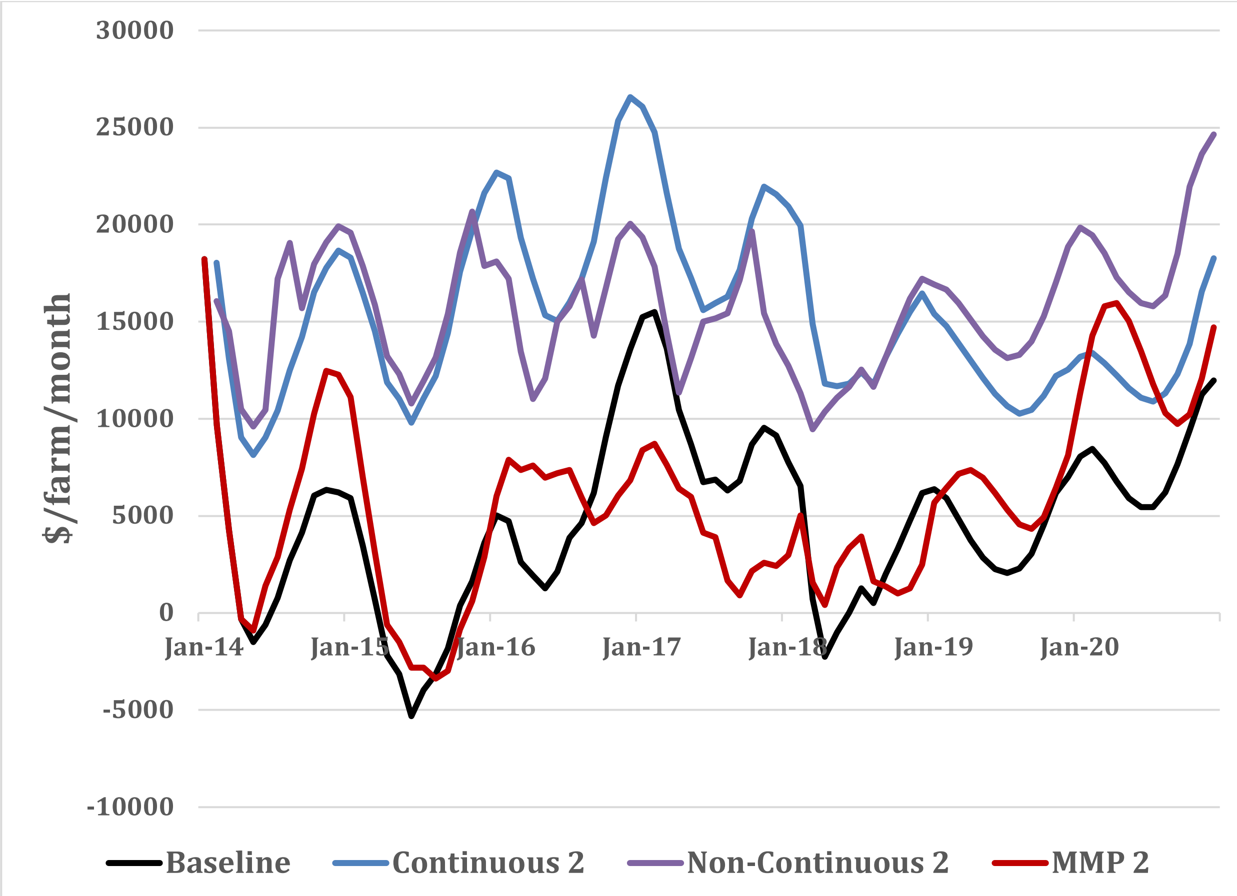

Figure 13. Simulated Net Farm Operating Income ($/Month), for a Farm with Approximately 200 Cows, Baseline and Most Restrictive of Each of Three Types of Programs, 2014-2020

Table 1. Selected Simulated Outcomes, Baseline and Six Proposed Programs, Annual Averages

Outcome	Units	Baseline	Continuous MAF 1	Continuous MAF 2	Non-Continuous MAF1	Non-Continuous MAF 2	MMP 1	MMP2
Description			*API 1% MAF $0.25 to $1.00*	*API 1% MAF $0.25 to $3.00*	*MFPR=2.5 MAF $0.015 to $1.00*	*MFPR=2.5 MAF $0.015 to $3.00*	*800 950 3% 2% MMP $0 to $8*	*800 950 3% 2% MMP $0 to $4*
US All Milk Price	$/cwt	17.43	17.44	17.95	18.70	17.68	17.50	17.57
Refund for Farms Within Allowable Growth	$/cwt	0.00	0.78	1.50	0.93	1.88	0.00	0.00
Milk Revenue for Farms Within Allowable Growth	$/cwt	17.00	18.19	19.59	18.33	19.98	16.99	16.98
Average Deviation After Program	$/cwt	0.88	0.66	0.87	0.72	0.96	0.63	0.69
Average Margin Over Feed Costs	$/cwt	8.16	8.56	9.25	8.57	9.26	8.15	8.13
NFOI, Small, US, Within	$/farm/year	33,633	52,379	68,855	53,063	66,345		
NFOI, Small, US, Not Within	$/farm/year	33,633	33,204	40,952	33,509	38,270	35,593	35,510
NFOI, Medium, US, Within	$/farm/year	58,794	129,651	195,322	136,240	197,795		
NFOI, Medium, US, Not Within	$/farm/year	58,794	48,856	82,240	50,738	76,322	72,624	68,858
NFOI, Large, US, Within	$/farm/year	359,012	712,462	981,426	724,009	962,881		
NFOI, Large, US, Not Within	$/farm/year	359,012	343,584	250,376	343,992	272,074	442,879	429,407
NFOI, Extra Large, US, Within	$/farm/year	1,844,715	3,661,143	4,780,447	3,612,609	4,553,660		
NFOI, Extra Large, US, Not Within	$/farm/year	1,844,715	1,800,513	980,006	1,852,154	1,166,020	2,087,006	2,089,798
NFOI, Small, CA, Within	$/farm/year	21,592	35,081	50,046	33,972	47,610		
NFOI, Small, CA, Not Within	$/farm/year	21,592	20,744	24,266	19,528	23,007	21,993	22,546
NFOI, Medium, CA, Within	$/farm/year	42,376	86,552	172,366	82,918	165,244		
NFOI, Medium, CA, Not Within	$/farm/year	42,376	27,972	41,039	29,081	45,246	57,448	66,893
NFOI, Large, CA, Within	$/farm/year	333,461	670,946	1,009,478	659,072	990,271		
NFOI, Large, CA, Not Within	$/farm/year	333,461	232,597	104,079	214,695	152,040	446,924	450,666
NFOI, Extra Large, CA, Within	$/farm/year	1,194,431	2,869,654	4,045,041	2,683,080	3,748,530		

Outcome	Units	Baseline	Continuous MAF 1	Continuous MAF 2	Non-Continuous MAF1	Non-Continuous MAF 2	MMP 1	MMP2
NFOI, Extra Large, CA, Not Within	$/farm/year	1,194,431	816,879	171,845	840,394	364,568	1,372,986	1,377,436
Total Milk Formally Marketed	bil lbs/year	240.7	233.6	224.8	233.7	225.3	250.2	250.6
Class I Price	$/cwt	18.88	19.28	19.92	19.28	19.92	19.37	19.35
Class II Price	$/cwt	16.10	16.55	17.27	16.56	17.30	15.18	15.16
Class III Price	$/cwt	15.71	16.04	16.52	16.04	16.53	16.37	16.36
Class IV Price	$/cwt	15.37	15.81	16.55	15.83	16.57	14.45	14.43
American Cheese Price	$/lb	1.55	1.58	1.63	1.58	1.63	1.62	1.62
Whey Product Price	$/lb	0.57	0.57	0.57	0.57	0.57	0.57	0.57
Butter Price	$/lb	1.39	1.44	1.53	1.44	1.53	1.31	1.31
NDM Price	$/lb	1.36	1.38	1.43	1.39	1.43	1.29	1.29
Total Value of US Exports	$ bil/year	9.94	9.12	8.18	9.15	8.34	10.72	10.79
Cumulative US Government Expenditures	$mil	1675.9	1346.3	1209.0	1174.8	431.2	829.0	943.7
American Cheese Sales	bil lbs/year	4.61	4.55	4.46	4.55	4.46	4.29	4.29
Other Cheese Sales	bil lbs/year	7.84	7.75	7.63	7.75	7.62	7.91	7.91
Butter Sales	bil lbs/year	2.07	2.05	2.03	2.05	2.02	2.11	2.11
Whey Product Sales	bil lbs/year	0.43	0.43	0.43	0.43	0.43	0.44	0.44
NDM Sales	bil lbs/year	1.01	1.00	0.98	1.00	0.99	1.01	1.01
US Dairy Farms	Farms	32,862	39,916	40,156	39,815	39,973	32,428	32,416

Note: In the NFOI rows reported above, "US" means farms other than in California and "CA" means California Farms. For the MAF programs, "Within" means limiting milk production growth to the allowable annual increase. "Not Within" means farms that increase production by more than the allowable annual increase, and thus pay the market access fee on all of their milk production. For DMSP programs, all farms are listed for "Not Within" entry because there are no annual allowable increases.

Table 2. Selected Simulated Outcomes, Baseline and Differences from Baseline for Six Proposed Programs

Outcome	Units	Baseline	Continuous MAF 1	Continuous MAF 2	Non-Continuous MAF1	Non-Continuous MAF 2	MMP 1	MMP2
Description			*API 1% MAF $0.25 to $1.00*	*API 1% MAF $0.25 to $3.00*	*MFPR=2.5 MAF $0.015 to $1.00*	*MFPR=2.5 MAF $0.015 to $3.00*	*800 950 3% 2% MMP $0 to $8*	*800 950 3% 2% MMP $0 to $4*
US All Milk Price	$/cwt	17.43	0.40	1.09	0.41	1.10	-0.01	-0.02
Refund for Farms Within Allowable Growth	$/cwt	0.00	0.78	1.50	0.93	1.88	0.00	0.00
Milk Revenue for Farms Within Allowable Growth	$/cwt	17.00	1.19	2.59	1.33	2.98	-0.01	-0.02
Average Deviation After Program	$/cwt	0.88	-0.22	-0.01	-0.16	0.08	-0.25	-0.18
Average Margin Over Feed Costs	$/cwt	8.16	0.41	1.09	0.41	1.10	-0.01	-0.03
NFOI, Small, US, Within	$/farm/year	33,633	18,746	35,223	19,430	32,712		
NFOI, Small, US, Not Within	$/farm/year	33,633	-429	7,319	-124	4,638	1,960	1,877
NFOI, Medium, US, Within	$/farm/year	58,794	70,857	136,528	77,445	139,001		
NFOI, Medium, US, Not Within	$/farm/year	58,794	-9,938	23,446	-8,057	17,528	13,829	10,063
NFOI, Large, US, Within	$/farm/year	359,012	353,451	622,415	364,997	603,870		
NFOI, Large, US, Not Within	$/farm/year	359,012	-15,427	-108,636	-15,020	-86,938	83,868	70,395
NFOI, Extra Large, US, Within	$/farm/year	1,844,715	1,816,428	2,935,733	1,767,895	2,708,945		
NFOI, Extra Large, US, Not Within	$/farm/year	1,844,715	-44,202	-864,709	7,439	-678,694	242,291	245,083
NFOI, Small, CA, Within	$/farm/year	21,592	13,489	28,454	12,380	26,018		
NFOI, Small, CA, Not Within	$/farm/year	21,592	-847	2,675	-2,063	1,415	402	954
NFOI, Medium, CA, Within	$/farm/year	42,376	44,177	129,990	40,543	122,868		
NFOI, Medium, CA, Not Within	$/farm/year	42,376	-14,404	-1,337	-13,295	2,870	15,073	24,517
NFOI, Large, CA, Within	$/farm/year	333,461	337,484	676,016	325,611	656,809		
NFOI, Large, CA, Not Within	$/farm/year	333,461	-100,865	-229,382	-118,766	-181,421	113,463	117,204
NFOI, Extra Large, CA, Within	$/farm/year	1,194,431	1,675,223	2,850,610	1,488,649	2,554,099		

Outcome	Units	Baseline	Continuous MAF 1	Continuous MAF 2	Non-Continuous MAF1	Non-Continuous MAF 2	MMP 1	MMP2
NFOI, Extra Large, CA, Not Within	$/farm/year	1,194,431	-377,551	-1,022,586	-354,036	-829,862	178,556	183,005
Total Milk Formally Marketed	bil lbs/year	240.7	-7.1	-15.9	-7.0	-15.4	9.4	9.9
Class I Price	$/cwt	18.88	0.39	1.04	0.40	1.04	0.48	0.47
Class II Price	$/cwt	16.10	0.45	1.17	0.46	1.20	-0.92	-0.94
Class III Price	$/cwt	15.71	0.32	0.80	0.33	0.82	0.66	0.64
Class IV Price	$/cwt	15.37	0.45	1.18	0.46	1.20	-0.92	-0.93
American Cheese Price	$/lb	1.55	0.03	0.08	0.03	0.08	0.07	0.07
Whey Product Price	$/lb	0.57	0.00	0.00	0.00	0.00	0.00	0.00
Butter Price	$/lb	1.39	0.04	0.13	0.05	0.14	-0.09	-0.09
NDM Price	$/lb	1.36	0.03	0.07	0.03	0.07	-0.06	-0.07
Total Value of US Exports	$ bil/year	9.94	-0.82	-1.76	-0.79	-1.60	0.78	0.85
Cumulative US Government Expenditures	$mil	1675.9	-329.6	-466.9	-501.1	-1244.7	-846.9	-732.1
American Cheese Sales	bil lbs/year	4.61	-0.06	-0.16	-0.06	-0.15	-0.33	-0.32
Other Cheese Sales	bil lbs/year	7.84	-0.09	-0.21	-0.09	-0.21	0.07	0.07
Butter Sales	bil lbs/year	2.07	-0.02	-0.05	-0.02	-0.05	0.04	0.04
Whey Product Sales	bil lbs/year	0.43	0.00	0.00	0.00	0.00	0.00	0.00
NDM Sales	bil lbs/year	1.01	-0.01	-0.02	-0.01	-0.02	0.00	0.00
US Dairy Farms	Farms	32,862	7,054	7,294	6,953	7,112	-434	-446

Note: In the NFOI rows reported above, “US” means farms other than in California and “CA” means California Farms. For the MAF programs, “Within” means limiting milk production growth to the allowable annual increase. “Not Within” means farms that increase production by more than the allowable annual increase, and thus pay the market access fee on all of their milk production. For DMSP programs, all farms are listed for “Not Within” entry because there are no annual allowable increases.

Table 3. Selected Simulated Outcomes, Baseline and Percentage Differences from Baseline for Six Proposed Programs

Outcome	Units	Baseline	Continuous MAF 1	Continuous MAF 2	Non-Continuous MAF1	Non-Continuous MAF 2	MMP 1	MMP2
Description			*API 1% MAF $0.25 to $1.00*	*API 1% MAF $0.25 to $3.00*	*MFPR=2.5 MAF $0.015 to $1.00*	*MFPR=2.5 MAF $0.015 to $3.00*	*800 950 3% 2% MMP $0 to $8*	*800 950 3% 2% MMP $0 to $4*
US All Milk Price	$/cwt	17.43	2.4%	6.4%	2.4%	6.5%	0.0%	-0.1%
Refund for Farms Within Allowable Growth	$/cwt	0.00	--	--	--	--	--	--
Milk Revenue for Farms Within Allowable Growth	$/cwt	17.00	7.0%	15.2%	7.8%	17.5%	0.0%	-0.1%
Average Deviation After Program	$/cwt	0.88	-24.6%	-1.3%	-17.9%	8.9%	-28.5%	-20.9%
Average Margin Over Feed Costs	$/cwt	8.16	5.0%	13.4%	5.0%	13.5%	-0.1%	-0.3%
NFOI, Small, US, Within	$/farm/year	33,633	55.7%	104.7%	57.8%	97.3%		
NFOI, Small, US, Not Within	$/farm/year	33,633	-1.3%	21.8%	-0.4%	13.8%	5.8%	5.6%
NFOI, Medium, US, Within	$/farm/year	58,794	120.5%	232.2%	131.7%	236.4%		
NFOI, Medium, US, Not Within	$/farm/year	58,794	-16.9%	39.9%	-13.7%	29.8%	23.5%	17.1%
NFOI, Large, US, Within	$/farm/year	359,012	98.5%	173.4%	101.7%	168.2%		
NFOI, Large, US, Not Within	$/farm/year	359,012	-4.3%	-30.3%	-4.2%	-24.2%	23.4%	19.6%
NFOI, Extra Large, US, Within	$/farm/year	1,844,715	98.5%	159.1%	95.8%	146.8%		
NFOI, Extra Large, US, Not Within	$/farm/year	1,844,715	-2.4%	-46.9%	0.4%	-36.8%	13.1%	13.3%
NFOI, Small, CA, Within	$/farm/year	21,592	62.5%	131.8%	57.3%	120.5%		
NFOI, Small, CA, Not Within	$/farm/year	21,592	-3.9%	12.4%	-9.6%	6.6%	1.9%	4.4%
NFOI, Medium, CA, Within	$/farm/year	42,376	104.2%	306.8%	95.7%	289.9%		
NFOI, Medium, CA, Not Within	$/farm/year	42,376	-34.0%	-3.2%	-31.4%	6.8%	35.6%	57.9%
NFOI, Large, CA, Within	$/farm/year	333,461	101.2%	202.7%	97.6%	197.0%		
NFOI, Large, CA, Not Within	$/farm/year	333,461	-30.2%	-68.8%	-35.6%	-54.4%	34.0%	35.1%
NFOI, Extra Large, CA, Within	$/farm/year	1,194,431	140.3%	238.7%	124.6%	213.8%		

Outcome	Units	Baseline	Continuous MAF 1	Continuous MAF 2	Non-Continuous MAF1	Non-Continuous MAF 2	MMP 1	MMP2
NFOI, Extra Large, CA, Not Within	$/farm/year	1,194,431	-31.6%	-85.6%	-29.6%	-69.5%	14.9%	15.3%
Total Milk Formally Marketed	bil lbs/year	240.7	-2.9%	-6.6%	-2.9%	-6.4%	3.9%	4.1%
Class I Price	$/cwt	18.88	2.1%	5.5%	2.1%	5.5%	2.6%	2.5%
Class II Price	$/cwt	16.10	2.8%	7.3%	2.9%	7.4%	-5.7%	-5.8%
Class III Price	$/cwt	15.71	2.0%	5.1%	2.1%	5.2%	4.2%	4.1%
Class IV Price	$/cwt	15.37	2.9%	7.7%	3.0%	7.8%	-6.0%	-6.1%
American Cheese Price	$/lb	1.55	2.0%	5.0%	2.1%	5.1%	4.6%	4.5%
Whey Product Price	$/lb	0.57	-0.1%	-0.2%	-0.1%	-0.1%	0.0%	0.0%
Butter Price	$/lb	1.39	3.2%	9.5%	3.4%	9.9%	-6.2%	-6.2%
NDM Price	$/lb	1.36	2.2%	5.3%	2.2%	5.3%	-4.8%	-4.9%
Total Value of US Exports	$ bil/year	9.94	-8.3%	-17.7%	-7.9%	-16.1%	7.9%	8.6%
Cumulative US Government Expenditures	$mil	1675.9	-19.7%	-27.9%	-29.9%	-74.3%	-50.5%	-43.7%
American Cheese Sales	bil lbs/year	4.61	-1.4%	-3.4%	-1.3%	-3.3%	-7.1%	-7.0%
Other Cheese Sales	bil lbs/year	7.84	-1.2%	-2.7%	-1.1%	-2.7%	0.9%	0.9%
Butter Sales	bil lbs/year	2.07	-0.9%	-2.3%	-0.9%	-2.6%	1.8%	1.9%
Whey Product Sales	bil lbs/year	0.43	-0.1%	-0.3%	-0.1%	-0.1%	0.5%	0.5%
NDM Sales	bil lbs/year	1.01	-0.9%	-2.0%	-0.9%	-1.9%	0.4%	0.5%
US Dairy Farms	Farms	32,862	21.5%	22.2%	21.2%	21.6%	-1.3%	-1.4%

Note: In the NFOI rows reported above, "US" means farms other than in California and "CA" means California Farms. For the MAF programs, "Within" means limiting milk production growth to the allowable annual increase. "Not Within" means farms that increase production by more than the allowable annual increase, and thus pay the market access fee on all of their milk production. For DMSP programs, all farms are listed for "Not Within" entry because there are no annual allowable increases.

APPENDIX MATERIALS

Methods and Data

Given the nature of the volatility in supply chains and its hypothesized causes, an analytical approach is required that is capable of replicating the types of behaviors observed in the industry under normal conditions and under large shocks. In particular, the model must be capable of producing variation in prices and other variables on a relevant time scale (in this case monthly) with an amplitude similar to that observed in the past. We have chosen to build a mathematical model for our analyses based on the commodity supply chain model described in Sterman (2000), which has been applied previously to numerous commodities that demonstrate cyclical production and profitability. (An early application to agriculture is a model of hog cycles by Meadows (1970)). Moreover, our approach is consistent with recent recommendations that the analysis of food systems and agricultural policies is best done using dynamic systems methods (Pinstrup-Andersen and Watson, 2010). This commodity model represents the essential elements of the stock, flow and feedback structure that is common to the supply chain for many commodities. It contains many features common to economic models, such as demand and supply responses, but represents them in a way that explicitly recognizes the inherent delays and limited information available to industry decision makers.

This commodity model used in this analysis has been developed and adapted to the U.S. dairy industry over a number of years, and many model details are provided in Nicholson and Fiddaman (2003), Pagel (2005), Nicholson and Stephenson (2007), Stephenson and Nicholson (2007), Nicholson and Kaiser (2008) and Nicholson and Stephenson (2009). The model employed under this project was adapted from previous modeling work, and relevant model elements were combined mathematically to allow analysis of major proposed programs. The key modification since the 2010 analysis was the expansion of the model to include explicit representation of other global trading regions. A detailed model description is available at www.dairymarkets.org in the document entitled "Global Dairy Trade Model Description."

Our assessment of the impacts of global trade policy changes uses a detailed empirical SD model of the U.S. dairy supply chain adapted from the commodity supply chain model described in Sterman (2000), which builds on an initial formulation by Meadows (1970). This model has been developed and adapted to the U.S. dairy industry during the past 10 years, and the feedback structure relevant for this analysis was discussed below (Figure 1). More detailed description of the model is provided in the below, but the basic structure for key model components is described below. The base year for the model is 2013, meaning that 2013 data on milk production and dairy product consumption and trade are used to initialize the model. The model simulates monthly outcomes from 2013 to the end of 2018 (when the current farm legislation will be revisited). The model comprises modules that represent farm milk supply, farm milk pricing, dairy product processing, inventory management and trade, and dairy policies including the margin insurance implemented in 2014). Each of these is discussed in detail below.

Model Regions

The Dynamic Global Dairy Supply Chain Model includes representations for 15 regions, two for the US (California and Rest of US), and 13 non-US regions including the ASEAN countries (10 countries), Oceania (Australia and New Zealand), the EU (28 countries), Russia, China, Mexico, India, Canada, former Soviet Union countries (11 countries), Middle East and North Africa (MENA; 19 countries), major South American milk producers (Brazil, Argentina, Uruguay), Other Net Importing Countries (described below) and Other Net Exporting Countries (described below).

Farm Milk Supply

The milk supply components of the model are based on up to four farm-type categories based per region. In the US, farm-types are based on numbers of cows owned for both the rest of U.S. and California. (California is modeled separately because it is the largest milk producing state and maintains a state-level system of milk price regulation different from the rest of the U.S.) For each farm-type category, the total number of farms is modeled[12], as is the average financial situation (both elements of the income statement and the balance sheet) for each farm category. The cost structure of farms in the different herd size categories is different, as is the responsiveness to profitability signals. Based on genetic improvement rates over the past 20 years, milk per cow[13] is assumed to grow at a potential rate of 2% per year, but is adjusted in the short run based on the margin between farm milk prices and feed prices. This is similar to the approach in Bozic et al., (2012), who used a linear trend in yield, but the yield increment varied with margins.

The number of cows for each farm size category is treated as a productive asset, and the evolution of cow numbers depends on heifers entering the herd (which depends on previous breeding decisions) and culling decisions (which can be voluntary or involuntary). Involuntary culling rates depend on the desired number of cows for each farm size category, which is modeled using an "anchoring and adjustment" approach based on Sterman (2000). This anchoring and adjustment mechanism assumes that desired cow numbers for each farm size category respond to expectations of future Net Farm Operating Income (NFOI) relative to a benchmark NFOI, both of which are updated over time. NFOI equals total revenues less variable costs for feed, labor, and other expenses. When the desired number of cows changes, the voluntary culling rate is adjusted. Changes in the culling rate in response to profitability changes are asymmetric: proportional changes in the voluntary culling rate are larger when desired cow numbers are below current cow numbers than when current cow numbers are larger than current cow numbers.

Farm Milk Pricing

The U.S. government and many other countries maintain regulations that set minimum allowable farm milk prices based on market prices of dairy product prices and the product for which the farm milk is used. The details for the US are provided in Nicholson and Stephenson (2010) and are not discussed here. For other countries, we assume that milk prices will be derived from dairy product prices, in a manner similar to that in the US but without minimum classified prices based on milk use. Milk prices affect both milk per cow and NFOI and therefore influence cow numbers. A standard measure of the farm milk price in the U.S. is the "All-milk" price reported for the entire U.S. (including California) by the National Agricultural Statistics Service, and this is included in the model as a benchmark price, with a similar indicator price calculated for other countries.

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[12] For some regions, the number of farms is assumed to be one, effectively aggregating the country's milk production response.
[13] The model also represents buffalo milk production for India and Pakistan in addition to milk from cattle.

Dairy Processing

The dairy-processing component of the dynamic model incorporates 23 products, 20 of which are "final" products (have explicit demand curves) and 13 of which are "intermediate" products that are used in the manufacture of other dairy products (Table 1). Non-storable products (fluid, yogurt, ice cream and cottage cheese) are assumed manufactured in the month in which they are consumed. Storable products have inventories, and the value of inventory in each region relative to sales (called "inventory coverage") is used in setting prices for these products. Milk is allocated preferentially to fluid, soft and cheese manufacturing, with the remaining milk allocated to nonfat dry milk (NDM) and butter manufacture. The model explicitly tracks skim milk and cream quantities to ensure component (mass) balance between sources (farm milk) and uses (dairy product demand). To represent potential substitutability among intermediate products as relative prices change, the lowest cost of three potential ingredient combinations (for example, NDM versus milk protein concentrates (MPC) used in cheese manufacturing) is calculated and adjustments in intermediate product use occur over the course of a month following a change in the lowest-cost combination. The proportional utilization of existing manufacturing capacity for storable products depends on current profit margins, calculated on an aggregated enterprise basis. The manufacturing capacity for each U.S. region was assigned based on production shares in California and the U.S. in 2013. Capacity for cheese and whey products changes over time in response to long-term changes in profitability for those products.

Dairy Product Demand

Dairy product demand for final products is represented separately for each region. U.S. fluid milk consumption is based on fluid utilization from California and sales from the Federal regulatory bodies that determine minimum regulated farm milk prices using data for 2013. Consumption of other products was calculated as national U.S. commercial disappearance (production + imports – exports – dairy industry use) and allocated on the basis of regional population. The impacts of product prices on demand are modeled using constant elasticity demand functions, which also are assumed to shift over time in response to population and income growth. Intermediate product demand is determined by the use of dairy components in the production of other dairy products, based on relative costs. Cross-price effects for intermediate products are included for NDM, MPC products, casein products and whey products but not for others. The quantity demanded adjusts over time in response to price changes, rather than instantaneously, to account for delays required for buyers to form price expectations, find substitutes, redesign products or for the expiration or renegotiation of contractual obligations with suppliers. Retail prices for fluid milk products, yogurt, cottage cheese and ice cream are modeled using constant proportional mark-ups over milk ingredient costs. Wholesale prices for storable products, as noted earlier, depend on inventory coverage.

Table A1. Dairy Product Categories Included in the Dynamic Global Dairy Supply Chain Model

Product Category	Final Product	Intermediate Product	Tradable Product
Fluid Milk	X		X
Yogurt	X		X
Frozen Desserts	X		X
Cottage Cheese	X		
American-type Cheeses	X		X
Other Cheeses	X		X
Fluid Whey		X	
Separated Whey		X	
Whey Cream		X	
Dry Whey	X	X	X
Whey Protein Concentrate 34% Protein	X	X	X
Whey Protein Concentrate 80% Protein	X	X	X
Lactose	X	X	X
Butter	X		X
Anhydrous Milk Fat (AMF)	X		X
Nonfat Dry Milk	X	X	X
Infant Formula	X		X
Condensed Skim Milk	X	X	
Other Evaporated, Condensed & Dry products	X		X
Casein	X	X	X
Caseinates	X	X	X
MPC, < 50% protein	X	X	X
MPC, >= 50% protein	X	X	X

Dairy Product Trade

The model includes a detailed international trade component, consistent with its purpose. Imports and exports are represented for 18 tradable dairy product categories (Table 1). Imports for each region are calculated separately for each origin (exporting region) and based on whether imports were subject to Tariff Rate Quota (TRQ) or “over-quota” restrictions. The TRQ specify a total annual amount of allowable imports at a relatively low tariff rate. We have ignored the country- and region-specific import restrictions (e.g., import licenses or TRQ allocations) associated with some products imported into the US. “Over-quota” imports are not limited in quantity but generally face higher tariff rates. Both *ad valorem* (percentage based on value) and specific (per unit) tariffs are represented for both categories of imports. The model uses 2013 trade data as base, and imports and exports in future years are determined based on the growth in demand in the ROW, relative prices in the importing and exporting regions, transportation costs and import restrictions. Total exports for each region and product are calculated as the sum of the product imported by all other regions from the origin region.

Dairy Policies

As noted in the discussion of programs analyzed above The suite of U.S. dairy policies implemented during 2013 to 2020 is represented in the model, including the MPP-Dairy/Dairy Margin Coverage program. We also include U.S. policies unchanged by the Agricultural Act of 2014, such as minimum farm milk price regulation under federal and California milk marketing orders, including relevant timing of pricing decisions. For regions other than the U.S., dairy policy (other than trade policy) is represented by intervention purchase programs in the EU, and supply management programs in the EU and Canada (for which more details are provided below); other policies and programs related to dairy in other countries are ignored. We include the policy structure of the model to account for the major impacts of MPP-Dairy in the U.S.

Data Sources and Qualifications

The model base year is 2013. The model data come from a variety of sources including, but not limited to, various branches of the U.S. Department of Agriculture (NASS, AMS, FAS), the Food and Agriculture Organization of the United Nations (FAO), the International Farm Comparison Network (IFCN), Eucolait (the European Association of Dairy Trade), CLAL (Italian Dairy Economic Consulting), Dairynz, Dairy Australia, and the Global Trade Atlas (GTIS). Where possible, it is useful to collect data from a single source such as FAOstat. This not only minimizes data collection efforts, but it may mean that the source aggregator has made the effort to report data in a unified way. However, it is also important to know what the data are reported as and being used for.

The Global Dairy Trade Model is interested in projecting dairy cow and buffalo milk production and consumption of milk and dairy products around the globe. And, to facilitate the transformation of milk into consumable dairy products, the model needs to estimate what dairy products are processed and where and how much of those dairy products are traded between countries of the world. Estimates are available for many country's dairy statistics, but these estimates break down where there is no formal market for the products. FAO may try to estimate consumption by country, but in many countries where the informal dairy sector thrives with milk production consumed on the farm or is informally traded outside of reported statistics, a mass balance estimate of production and consumption estimates will not equate. The FAOstat database[14] is used as the source for several pieces of data. The FAO database also provides estimates of agricultural trade. However, it is felt that this is not a very complete source of trade data and GTIS data are sourced and used instead. The GTIS trade flow data are available for most countries. These data are monthly, but 6 digit HTS code and are reported by the exporting country and/or the importing country. The GTIS data list the reporting country and the partner country for both imports and exports. Only one of these are needed and to minimize duplicate trade flow reporting, we use the export data.

Model Evaluation

Sterman (2000; pp. 859-861) describes 12 model evaluation processes that are relevant for most models, not just SD models. We undertook selected components of all 12 tests during model development and evaluation. These processes are summarized in below (Table 2), with a brief

[14] http://faostat3.fao.org/

discussion of their implementation in the U.S. dairy supply chain model. An additional comment regarding sensitivity analysis is appropriate here. A common feature of feedback-rich models such as SD models is that relatively few feedback loops determine system behavior. That is, a small number of feedback loops demonstrate "feedback loop dominance", which can be evaluated using methods such as those in Olivia (2014). This characteristic suggests that only parametric values contained within dominant feedback loops have the potential to effect large-magnitude changes in the numerical or behavioral results of the model. Thus, it is not surprising that our model is not sensitive to many of the parameter values other than those related to the dominant feedback processes (which appear to be those for milk supply). This result also suggests that not all information (or assumptions) have equal weight in determining system outcomes, so model behavior often is not strongly influenced by most of the parameters assumed in a dynamic model. We find that to be the case for our model of the U.S. dairy supply chain.

The behavioral pattern and values of the US All-milk price was reasonably well captured by the model (Figure 3), particularly from 2015 to 2018. The average percentage difference between the model all-milk values and the actual values during 2013 to 2018 was 8.2%, which compares favorably to forecasting performance for many supply chains (which often experience values of 30% or more). For 2015 to 2018, the average percentage difference was better—4.9%--and the average difference between the actual and model-predicted price was \$0.83/cwt. In addition, the model captures the basic pattern (but not the duration) of high prices in 2014, and lower but oscillating prices after that year. Given that the model base year is 2013, this is quite good forecasting of monthly prices over a six-year time horizon.

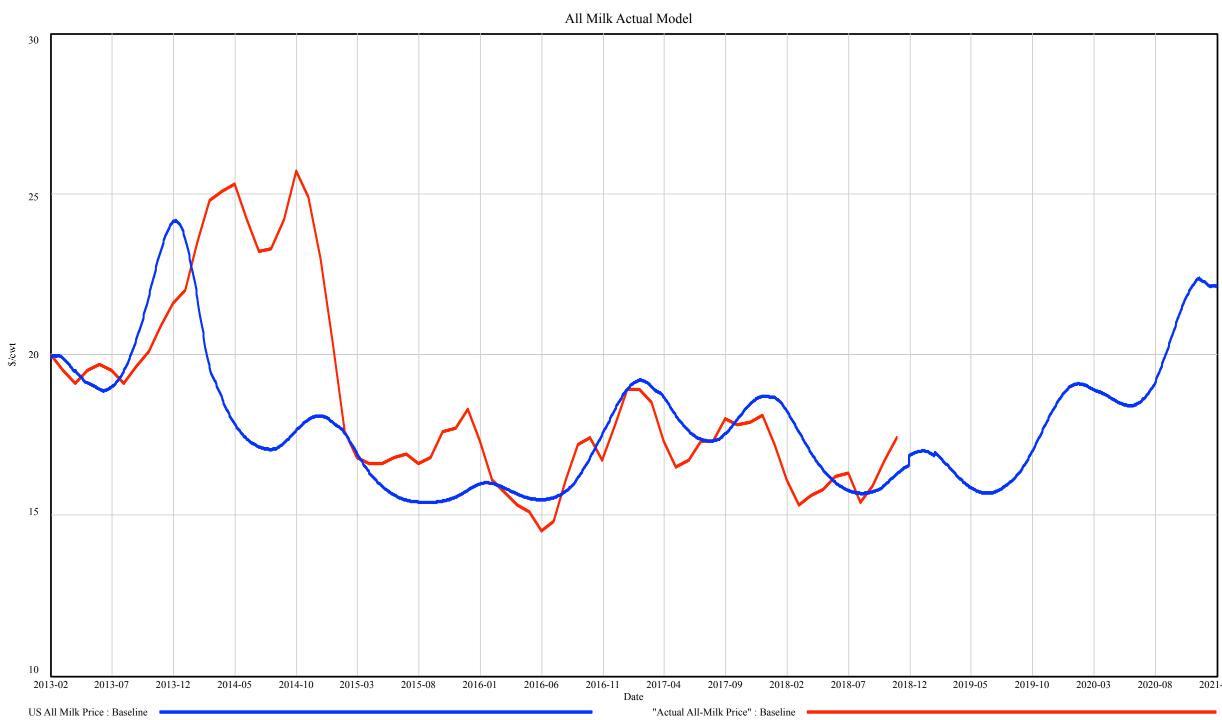

Figure A1. Comparison of Model-Simulated and Actual Farm Milk Prices, 2013 to 2018

Table A2. Summary of Model Evaluation Testing Procedures

Model Evaluation Test	Purpose and Description	Implementation in Global Dairy Supply Chain Model
Boundary adequacy	Are important concepts endogenous? Does model behavior changed when model boundary assumptions are modified?	Relevant concepts were endogenized consistent with generic commodity supply chain model. Model boundary was assessed formally for inclusion of an endogenous trade component and this did not change the behavioral mode for milk prices.
Structure assessment	Is the model structure consistent with relevant descriptive knowledge of the system, at an appropriate level of aggregation, decision rules capture the behavior of agents in the system?	System structure was developed based on previous models, previous literature, descriptive knowledge, statistical analysis of dairy industry data and through group discussions with industry decision makers.
Dimensional consistency	Is each equation dimensionally consistent? (Are units consistent without the use of parameters without real-world meaning?)	All equations were tested using routines in Vensim Professional software to ensure consistent units. There currently are 8 "units errors" of which 3 are warnings about the use of dimensioned arguments in LOOKUP functions and the others are related to time units in MODULO or SAMPLE IF TRUE functions. None affects model function or indicates an incorrectly specified equation.
Parameter assessment	Are the parameter values consistent with relevant descriptive and numerical knowledge of the system?	Parameter values developed based on previous models, previous literature, descriptive knowledge, statistical analysis of dairy industry data and through group discussions with industry decision makers. For milk supply response parameters, qualitative assessments with industry professionals about relative magnitudes of asymmetric responses by farm size and region were complemented with Vensim Professional optimization routines to determine values consistent with the observed periods and amplitudes of price cycles.
Extreme conditions	Do all equations make sense at extreme values? Does the model respond plausibly to extreme shocks, policies and parameters?	Model was evaluated for consistency with extreme shocks (e.g., large domestic supply and demand reductions or increases, rapid increases in U.S. exports) and responded plausibly to these conditions. Large increases in milk production would likely have exceeded available production capacity for NDM and butter in the short-term, given our assumption of no capacity constraints for these products.
Integration error	Are the results sensitive to the choice of time step for numerical integration?	The model was evaluated for integration error using the process identified in Sterman (2000) that progressively reduces the time step, until limited behavioral changes resulted. A time step of 0.125 months was used for all simulations.
Behavior reproduction	Does the model reproduce the behavior of interest in the system? Does the model generate modes of behavior observed?	The model generated oscillatory behavior in milk price and margins consistent in period and amplitude with those observed in 2000-2014, consistent with the analysis of Nicholson and Stephenson (2015). A previous model version assessed point prediction during 2012-2013 and appropriately represented patterns and turning points in observed data (more below).

Model Evaluation Test	Purpose and Description	Implementation in Global Dairy Supply Chain Model
Behavior anomaly	Do anomalous behaviors result when assumptions of the model are changed or deleted?	Assessed the assumption that milk components used in NDM and butter are residual claimants on the milk supply by modifying model structure. Relationships between Class III and IV prices in the FMMO system demonstrated anomalous behavior in response to this modification.
Family member	Can the model generate the behavior observed in other instances of the same system?	No formal analysis of other systems undertaken, but Bergmann et al., (2013) note that cyclical behavior with properties similar to that in the U.S. has emerged in the EU and international dairy product markets, which they attribute in part to the reduction in support under the CAP—similar to the emergence of greater cyclical behavior in the U.S. when the DPSP became largely inactive.
Surprise behavior	Does the model generate previously unobserved or unrecognized behavior?	Model analyses indicate that increases in regulated milk prices can demonstrate "dynamic complexity," i.e., that short-term increases can be more than offset by longer-term decreases in price. The model also suggests that a reason for increasing amplitude of price cycles is structural change, if the assumption that larger farms have a greater supply responsiveness to expected profitability than do small farms.
Sensitivity analysis	Numerical, behavioral and policy sensitivity to parameters, boundary and aggregation are varied over a plausible range of uncertainty?	The model demonstrates numerical sensitivity in the sense that simulated results change in response to changes in a variety of assumed parameter values. However, the model was only behaviorally sensitive to large changes in the model parameters affecting the responsiveness of milk supplies (desired cows, culling rates) to expected profitability. Alternative values of these parameters could generate very limited or very large oscillations that were not consistent with the behavior observed since 2000.
System improvement	Can the model suggest means to improve system outcomes	This evaluation is more typical of modeling efforts to support management changes, but previous versions of the model have been used to suggest the benefits (and limits) or dairy product promotion to the industry or changes in regulated pricing formulae.

Excerpt from *Analysis of Proposed Programs to Mitigate Price Volatility in the U.S. Dairy Industry* by Charles F. Nicholson and Mark W. Stephenson, September 2010

Introduction

Volatility predominates in supply chains for many commodities—from aircraft to zinc—and agricultural commodities are no exception (Sterman, 2000). Historically, one of the principal motivating factors for government intervention in agriculture has been the high degree of variability of farm incomes, in part because variations in revenues for businesses with large fixed costs results in large changes in net incomes (Knutson and Outlaw, 2010). A standard explanation for this variability in agriculture—usually measured by the degree of variation in farm-level prices—is that both supply and demand are inelastic, that is, changes in the amount produced or consumed are relatively insensitive to prices, at least over a short time horizon. Variation in prices and profitability also can be viewed more specifically from a supply chain perspective. Supply chains typically involve substantial time delays, so they are prone to oscillation. Sterman (2000) notes that "production in inventories chronically overshoot and undershoot the appropriate levels" in many industries, and it is common to observe what is called "amplification." The size (amplitude) of price oscillations tends to increase as one moves along the supply chain (that is, from consumer to farmer, in the case of agriculture) so that price and income variation is larger for primary suppliers (farmers) than for consumers.

Prices and other key indicators in the dairy industry have strong cyclical components (Nicholson, Stephenson and Novakovic, 2009) [See also Nicholson and Stephenson (2015).] Why is such cyclical variation so prevalent for dairy and other commodities? Sterman (2000) argues that one source of the problem is a lack of information about the aggregated effects of individual businesses' (farms') impact. The individual company tends to view itself as small relative to the market and thus treats the market as beyond its control. Thus, firms (farms) tend to continue to invest and expand when profits are high, without regard for the production (expansion) decisions of others. When most businesses respond in this way to current profitability, "the result is overshoot and instability." Sterman also notes that a common explanation for commodity cycles is that demand is cyclical. He argues, however, that the evidence for this explanation is limited: commodity markets fluctuate far more than the economy as a whole (and therefore more than demand changes) and the cycles in commodities are not "entrained" (in line with the timing) to business cycle movements. This suggests that many commodity cycles are endogenous, that is, generated by the aggregated decisions of the companies in the supply chain. Nor are exogenous shocks typically a good explanation for observed variability in prices, in part because the cyclical patterns are often quite regular—in a way that (random) shocks would not be. Moreover, it is essential to ask why the current supply chain organization cannot mitigate random shocks (Nicholson and Fiddaman, 2003).

Although farmer incomes have historically been the focal point for policy efforts, other companies in the supply chain often are affected by volatility. A recent and costly example is the U.S. housing market. In the U.S. dairy industry, concerns have been expressed about the loss of equity at the farm level and reductions in demand growth—both domestic and export—or modification of product formulations to use more non-dairy ingredients due to price variability. Sterman notes that "there is no doubt that instability and oscillation are costly," and adds that these costs are likely to occur in all levels and functions in the supply chain (including operations, reliability of suppliers, labor force, financial transactions, management, marketing, and pricing). Although in principle many of these costs are measurable (at least at the level of an individual firm), little or no information is available about the magnitude of these costs in the U.S. dairy supply chain. This restricts, to no small extent, the ability to assess the costs and benefits of alternative approaches to address volatility in the dairy industry.

The existence of persistent and pervasive costs of instability in commodity supply chains does not in and of itself suggest that government intervention to address the problem is appropriate. (In fact, such intervention is limited in most supply chains outside of agriculture.) There are a number of issues to be assessed to determine the desirability of government intervention. One such issue is whether private (individual firm) solutions could be developed and implemented at lower cost or greater effectiveness than government interventions. Examples of such interventions might be additional information about key (aggregated) supply chain decisions, forward contracts or risk management tools such as hedging with futures or options contracts. Information about supply chain developments is relatively well-developed in the dairy industry and risk management tools (also including the recent Livestock Gross Margin Insurance) have seen limited use by dairy producers. Perhaps new forms of information or additional incentives for private risk management could reduce volatility, particularly if some participation threshold is reached[15].

Another important issue is whether government interventions can be effective. The history of U.S. agricultural policy provides numerous examples of programs that were less effective than expected (payment limits and production controls are notable examples) or that had other undesirable (and sometimes unanticipated) negative consequences. The Dairy Price Support Program was implemented through the Agricultural Act of 1949. It provided a mechanism to moderate milk price swings by purchasing storable dairy products from the market during times of low milk prices and selling those products back into the market when prices were higher. The program was effective in moderating price volatility. However, it became clear that although a Dairy Price Support Program with a support price greater than $13/cwt provided price stability, that stability came at what was considered a large cost to the government in the 1980s.

Other dairy programs have been implemented to moderate milk production. Prior to the 1990s, much of price volatility was attributed to seasonal differences in the milk supply and demand for dairy products. A surge of calvings and a greater reliance on pastured-based feeding meant that the spring flush of milk was much greater than the fall production. This pattern of production was out of phase with consumption, which was lower during the summer and higher during the fall-winter holiday season. Attempts to modify producer supply patterns using financial incentives and disincentives through the Federal Milk Marketing Orders were common in the 1950s through the 1970s. Base-excess, takeout-payback and Louisville plans transferred a portion of income to producers who altered their production patterns from those who did not.

In the early 1980s the Milk Diversion Program made direct payments of $10 per hundredweight to producers who agreed to reduce their marketings 5 to 30% below their established base for a fifteen-month period of time. Later in the 1990s, Congress collected two separate 50-cent assessments from dairy producers. The first assessment was used to partially offset the large taxpayer expenditures on the Dairy Price Support Program but the second assessment was to be refunded to producers who reduced their marketings at least 8.4% below their base. This was

[15] Bill Schiek of the Dairy Institute of California has suggested that this might be the case for hedging in the U.S. dairy industry.

later modified in the 1990 Omnibus Budget Reconciliation Act to an 11.25-cent assessment that was refunded to producers who held their milk marketings constant relative to the previous year.

A related question for the volatility of the supply chain is the nature of the problem to be addressed. As noted previously (Nicholson and Stephenson, 2009), the objective of limiting variation in prices (or incomes) is often blurred with the adequacy of the average price level, the depth and length of low-price or low-income periods and the predictability of price changes. Programs may be effective at addressing some but not all of these dimensions. Producers who simply wish to "take the bottom" out of milk price volatility are fundamentally requesting a higher average milk price—a price adequacy problem. If the problem is truly price volatility, then being willing to give up some of the price peaks to fill in some of the troughs should be an acceptable practice.

Finally, any government intervention would involve costs as well as potential benefits. The most visible and direct cost for many programs is government expenditures funded by taxpayers, but government programs also affect the distribution of income and wealth for all supply chain actors. In general, few policy options exist that are "Pareto superior," that is, that improve the economic well-being for all groups.

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