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Dynamic Market Impacts of the Dairy Margin Protection Program

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The U.S. Agricultural Act of 2014 creates a new Margin Protection Program for Dairy (MPP-Dairy) under which dairy farmers can receive indemnity payments from the U.S. government if the margin falls below the insured level. The design of MPP-Dairy suggests that the program has the potential to weaken processes that would adjust milk production, prices and margins if the proportion of milk covered by insurance is large. This paper describes potential impacts of MPP-Dairy using a conceptual analysis (feedback loop diagram), then uses an empirical system dynamics (SD) commodity model for the U.S. dairy industry to assess the impacts quantitatively.

***Key words**:* dairy, margin insurance, margin protection program, mpp-dairy, system dynamics

In 2009, farm milk prices and the margin between milk price and the costs of feed for dairy animals fell to historically low levels. Dairy farmers in many parts of the United States experienced substantial losses of business equity and some exited the industry (AgWeb, 2012). This event suggested to many observers that previously-enacted dairy policies no longer provided an adequate "safety net" for dairy farmers. Many policy options were discussed during the intervening years, but early in 2014, the U.S. Congress passed the Agricultural Act of 2014 (AA2014) that markedly changed the nature of U.S. dairy policy. This legislation will suspend the Dairy Product Price Support Program (DPPSP) that followed the DPSP, and eliminate the Milk Income Loss Contract (MILC) and the Dairy Export Incentive Program (DEIP). The AA2014 replaces them with a program that provides dairy farmers with the opportunity to purchase "margin insurance" through the Margin Protection Program (MPP-Dairy; Schnepf, 2014). Under this program, farmers determine a level of margin (milk price less a specified feed cost value) they want to protect for a certain proportion of their historical milk production (their "production history"), and pay premiums to the government. If average margins for two consecutive months become lower than the level covered by the margin insurance, the government will pay farmers an indemnity based on the difference between the observed margin and their protected margin.

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Much of the analysis of MPP-Dairy to date comprises calculations of what unit payments MPP-Dairy program would been in previous years for various margin coverage levels (e.g., Nicholson and Stephenson, 2014a) and comparisons to payments made under the MILC program (e.g., Nicholson and Stephenson, 2014b). Available online resources such as MPP-Dairy decision tool developed by the Program on Dairy Markets and Policy (DMaP; http://www.dairymarkets.org/MPP/Tool/) or National Milk Producers' Federation (http://www.futurefordairy.com/mpp-calculator) allow producers to undertake this type of historical analysis (although the former also includes future margin projections to support decision making). A key limitation of these previous approaches is that they do not account for the likely market effects of the program, and do not assess potential outcomes during the years the program is authorized, 2014 to 2018.

Given the major change in the U.S. government's approach to providing support to dairy farmers, the potential for market impacts and the voluntary nature of MPP-Dairy, an *ex ante* analysis of program impacts is relevant. Thus, this paper has two principal objectives:

1) Provide a dynamic conceptual analysis based on economic feedback processes that provides insights into possible behaviors of the U.S. dairy supply chain with MPP-Dairy;

2) Empirically assess key outcomes with MPP-Dairy compared to previous support policies, under different assumptions about participation by dairy farmers and market conditions using a detailed empirical model of the U.S. dairy sector.

Dynamic Conceptual Model Analysis

Although the approach used in MPP-Dairy makes U.S. dairy programs more consistent with other agricultural support programs such as crop insurance, it has several design features that could result in the program being less effective at supporting farm incomes and more costly than expected. First, payment when margins are low will help sustain farm income, but this is likely to prolong the periods of low prices because milk production adjustments in response to market conditions could be muted. Second, there is evidence that the premium payments are subsidized (i.e., not 'actuarially fair') for many of the margin levels protected (conditional on the program being activated by sufficiently low margins) which could encourage farmers to insure larger amounts and premium payments are likely to be insufficient funding for indemnity payments. We assessed this empirically by evaluating a variety of MPP-Dairy participation strategies for farms of various sizes based on historical margins from 2007 to 2013, finding that all would have resulted in program payments net of premiums ranging from $0.08/cwt to $0.79/cwt (Nicholson and Stephenson, 2014a, 2014c, 2014d). Moreover, the degree of subsidization would have been larger if market impacts were included because lower margins would increase payments whereas premium payments were fixed. Third, farmers can decide for individual years whether to insure and how much, rather than making a decision to participate over the five-year life of the program. Thus, adverse selection may result where farmers purchase margin insurance only when payments are likely to be made, further increasing government costs (Newton, Thraen and Bozic, 2013b). Finally, the amount that farms can insure could increase each year based on overall increases in total U.S. milk production.

These program features suggest that if low margins occur that result in indemnity payments, these could result in the unintended consequences of prolonged periods of low margins and large government expenditures. The feedback processes that could result in these outcomes are depicted in a Causal Loop Diagram (CLD), which represents hypothesized feedback loops in the dairy supply chain (Figure 1). The feedbacks include a number of key balancing and reinforcing loops, some with relevant delays. To illustrate potential impacts of MPP-Dairy, consider an increase in feed costs, which can comprise 50% of the variable costs of milk production. In the absence of the margin insurance program, an increase in feed costs would reduce farm profitability, which over time would reduce dairy farmers' expectations of profits and this would likely lead them to reduce their cow numbers (the key productive capital stock) and reduce milk per cow (intensity of utilization of that capital stock). This would result in less milk production, lower dairy product inventories, higher dairy product prices and higher farm milk prices. These balancing loops (*Profitability & Cows* and *Profitability & Productivity*) suggest effects that at least partly offset the initial increase in feed costs.

The margin insurance program alters this dynamic adjustment process by reducing the strength of the balancing feedback implied in the *Profitability & Cows* and *Profitability & Productivit*y feedback loops by adding the *Margin Profit Support* loop (Figure 1). An increase in feed costs would reduce profitability, but if it also reduces margins (i.e., milk price less feed costs) below the coverage level selected by the farmer, the government makes an indemnity payment that helps to support farm profitability, which weakens the balancing loop that would otherwise more fully reduce milk production. Low margins affect farmer expectations of lower margins in the future and farmers would choose to cover larger amounts of production at higher production levels (*Margin Coverage Elected* loop).

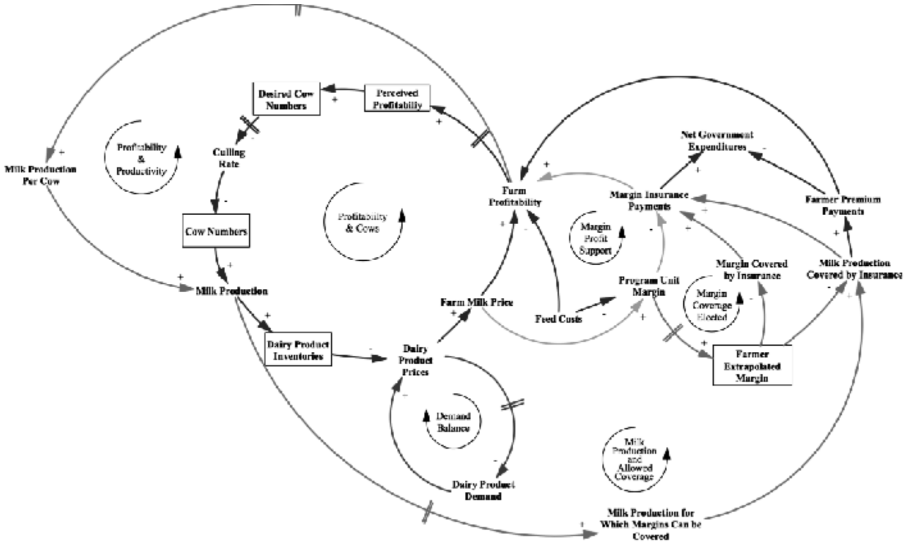

Figure 1. Hypothesized Feedback Structure Related to Dairy Production, Demand, and the Margin Protection Program-Dairy

If the MPP-Dairy is sufficiently subsidized, aggregate milk production could actually increase over time, which would allow larger amounts of milk to be covered under the margin program in the future, also increasing the milk production covered by insurance (*Milk Production and Allowed Coverage* loop). Although farmer premium payments will also increase as higher levels of insurance are selected, the subsidization of the program implies that net government expenditures would increase. Under certain conditions, it is possible that the feedback structure implied by farmer decisions and margin program insurance design could “lock-in” low margins, low milk prices and high government expenditures. (Although this is undesirable for government and farmers, consumers in the U.S. and countries to which we export dairy products would be beneficiaries of the program.) As noted by Sterman (2000), conceptual models such as the one described above are useful but are complemented by the development of empirical simulation models. The extent to which MPP-Dairy would result in extended periods of low prices, low margins, low farm incomes and large government expenditures will depend on a variety of factors that are best assessed with an empirical model.

Empirical U.S. Dairy Supply Chain Model Methods and Data

Our assessment of the impacts of MPP-Dairy 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 above (Figure 1). The base year for the model is 2011, meaning that 2011 data on milk production and dairy product consumption and trade are used to initialize the model. The model simulates monthly outcomes from 2012 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 (both those existing prior to implementation of the AA2014 and the margin insurance to be implemented going forward). Each of these is discussed in detail below.

Farm Milk Supply

The milk supply components of the model are based on four farm-size categories based on numbers of cows owned for two U.S. regions, California and the rest of the U.S. 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 United States. For each farm size category, the total number of farms is modeled, 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 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, Kanter and Gould (2012), where a linear trend in yield was used, 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 states 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. Milk prices affect both milk per cow and NFOI and therefore influence cow numbers. A standard measure of the farm milk price is the “All-milk” price reported for the entire United States (including California) by the National Agricultural Statistics Service, and this is included in the model as a benchmark price. It is also the milk price used by USDA to calculate the margin in the new MPP-Dairy.

Dairy Processing

The dairy-processing component of the dynamic model incorporates 21 products, 18 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).

Table 1. Dairy Product Categories Included in the Dynamic Model

Product Category	Final Product	Intermediate Product	Tradable Product
Fluid Milk	X		
Yogurt	X		X
Frozen Desserts	X		X
Cottage Cheese	X		
American Cheese	X		X
Other Cheese	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
Nonfat Dry Milk	X	X	X
Condensed Skim Milk	X	X	
Other Evaporated, Condensed & Dry products	X		X
Casein & Milk Protein Concentrates	X	X	X

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 inventories relative to sales (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 region was assigned based on production shares in California and the U.S. in 2011. 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 California and the rest of the United States. 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 2011. 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.

Dairy Product Trade

The model includes a simplified international trade component. Imports and exports are represented for 12 "tradable" U.S. dairy products (Table 1). Imports and exports are modeled separately and "net exports" (exports minus imports) can be calculated. For U.S. imports, products are subject to Tariff Rate Quota (TRQ) and "over-quota" restrictions. The TRQ specify a total annual amount of allowable imports at a relatively low tariff rate. We have ignored the country-specific restrictions associated with some imported products. "Over-quota" imports are not limited in quantity but face higher tariff rates. Both *ad valorem* (percentage based on value) and specific (per unit) tariffs are represented for both categories of imports. U.S. exports of dairy products are modeled using a simplified "Rest of World" (ROW) structure that has production and inventories of tradable products but also demands U.S. dairy products. The model uses 2011 U.S. 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 U.S. and the world market (using Oceania pricing as a base) and import restrictions. Total exports for each product are calculated based on interactions between an aggregated U.S. market and the ROW, and sales for California and the rest of the United States are assigned proportional to production in each region.

Dairy Policies

The pre-AA2014 suite of dairy policies is represented in the model to allow comparison of simulated MPP-Dairy outcomes to the counterfactual of continuation of previous policies. Thus, the model represents the operations of the DPPSP, MILC and the DEIP, all of which will be eliminated under the AA2014. We also include policies unchanged by the AA2014, such as minimum farm milk price regulation under federal and California milk marketing orders, including relevant timing of pricing decisions.

The Margin Protection Program

We modify the policy structure of the model to account for the major impacts of MPP-Dairy. The program includes a premium schedule (Table 2) based on the margin level protected, from \$4 to \$8 per 100 lbs. of milk produced. Premiums are lower for the first tier (for coverage on up to 4 million lbs. milk produced per year, or the production from about 180 cows) than for the second tier, so larger farms that want to protect more than 4 million lbs. of milk will pay higher average rates. The formal administrative procedures for implementation developed by the Farm Service Agency of USDA required dairy farmers to select a participation level by the end of November 2014 for coverage during the 2014 and 2015 calendar years, and by the end of September of the previous year for coverage during 2016 to 2018.

Table 2. Premium Schedule for MPP-Dairy Margin Coverage Levels, $/100 lbs. Milk

Margin Level Insured, $/100 lbs. Milk	Tier 1 (up to 4 million lbs. milk per year)	Tier 2 (for above 4 million lbs. milk per year)
4.00	0.000	0.000
4.50	0.010	0.020
5.00	0.025	0.040
5.50	0.040	0.100
6.00	0.055	0.155
6.50	0.090	0.290
7.00	0.217	0.830
7.50	0.300	1.060
8.00	0.475	1.360

Data Sources

The data used to develop the structure and parameter values for the model are from diverse sources, including NASS publications, U.S. Census Bureau (for trade statistics) previous modeling studies (e.g., Bishop, 2004; Pagel, 2005), other industry documents, and in some cases, judgment of dairy industry decision makers and analysts. This use of a broad range of sources is common for dynamic simulation models, and is consistent with the three types of data needed according to Forrester (1980): numerical, written and mental (professional knowledge) 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. Our evaluation concluded that the model passed a key test, that of behavioral mode reproduction: it replicated observed cyclical behaviors in U.S. milk prices with a period and amplitude similar to those described in Nicholson and Stephenson (2015). The behavioral mode (i.e., oscillation) was not sensitive to a wide variety of model parameters assessed, although changes in supply-response parameters did substantively alter the period and amplitude of milk price behavior. In addition to more formalized model evaluation procedures, throughout model development and afterwards, a wide variety of industry decision makers reviewed model behaviors, typically in meetings in which the model was simulated in real time in response to inquiries or proposed assumptions/scenarios from these decision makers. A wide variety of model behaviors were explored in these meetings, including the relationship between Class III and IV prices under FMMO price regulation, impacts of changes in regulated pricing under FMMOs and the California state order, U.S. exports of cheese and NDM, the relationships between U.S. and international dairy product prices, cow numbers, milk production, milk prices and others. Industry decision makers and analysts regarded the behavioral patterns generated by the model and the orders of magnitude were reasonable. This more qualitative evaluation provides an additional point of contact between the model outputs and the reality of the U.S. dairy supply chain and builds confidence that the model is appropriate for its stated purpose.

Scenarios Analyzed and Key Variables

We simulate a number of scenarios to assess the impacts of MPP-Dairy and its relationship to our underlying assumptions. To illustrate empirically the basic impacts of the program, we compare two sets of scenarios, a *Baseline* that assumes continuation of the pre-AA2014 suite of U.S. dairy programs (DPPSP, MILC, DEIP) to MPP-Dairy scenarios that assume implementation of the dairy provisions of AA2014. The MPP-Dairy scenarios assume elimination of MILC, DPPSP and DEIP, and implementation of MPP-Dairy provisions in January 2015. To assess the impacts of key uncertainties on the impacts of MPP-Dairy, we simulate four producer participation scenarios and four conditions with alternative market conditions. The principal variables of interest include the margin, farm milk prices and government expenditures, but we also examine impacts on dairy farm incomes, selected dairy product prices and U.S. dairy net exports.

Program Participation Scenarios

The extent to which farmers will participate in a new program such as margin insurance is unknown, so we assess market impacts based on four alternative assumption that capture a wide range of participation options. MPP-Dairy has features that imply it can be used to provide catastrophic insurance, as risk management or as a countercyclical payment program for which the expected monetary value of participation is positive. Each of these suggests a different preferred margin coverage level.

Although it is unlikely that all producers will choose one of these options, we model the outcomes for each to suggest the range of potential market outcomes. Under the

Catastrophic coverage scenario, all farms are assumed to cover 90% of their production history at a $4.00/cwt margin level in all program years (Table 3).

Table 3. Assumptions for Four Farmer MPP-Dairy Participation Scenarios Analyzed

Participation Scenario	Proportion of Milk Insured	Margin Level Insured, $/cwt
Catastrophic	90%	All farms: $4.00
6.50 Margin	90%	All farms: $6.50
Bozic, Wolf and Yang Participation	90%	Proportion of farms in category: $4.00: 0.286 $4.50: 0.029 $5.00: 0.108 $5.50: 0.065 $6.00: 0.254 $6.50: 0.117 $7.00: 0.061 $7.50: 0.020 $8.00: 0.061
Conditional Participation	90%	All farms: Margin Expectation > $8.00, $4.00 Margin Expectation ≤ $8.00, $8.00

(This is what the FSA calls "catastrophic coverage, which incurs only the cost of a $100 per year administrative fee, with no cost for premiums.) The *6.50 Margin* scenario assumes all farms cover 90% of their production history at a $6.50/cwt margin level, to assess a relatively simplistic risk management strategy. A *Conditional Participation* strategy assumes that farms would use MPP-Dairy conditional on margin expectations. For margin expectations above $8.00/cwt, we assume that producers would choose the "catastrophic" coverage, 90% of production history and a $4.00/cwt margin coverage level. If expected margins are less than $8.00/cwt, producers would cover 90% of production history at the $8.00/cwt margin coverage level. Thus this strategy represents a high degree of program participation when payments are expected, and for farms with a production history less than the 4 million lbs (which defines the lower-tier of MPP-Dairy premium payments) this decision rule would have maximized net returns from program participation during 2007 to 2013. We assumed that margin expectations are developed based on the so-called TREND function (Sterman, 2000; pp. 634-638), which combines exponential smoothing of previous MPP-Dairy margin values with extrapolation of recent trends in margin. Sterman demonstrates that this function reflects common underlying decision rules used in forecasts for energy consumption, cattle prices and inflation and other sectors (pp. 638-654). The expected margin value at the latest possible decision date (e.g., 30 September 2015 for 2016 program participation) determines the extent of coverage for the years 2014 to 2018.

We also assess MPP-Dairy outcomes based on stated preferences of dairy farmers for program participation. Bozic, Wolf and Yang (2014) surveyed U.S. dairy producers and reported the margin coverage levels that farmers indicated they would select "in most years." We used the proportion of farms indicating specific margin coverage levels from Bozic, Wolf and Yang and assumed 90% production history coverage (Table 3). We assume 90% production history coverage because this typically results in the largest net payments for a given margin level covered based on our optimization analysis.

Market Condition Scenarios

In addition to participation decisions, the impacts of MPP-Dairy are likely to depend to a large extent on market conditions. If margins remain above \$8.00/cwt during all program years, then no payments would be made and the program's hypothesized impact on milk supplies will not occur. If margins fall to levels such as those observed in 2009 and 2012, the impacts of MPP-Dairy are likely to be much larger. To assess how market conditions affect program impacts, we compare outcomes with status quo dairy policies and MPP-Dairy implementation under the Bo Bozic, Wolf and Yang participation assumptions for two additional sets of market conditions, *Limited Impacts* conditions and *Major Impacts* conditions. The *Limited Impacts* conditions assume 25% lower feed prices (and therefore a larger margin—at least initially) beginning in May 2015 and lasting through 2018 and a 10% increase global demand for all dairy products that persists for 12 months beginning in May 2015. The *Major Impacts* conditions assume 25% higher feed prices (and therefore a smaller margin—at least initially) beginning in May 2015 and lasting for through 2018 and a 10% decrease in global demand for all dairy products that persists for 12 months beginning in May 2015. These assumptions about market conditions will have a direct impact on margins and milk prices and therefore on MPP-Dairy impacts compared to pre-AA2014 dairy programs. We further explore the ranges of possible impacts with a stochastic analysis that uses Latin hypercube sampling of a range of possible feed costs increases (-25% to +25% through 2018 beginning in May 2015) and global demand changes (-10% to +10% for 0 to 24 months beginning in May 2015) for N=200 simulations. Using the same random seed for each N=200 simulations (and thus the same randomly-generated set of parameter values for the *Baseline* and MPP-Dairy scenarios), we develop the empirical probability distribution of differences in outcomes between *Baseline* and MPP-Dairy scenarios.

Results

Empirical Results of Baseline and MPP-Dairy Participation Scenarios

The simulated outcomes (Table 4) are largely consistent with our hypothesis that implementation of MPP-Dairy based on our assumptions about participation has the potential to sustain lower margins, lower milk prices and larger government expenditures.

Table 4. Simulated Outcomes During 2015-2018, Baseline, and 4 MPP-Dairy Participation Scenarios

Outcome	Baseline	MPP-Dairy Participation Strategies			
		Catastrophic	650 Margin	Bozic, Wolf, and Yang	Conditional Participation
All-milk price, $/cwt	16.98	17.10	16.08	16.54	16.27
MPP-Dairy margin, $/cwt	7.40	7.52	6.50	6.96	6.68
Cumulative government payments, $ billion	244	0	2,672	673	2,120
NFOI, Medium U.S. Farm, $/farm/year	76,706	79,294	54,818	61,716	61,869
Indemnity payments, Medium U.S. farm, $/farm/year	0	0	23,714	12,647	34,903
Cumulative NFOI, $ billion	19.6	20.5	14.2	15.9	14.8
Cheese price, $/lb.	1.57	1.58	1.49	1.53	1.51
U.S. net exports, cheese, mil lbs./year	546	539	603	572	590
ROW NDM price, $/lb.	1.99	2.00	1.93	1.96	1.94
U.S. net exports, NDM, mil lbs./year	1,737	1,727	1,803	1,770	1,782

Table 4 continued.

Outcome	Baseline	MPP-Dairy Participation Strategies			
		Catastrophic	650 Margin	Bozic, Wolf, and Yang	Conditional Participation
Difference from Baseline					
All-milk price, $/cwt		0.12	-0.90	-0.45	-0.72
MPP-Dairy margin, $/cwt		0.12	-0.90	-0.45	-0.72
Cumulative government payments, $ billion		-244	2,428	429	1,876
NFOI, Medium US Farm, $/farm/year		2,588	-21,888	-14,989	-14,836
Indemnity payments, Medium US farm, $/farm/year		0	23,714	12,647	34,903
Cumulative NFOI, $ billion		0.9	-5.4	-3.7	-4.8
Cheese price, $/lb.		0.01	-0.07	-0.03	-0.06
U.S. net exports, cheese, mil lbs./year		-7	57	26	44
ROW NDM price, $/lb.		0.01	-0.06	-0.03	-0.05
U.S. net exports, NDM, mil lbs./year		-10	66	33	45
% Difference from Baseline					
All-milk price, $/cwt		0.7	-5.3	-2.6	-4.2
MPP-Dairy margin, $/cwt		1.6	-12.1	-6.0	-9.7
Cumulative government payments, $ billion		-100.0	993.1	175.4	767.4
NFOI, Medium U.S. Farm, $/farm/year		3.4	-28.5	-19.5	-19.3
Indemnity payments, Medium US farm, $/farm/year					
Cumulative NFOI, $ billion		4.6	-27.6	-18.9	-24.5
Cheese price, $/lb.		0.6	-4.5	-2.2	-3.6
U.S. net exports, cheese, mil lbs./year		-1.4	10.5	4.8	8.2
ROW NDM price, $/lb.		0.5	-3.1	-1.7	-2.4
U.S. net exports, NDM, mil lbs./year		-0.6	3.8	1.8	2.5

The *Baseline* scenario includes the effects of MILC payments (and that program's payment limits) but not DPPSP or DEIP because our simulations did not project these latter two programs to become active during 2015-2018. Thus, comparisons between pre-AA2014 dairy policies and MPP-Dairy largely represent the dynamic effects of differences in the payments under MILC and MPP-Dairy. Compared to this *Baseline*, the average margin used to make indemnity payments is lower under participation strategies other than *Catastrophic* (Figure 2, Table 4).

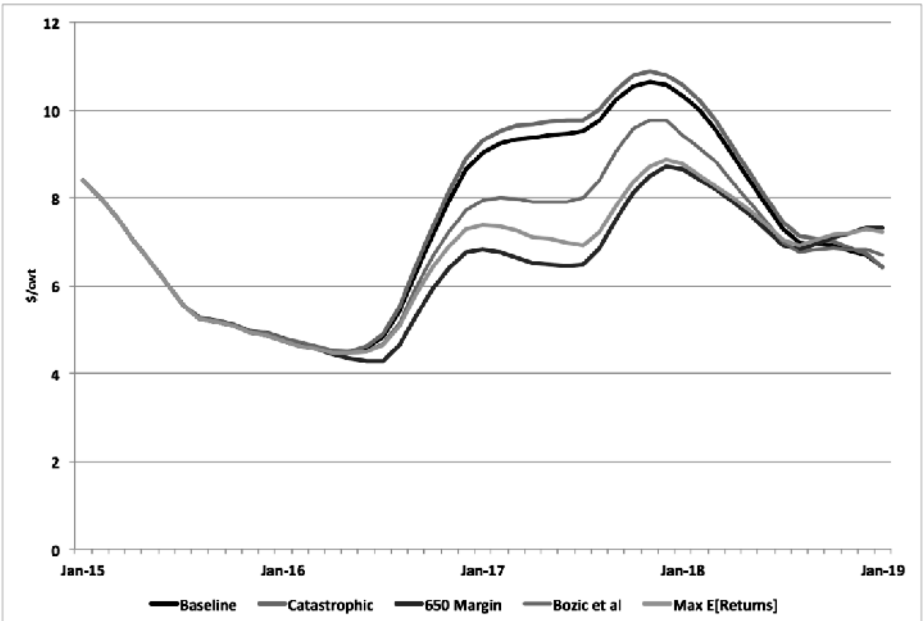

Figure 2. Simulated Value of the Margin Used to Pay Indemnities, Baseline, and 4 Margin Protection Program Participation Scenarios, 2015 to 2018

The principal effect occurs when margins become low due to a reduction in milk prices in 2016 that is consistent with a three-year price cycle (Nicholson and Stephenson, 2015). Once the program becomes active as a result of low margins, the program margin is more frequently below a value $8 (Figure 3) due to increased milk production arising from the effects of the program that weaken feedback loops that would otherwise bring about stronger supply adjustments in response to lower profitability. The *Catastrophic* participation assumption results in a higher average margin than the *Baseline* due to the difference in government payments between MPP-Dairy and MILC. Under the

Catastrophic assumptions, no MPP-Dairy payments are made, but under the *Baseline*, MILC payments are. The impact of MILC payments is to somewhat reduce milk prices and margins, which are therefore lower than for the *Catastrophic* scenario under which no payments are made.

The average value of the program margin is under the three participation scenarios other than *Catastophic* ranges from $0.45/cwt to $0.90/cwt less than the Baseline from 2015 through 2018 (Table 4). The average U.S. All-milk price is also lower by this amount under these participation scenarios. To the extent that variation in milk prices *per se* is considered a management challenge by dairy farmers, dairy buyers and agricultural lenders, MPP-Dairy has a positive effect because it reduces the coefficient of variation by up to 30%.

Once the program becomes active, lower margins result in government payments through the end of 2016 (Figure 4a), and for the *6.50 Margin* and *Conditional Participation* scenarios these payments reach nearly than $400 million per month.

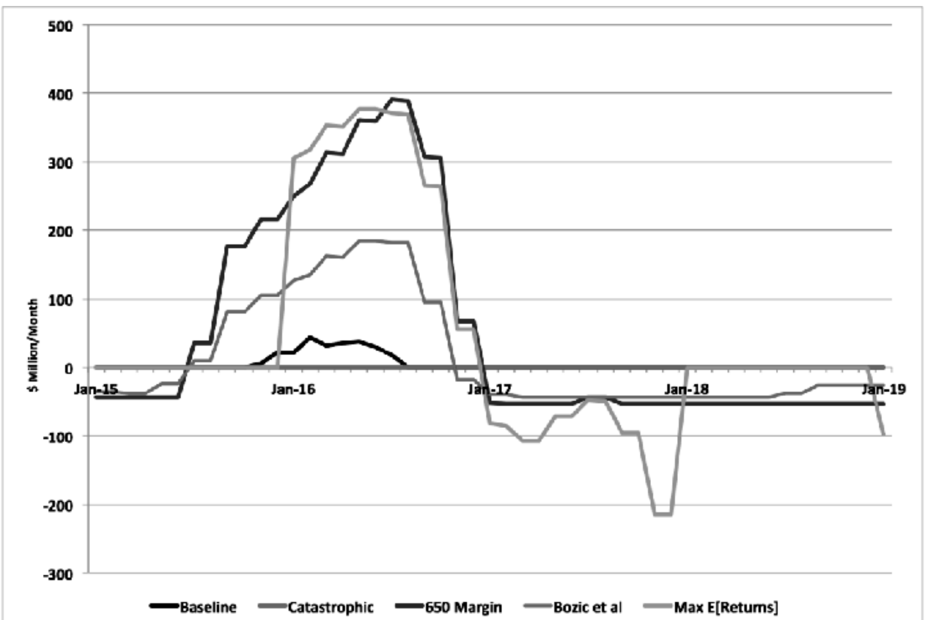

Figure 3. Simulated Value of Monthly Government Indemnity Payments, Baseline, and 4 Margin Protection Program Participation Scenarios, 2015 to 2018

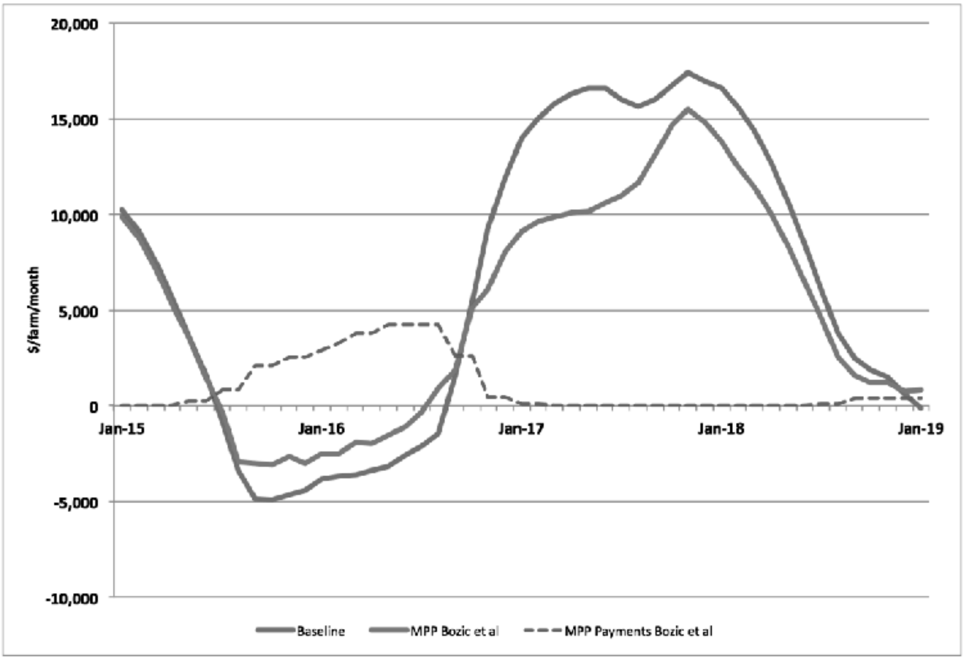

Figure 4a. Simulated Value of Monthly Net Farm Operating Income and Indemnity Payments for a Medium-size (230 cows) U.S. Dairy Farm, *Baseline*, *Bozic, Wolf, and Yang,* and *MPP-Dairy* Participation Scenarios, 2015 to 2018

The cumulative government expenditures under the margin program range from $673 million to nearly $2.7 billion from 2015 to 2018 (Table 4), compared to about $250 million simulated under pre-AA2014 programs (all of which would have been MILC payments). Compared to recent historical expenditures on dairy programs and agricultural programs more generally, $2.7 billion is large. The Congressional Budget Office (CBO, 2014) estimated that all "commodity" provisions of the Agricultural Act of 2014 would cost $21.4 billion during 2015 to 2019, with crop insurance programs costing an additional $44 billion. If this captures the attention of Congress before the current MPP-Dairy authorization expires, the program could be modified—by raising premiums and(or) lowering coverage levels—prior to 2018.

Our simulations indicate that MPP-Dairy will decrease farm incomes for participation scenarios other than *Catastrophic*, but to make them more stable, with fewer months in which NFOI is negative. Despite average annual payments (most occurring during the low-price period of 2016) ranging from about $13,000 to $34,000 per year for a medium-sized U.S. dairy farm (230 cows), simulated NFOI during 2015 to 2018 is decreased from $15,000 to $22,000 per year compared to current dairy policies (Table 4). Because it seems counter-intuitive that a payments program that appears more generous than MILC could lower NFOI, we examined the components of the changes in NFOI for our medium-farm size category to assess this outcome. Average monthly revenues including those from milk sales and MPP-Dairy program payments were higher by about 2% with MPP-Dairy than for the Baseline, but operating costs were more than 3% larger than the *Baseline* due to the expansion of cow numbers for which MPP-Dairy payments comprised an incentive. These results are consistent with boundedly-rational decisions about expansions of the cow herd in response to profitability incentives, and the dynamic complexity of profitability (profitability first increases under MPP-Dairy compared to the *Baseline*, but the dynamic effects are sufficient to more than offset the initial benefits). It is also consistent with asymmetric culling responses to profitability, indicating that farmers are more reluctant to cull animals when they are increasing cow numbers, but the result is higher farm operating costs. Although average NFOI income is simulated to decrease, the program provides payments during low margins (Figure 4a for Bozic, Wolf and Yang. participation assumptions and Figure 4b for *Conditional Participation;* green dashed lines) that decrease the number of months of negative NFOI. Lower average—but more stable—returns may be welcomed by some U.S. dairy farmers, reflecting risk-return trade-off preferences.

Although cumulative NFOI for all U.S. farms including MPP-Dairy payments would be increased by about $1 billion by under the *Catastrophic* participation assumption, simulated cumulative NFOI for all U.S. dairy farms would be between $3.7 and $5.4 billion lower than under the *Baseline* (Table 4) for the other participation scenarios. Thus, MPP-Dairy is likely to reduce total NFOI for U.S. dairy farms if there is substantive participation. However, cumulative NFOI is less variable with MPP-Dairy compared to the *Baseline*. To the extent that the reduction in variability of NFOI and the risk of negative profitability is decreased, many dairy farmers could consider the program successful (despite its negative impact on NFOI).

Another outcome that could be considered positive by many in the U.S. dairy industry is the effect of MPP-Dairy on dairy product exports. The share of U.S. dairy product exports has grown rapidly in recent years, and most policy proposals have been examined for their impacts on dairy trade. Because MPP-Dairy reduces the cost of the major input (milk) for dairy product manufacturers, it lowers dairy product prices. For example, average American (cheddar-type) cheese prices would be reduced between $0.03/lb. and $0.07/lb. (2 to 5%) for participation assumptions other than *Catastrophic* and would be more stable. This would increase average annual exports of U.S. cheese between 5% and 10% during 2015-2018 (Table 4). Thus, the price effects of MPP-Dairy compared to pre-AA2014 policies are likely to be experienced by other global dairy suppliers and buyers, not just those in the U.S.

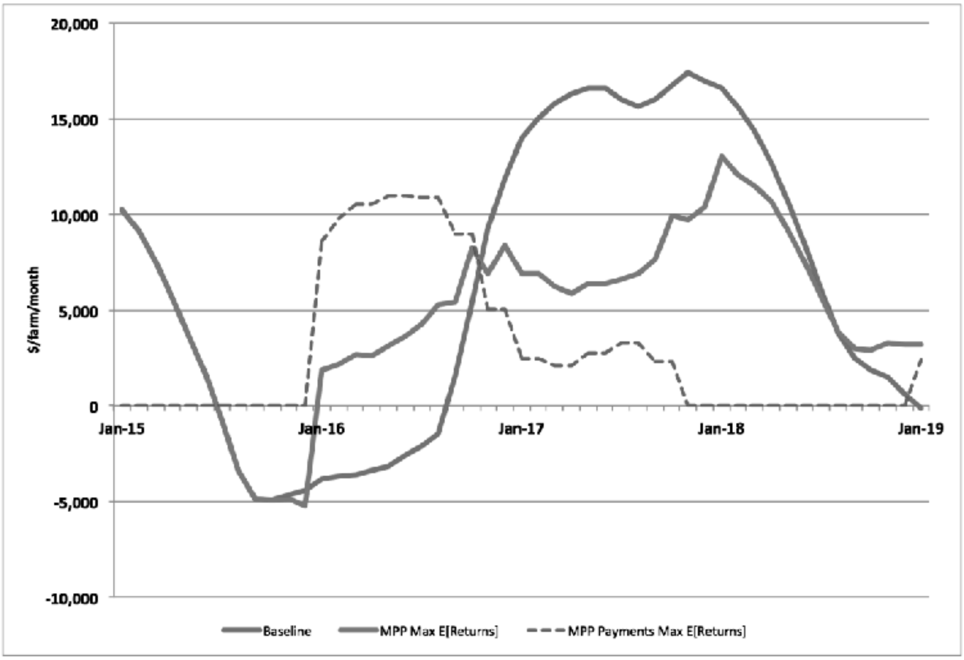

Figure 4b. Simulated Value of Monthly Net Farm Operating Income and Indemnity Payments for a Medium-size (230 cows) U.S. Dairy Farm, *Baseline,* and *Conditional Participation* MPP-Dairy Participation Scenarios, 2015 to 2018

Impacts of MPP-Dairy with Alternative Market Conditions Assumptions

Market conditions substantially affect the impacts of MPP-Dairy compared to current dairy policies. As expected, when market conditions are more favorable (lower feed prices and stronger global demand) under the *Limited Impacts* assumptions, the effects of MPP-Dairy on the All-milk price and margin are much smaller, with a increase of $0.13/cwt rather than a decrease of $0.45/cwt during 2015 to 2018 (Table 5).

Table 5. Simulated Outcomes During 2015-2018, Baseline and Three MPP-Dairy Scenarios with Different Assumptions about Decision Timing and Participation

Outcome	Baseline	Bozic, Wolf, and Yang	Baseline for Limited Impacts	Bozic, Wolf, and Yang Limited Impacts	Baseline for Major Impacts	Bozic, Wolf, and Yang Major Impacts
All-milk price, $/cwt	16.98	16.54	14.94	15.07	20.58	17.66
MPP-Dairy margin, $/cwt	7.40	6.96	7.56	7.69	8.79	5.87
Cumulative government payments, $ billion	244	673	1,383	-657	107	6,056
NFOI, Medium U.S. Farm, $/farm/year	76,706	61,716	76,255	78,572	142,997	49,820
Indemnity payments, Medium US farm, $/farm/year	0	12,647	0	7,677	0	33,741
Cumulative NFOI, $ billion	19.6	15.9	18.4	18.4	32.7	14.0
Cheese price, $/lb.	1.57	1.53	1.38	1.40	1.84	1.63
U.S. net exports, cheese, mil lbs./year	546	572	762	751	353	447
ROW NDM price, $/lb.	1.99	1.96	1.86	1.90	2.42	2.09
U.S. net exports, NDM, mil lbs./year	1,737	1,770	2,008	1,949	1,197	1,497
Difference from Baseline						
All-milk price, $/cwt		-0.45	-2.04	0.13	3.59	-2.92
MPP-Dairy margin, $/cwt		-0.45	0.16	0.13	1.39	-2.92
Cumulative government payments, $ billion		429	1,139	-2,040	-138	5,950
NFOI, Medium U.S. Farm, $/farm/year		-14,989	-451	2,317	66,292	-93,177
Indemnity payments, Medium U.S. farm, $/farm/year		12,647	0	7,677	0	33,741
Cumulative NFOI, $ billion		-3.7	-1.2	0.0	13.1	-18.7
Cheese price, $/lb.		-0.03	-0.18	0.01	0.28	-0.21
US net exports, cheese, mil lbs./year		26	216	-11	-193	95
ROW NDM price, $/lb.		-0.03	-0.12	-0.08	0.43	0.10
U.S. net exports, NDM, mil lbs./year		33	271	212	-540	-240

Outcome	Baseline	Bozic, Wolf, and Yang	Baseline for Limited Impacts	Bozic, Wolf, and Yang Limited Impacts	Baseline for Major Impacts	Bozic, Wolf, and Yang Major Impacts
% Difference from Baseline						
All-milk price, $/cwt		-2.6	-12.0	0.8	21.2	-17.2
MPP-Dairy margin, $/cwt		-6.0	2.2	1.8	18.8	-39.4
Cumulative government payments, $ billion		175.4	466.0	-834.7	-56.3	2434.0
NFOI, Medium U.S. Farm, $/farm/year		-19.5	-0.6	3.0	86.4	-121.5
Indemnity payments, Medium U.S. farm, $/farm/ year						
Cumulative NFOI, $ billion		-18.9	-6.1	0.0	66.8	-95.4
Cheese price, $/lb.		-2.2	-11.6	0.8	17.7	-13.7
U.S. net exports, cheese, mil lbs./year		4.8	39.5	-2.0	-35.4	17.3
ROW NDM price, $/lb.		-1.6	-6.4	-4.6	22.5	4.1
U.S. net exports, NDM, mil lbs./year		1.9	15.3	10.6	-27.7	-20.0

Note: Differences and percentage differences for Baseline for Limited Impact and Baseline for Major Impact scenarios compare to the Baseline scenario. Differences for MPP-Dairy scenarios compare to the Baseline scenarios in the columns immediately to their left.

The impacts of MPP-Dairy on government expenditures compared to the *Baseline* are much smaller (the U.S. treasury gains about $660 million rather than expending $1.3 billion on MILC), and there are increases in NFOI for a medium-sized farm and no negative impacts on cumulative NFOI US dairy farms (Table 5). There would be a small increase in U.S. cheese prices and a small decrease in cheese exports due to MPP-Dairy under these assumed more favorable market conditions.

When market conditions are less favorable (higher feed prices and weaker global demand in the *Major Impacts* assumptions) than for the initial Baseline and MPP-Dairy scenarios, the impacts of MPP-Dairy are much larger (Table 5). The decrease in the All-milk price and margin is more than five times larger than for our original market condition assumptions ($2.92/cwt compared to $0.45/cwt). Government expenditures are simulated to increase by nearly $6 billion during 2015-2018 with MPP-Dairy compared to the *Baseline* under these market conditions. Despite indemnity payments averaging more than $34,000 per farm per year for a medium-sized U.S. farm, average NFOI is reduced by nearly $100,000 per year during 2015 to 2018 (Table 5), and cumulative NFOI for all U.S. dairy farms is reduced by nearly $19 billion. There is a major impact on U.S. cheese markets (a 14% decrease in average cheese prices) and U.S. net exports increase by about 17%.

Thus, market conditions can have a substantial influence on the impacts of MPP-Dairy. However, the two market conditions simulated above assume rather extreme values for feed costs and global demand shocks. To provide further insights about the ranges and probabilities of possible outcomes under the MPP-Dairy scenarios compared to the *Baseline*, we assess the distributions generated by N=200 stochastic simulations. Unsurprisingly, the range of possible margin values during 2015 to 2018 is large for both the *Baseline* and MPP-Dairy as market condition parameters are modified (Figure 5). However, it is clear that the distribution of margin values over time has a smaller range and a lower average value for the MPP-Dairy simulations than for the *Baseline* simulations. This is further quantified by comparison of the average difference in the margin (and all-milk price) values during 2015 to 2018 for each of the N=200 stochastic simulations (Figure 6). Only 10 of 200 simulations—all with large reductions in feed costs and strong increases in export demand—resulted in an increase in the average margin and all-milk price during 2015 to 2018, and the average reduction in margin or milk price was $0.68/cwt. More than half of the simulations are in the range of $0/cwt to -$1.00/cwt.

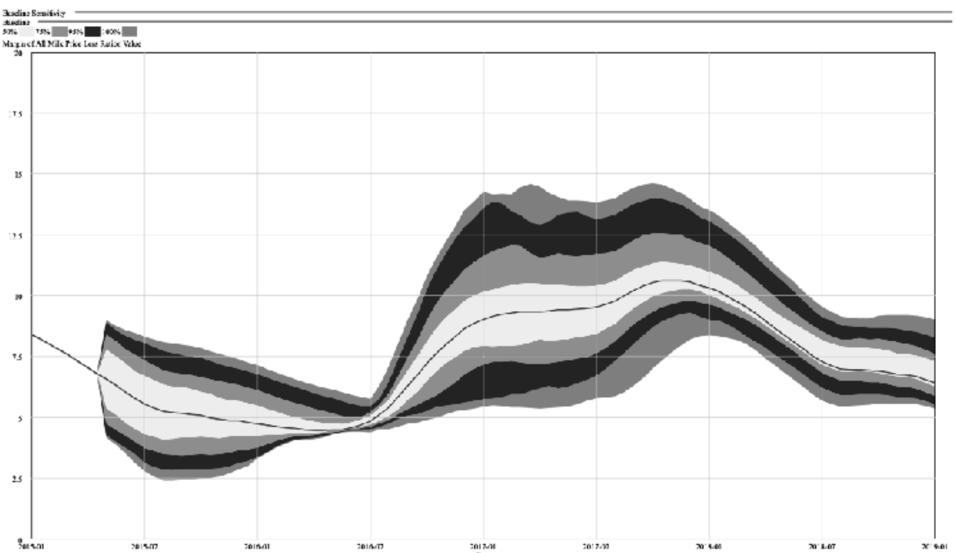

Figure 5. Range of Margin Values during 2015 to 1018 for N=200 Simulations for Stochastic Simulation Results with Baseline Assumptions

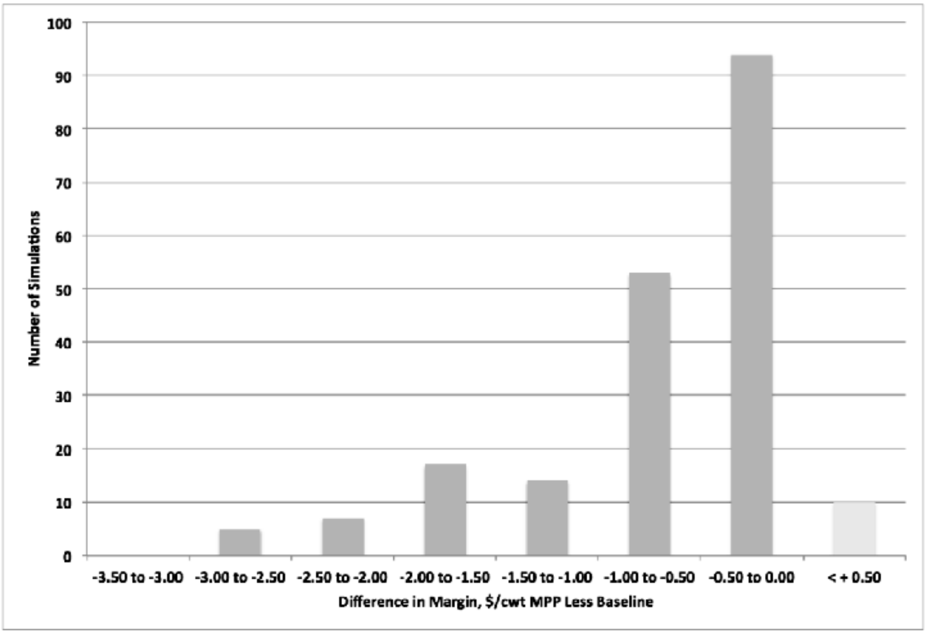

Figure 6. Distribution of Differences in the Average All-milk Price and MPP-Dairy Margin During 2015 to 2018 Between *Baseline* and *MPP-Dairy* Scenarios for N=200 Simulations with Variable Feed Prices and ROW Demand Pulse Values

The distribution of cumulative NFOI outcomes suggests a high probability of reductions in that value, with nearly three-quarters of the simulation values in the range from $0 billion to -$8 billion (Figure 7). The average reduction in cumulative NFOI for N=200 simulations was -$5.2 billion. There also appears to be a substantial probability that MPP-Dairy will increase government expenditures compared to current programs—about 60% of simulations indicated an increase in expenditures with MPP-Dairy compared to the *Baseline* (i.e., MILC payments). The average increase for N=200 simulations was $2.8 billion, based on distribution ranging up to more than $6 billion (Figure 8). Thus, although the exact empirical magnitude of impacts of MPP-Dairy are uncertain, there appears to be a high probability of the types of impacts predicted by the conceptual model and reported in our comparisons of the initial Baseline and MPP-Dairy scenarios.

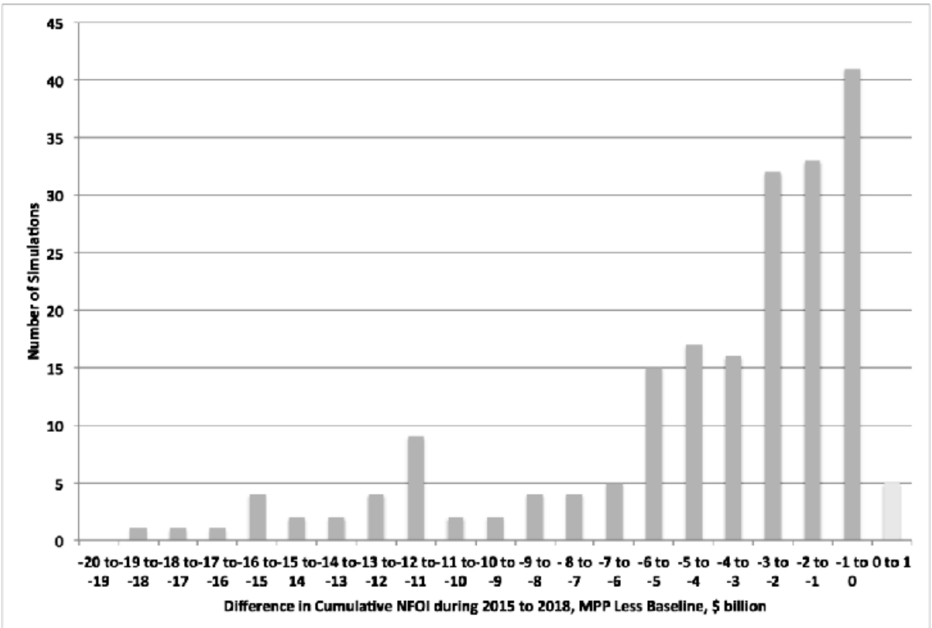

Figure 7. Distribution of Differences in the Cumulative Net Farm Operating Income During 2015 to 2018 Between *Baseline* and *MPP-Dairy* Scenarios for N=200 Simulations with Variable Feed Prices and ROW Demand Pulse Values

Implications

The foregoing conceptual and empirical analyses are largely consistent in their assessment of MPP-Dairy impacts compared to current policies, albeit with considerable uncertainty based on participation decisions and the range of future market conditions under which MPP-Dairy would operate. Despite the uncertainty inherent in the stochastic analysis, there are a number of implications of our conceptual and empirical findings:

- *Participation decisions have the potential to markedly affect MPP-Dairy outcomes, but outcomes are also likely to affect future participation decision*. As noted in our analysis, lower participation implies much more limited impacts of MPP-Dairy. However, participation decisions may also be affected by outcomes. For example, participation may be enhanced by periods of lower margins that are brought about in part by MPP-Dairy. This would create a reinforcing effect of the program on both margins and participation, which could make the outcomes more like those under the *Conditional Participation* scenario.

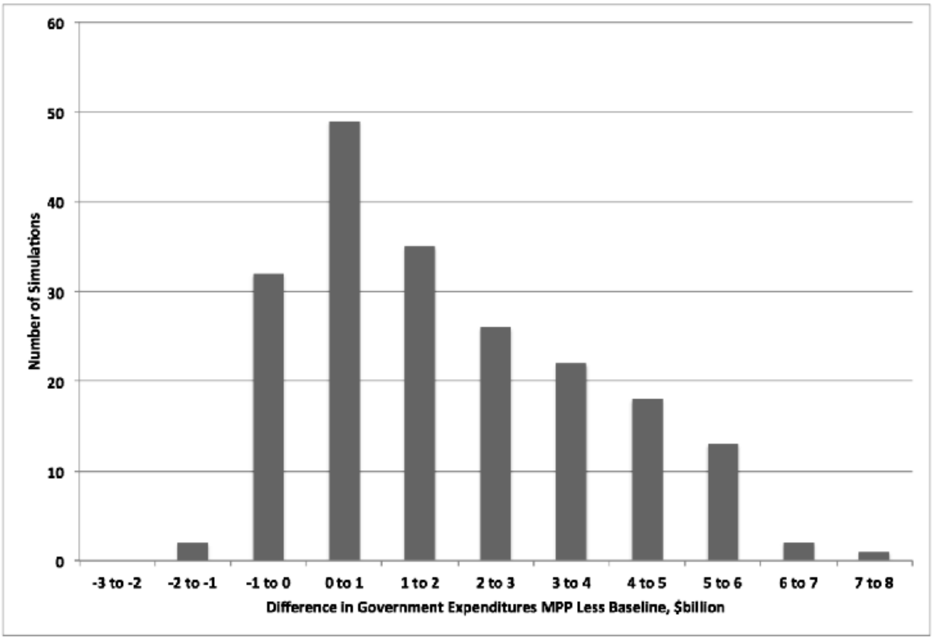

Figure 8. Distribution of Differences in the Cumulative Government Expenditures During 2015 to 2018 Between *Baseline* and *MPP-Dairy* Scenarios for N=200 Simulations with Variable Feed Prices and ROW Demand Pulse Values

- *Use of historical margin data to make participation decisions for the future could be of very limited usefulness and may be misleading*. A common approach to illustrate the potential impacts of MPP-Dairy at the farm level (e.g., Smith and Laughton, 2014) or to calculate an implied basis with the MPP-Dairy margin (e.g., Newton, 2014) has been the use of historical margin data but this may be misleading, for at least two reasons. First, our analyses suggest that under conditions observed during the previous decade or so, the program would have been active on many occasions (assuming at least moderate levels of producer participation), and MPP-Dairy probably would have markedly altered the trajectory of future margins, prices and program participation decisions. That is, the past with the program probably would have been very different from the actual past observed without the program, and therefore cannot reliably be used to assess the impacts of alternative farm-level decision strategies. Second, future costs and benefits of the program for producers will depend on current market conditions and the degree of participation by other producers, not on the potential benefits observed under previous years. These are not easily assessed with historical data.

- *The dairy producer participation decision is different for MPP-Dairy than for other risk-management decisions, but may not be independent of them.* We assumed various levels of participation in our analyses based on the use of MPP-Dairy as insurance, risk management or countercyclical payments. Although it was marketed as an insurance tool and will perform that function (paying when NFOI is low), the program differs from other insurance programs that pay indemnities in the case of catastrophic losses. Our analyses suggest that MPP-Dairy may be frequently active during 2015 to 2016, with substantive impacts on margins. This will affect both the future probability of indemnity payments and the participation decision, neither of which is typical for a product such as fire insurance (or crop insurance). Moreover, for most risk management products, producers would make decisions based on a careful assessment of their costs and benefits. For a highly subsidized program such as MPP-Dairy, this decision could focus more on how to maximize benefits from the program, given its relatively low costs. Finally, for farmers currently using other risk-management tools, the option for coverage under MPP-Dairy could modify the best use of these tools—with aggregate effects on the markets for risk if a sufficient number of producers substitute MPP-Dairy coverage for other risk management coverage.

Conclusions

Our analyses suggest that MPP-Dairy could weaken corrective market feedback processes through increased milk supply, resulting in more persistent periods of lower prices, lower margins and larger government expenditures. However, these results are conditioned on three key assumptions. The first is that cyclical behavior in U.S. milk prices results in sufficiently low margins in 2016, thereby activating indemnity payments under the program and muting the adjustment process. Although our simulated milk prices are consistent with previous price patterns, it is possible that future milk and feed prices will be sufficiently different from those in our baseline projections that MPP-Dairy is not frequently activated during 2015 to 2018. If this occurred, then the importance of weakening the relevant corrective feedback processes could be minimal, because they would not be activated. However, our stochastic analyses suggest that these types of impacts have a high probability of occurring with MPP-Dairy under a wide variety of market conditions and price trajectories. We also assumed a significant degree of farmer participation for some of the scenarios analyzed. If participation is less than assumed, this could also lessen the degree to which the feedback processes are weakened by the margin insurance program, which could markedly alter the program's dynamics during 2015 to 2018.

A perhaps more contentious assumption upon which our results are conditioned is that producer supply-response behavior *per se* is not modified by the implementation of MPP-Dairy, at least not significantly during the next couple of years. The so-called 'Lucas critique' (Lucas, 1976) suggests that a frequent limitation of policy analyses is their inability to anticipate the impacts of changes in policy on behavioral responses. We did not formally assess the impacts of possible changes in the behavioral relationships for MPP-Dairy, but believe this is reasonable in this case. First, Lucas' critique applied primarily to aggregated macroeconomic data, and stimulated significant research on the "microfoundations" of that aggregate behavior. Our model structure is broadly consistent with that idea given the highly disaggregated decision-making structure represented in our adaptation of the generic commodity model. Second, to the extent that changes in behavioral responsiveness arise from structural change (e.g., changes in the number and size of farms, reference values of NFOI and reference margins for cheese and whey), we have already accounted for this to some degree because the model endogenously generates these outcomes. For example, if the responsiveness differs for individual farm size categories, the model endogenizes at least some of the behavioral change that could result from MPP-Dairy. We also believe that most farmers and other industry decision makers will only substantively modify their decision rules (especially for culling) in response to MPP-Dairy after they have had a few years of experience with the program, conditional on which of a range of many possible market conditions occurs through the life of this Farm Bill. This is particularly likely because MPP-Dairy decisions are made annually, and because many MPP-Dairy participants have limited previous experience with any sort of risk management tools. For this to affect our results, behavioral changes would need to substantively change behaviors in the very near future—prior to the participation sign-up period in 2015—when there is less than a full year of experience with the program. We also believe that policy change *per se* does not generate changes in behaviors. Our experience suggests that many U.S. dairy producers are only vaguely familiar with dairy policy provisions and their likely effects. As a result, they base decision-making on farm-specific indicators such as NFOI (changes which may result from policy modification).

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APPENDIX: MODEL BACKGROUND AND MATHEMATICAL DESCRIPTION

The analysis reported in the text is based on a supply chain commodity model of the U.S. dairy industry using the System Dynamics (SD) modeling approach. Although the model represents the economic structures and behaviors we believe are most important to assess the impacts of MPP-Dairy, it does so using methods and assumptions that may not be familiar to many agricultural economists and agribusiness analysts. To assist with the interpretation of the modeling structure and results, we provide a basic background on the SD modeling process, an overview of the commodity model upon which our analysis is based, and specific mathematical structures and assumptions for key components of the model, particularly the milk supply response component. We also provide additional details about model evaluation processes.

SD Modeling Process

SD modeling begins with the premise the observed behaviors result endogenously from system "structure" that is conceived of in terms of stock-flow-feedback processes. The process of developing a model with SD (based on Sterman (2000; pp. 83-105) includes:

1) *Problem Articulation*, which includes identification of a problem behavior (a "reference mode" behavior observed over time) for a relevant time horizon. Our model development was guided by a desire to understand the sources of cyclical behavior of milk prices in the U.S. over a time horizon of 10 years;

2) *Formulation of a Dynamic Hypothesis*, which develops an endogenous causal theory of the behavior, often expressed using diagramming tools such as Causal Loop Diagrams (CLD; Figure 1), diagrams of system stocks and flows, and(or) model boundary diagrams that indicate which variables are to be considered endogenous, with exogenous and which

excluded. These diagrams build on existing literature and other information sources (e.g., industry documents, expert opinion) regarding potential causes of the behavior and provide a basis for mathematical formulation of the model. A CLD (e.g., Figure 1) can be used to provide qualitative insights about likely feedback effects. In our case, the CLD indicates a number of key assumptions in the context of feedback processes likely to drive oscillatory behavior in milk prices over time and the potential impacts of MPP-Dairy on those feedback processes. Although many of these processes can be understood in terms of concepts more familiar to economists (like “supply response”) they can also usefully be expressed in terms of feedback processes and we do so for consistency with our overall approach to modeling.

3) *Simulation Model Formulation,* in which the mathematical structure of the model is developed and parameter values selected. Much of the discussion below focuses on the details of key model structures and assumptions. These structures were developed based on the commodity model described by Sterman (2000; pp. 791-841), previous model development experience (e.g., Nicholson and Fiddaman, 2003; Pagel, 2005; Nicholson and Kaiser, 2008; Nicholson and Stephenson, 2010), but also included substantive consultation with industry participants and analysts to specify structural and parametric assumptions. There is a broad literature in the SD perspective on “Group Model Building” (e.g., Vennix, 1996; Bérard, 2010) in which stakeholder groups are involved in the modeling process to ensure that key problematic behaviors and appropriate decision rules are modeled. This process complements, not replaces, relevant disciplinary knowledge, but SD modeling gives priority to understanding decision rules used by actual decision makers. Decisions

rules used in modeling should be based on information actually available to decisions makers, using their heuristics.

4) *Model Evaluation,* which includes a variety of tests discussed in further detail in our section on model evaluation below. A key test is whether the model can replicate the "reference mode" behavior, but also model robustness to extreme conditions, and how model behavior changes in response to parameter changes (one form of sensitivity analysis). In this case, replication of the reference mode behavior involves the model's ability to generate oscillatory behavior in milk prices with a period and amplitude similar to that observed in a relevant previous time periods (in our case, the years 2000-2011). It is worth noting here that SD models are <u>not</u> typically evaluated for their ability to predict specific values at specific times (termed "point prediction") as are most forecasting models. This is because for dynamic systems models, replication of the behavioral <u>mode</u> (e.g., oscillation) is a better indicator of model adequacy. Sterman (2000, pp. 877-878) shows that even a perfectly formulated dynamic system model (i.e., with correct structures and parameter values) can fail to point predict accurately in the presence of "noise" (random perturbations or initial conditions errors). [This is analogous to the conclusion reached by the MIT meteorologist Edward Lorenz in the 1960s based on what came to be called the "butterfly effect".]

5) *Policy Design and Evaluation,* in which scenarios are specified based on potential decision rules, strategies and structures, the effects of the policies are represented in the model, and the sensitivity of policy outcomes to scenario and parametric uncertainties are evaluated. In this case, our scenarios examine the policy impacts of MPP-Dairy under key uncertainties: program participation (margin coverage levels and production history

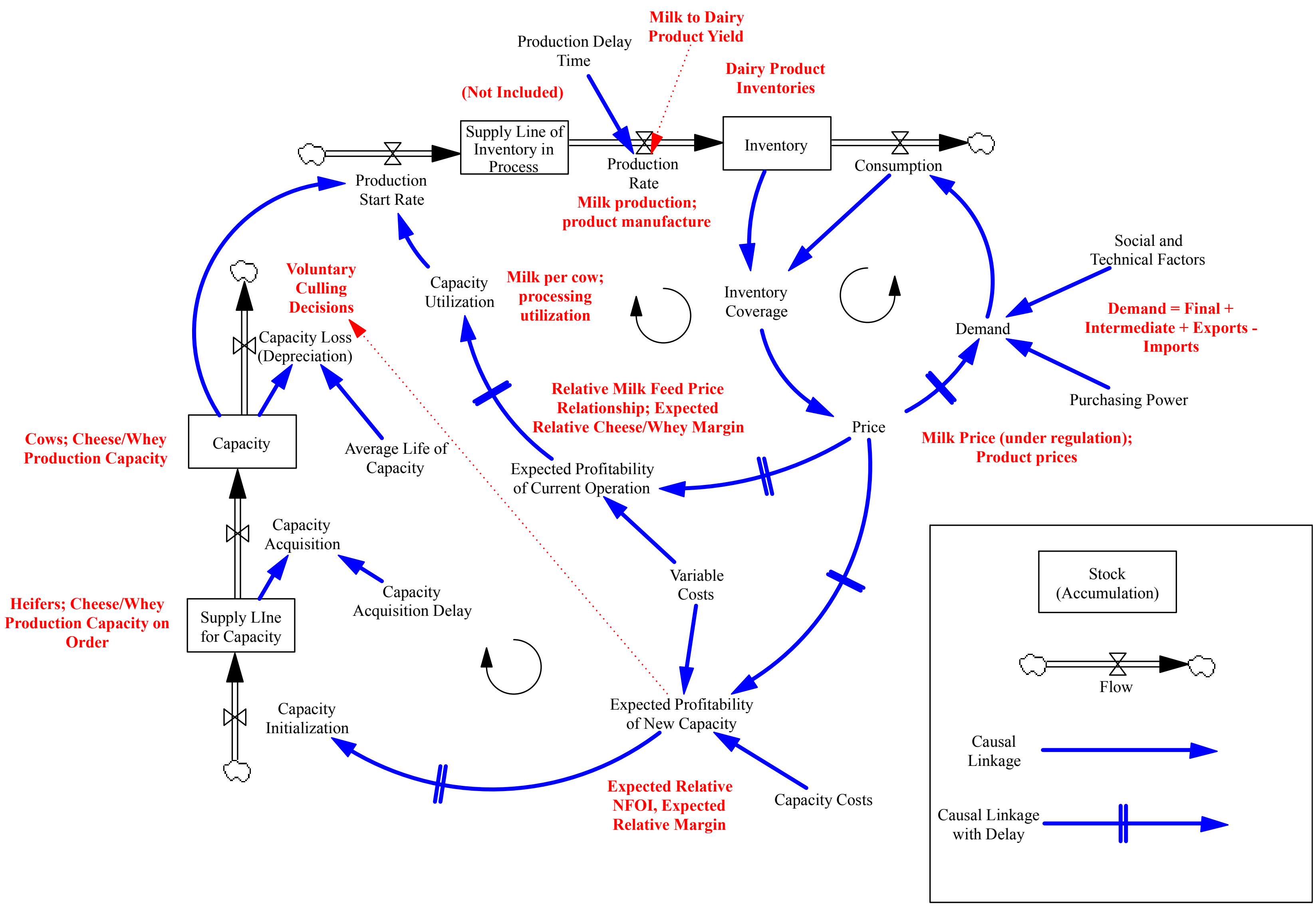
proportions) and market conditions (feed prices and export demand for U.S. dairy products).

In practical terms, SD modeling is the application of systems engineering concepts to social and economic systems. Thus, SD models are typically formulated as systems of ordinary differential equations that because of their complexity (and sometimes nonlinearity) are typically solved by numerical integration rather than by analytical methods. Because many disciplines have employed systems of differential equations in their analyses, this often leads to the observation that SD is "nothing new." In a mathematical sense, this is certainly true. For example, Chiang's well-known textbook *Fundamental Methods of Mathematical Economics* includes more than 200 pages on economic dynamics, including a chapter on solving simultaneous differential equations. Most differential equations texts (e.g., Blanchard et al., 2002) also cover this topic in extensive detail—although with emphasis on applications to physical and biological systems. However, it is worth noting that many mathematics and engineering texts and analyses emphasize analytical solutions to these systems (which often require linearization to be tractable) rather than numerical integration techniques, which allow a broader range of dynamic systems to be simulated.

Description of a Generic Commodity Model

Our SD model is based on the generic commodity model described in Sterman (2000; pp. 791-841), as adapted to represent structures specific to the U.S. dairy supply chain. This generic model has been applied to numerous commodities, dating back to Meadows' (1970) model of the U.S. hog sector. Güvenen, Labys and Lesourd (1991) provide a good overview of commodity model development through the early 1990s that includes a discussion of SD model formulations. This model was selected as a basis for our model development because it focuses specifically on the origins of oscillatory behavior in prices and production, which was our key "reference mode" behavior of interest for the U.S. dairy supply chain. It is useful to provide a brief discussion of this generic model here to facilitate discussion of the specific structures and assumptions in our model for the U.S. dairy supply chain.

The generic commodity model structure involves stocks for capacity and inventory that are influenced by (and influence) prices and demand (Figure S1). The capacity structure determines the amount of available productive capacity in an industry (a stock), which integrates the inflows and outflows of capacity. In the basic commodity model the outflow (capacity loss) is based on aging of existing capacity (rendering it either physically or economically unviable for further production) and inflows (capacity initiation) represent investments in capacity, which are assumed to be driven by long-term expectations of the profitability of new capacity. In our model, a key productive capacity stock at the farm level is the number of cows (and heifers comprise the supply line for capacity). However, because there is a biological linkage between the existing cows and "capacity initiation," the control variable for capacity management for cows is assumed to be the outflow, in this case, the culling rate, rather than capacity initiation. Our assumption that culling rates respond to expected profitability rather than prices *per se* derives from this specification in the generic commodity model. Inventories of product in the generic commodity model are determined based on existing capacity and its utilization. Utilization is assumed to respond to the expected profitability of current operations, which depend in turn on prices and variable costs. In our model, utilization of farm capacity is represented by milk per cow, which responds to expected profitability in a manner different than does capacity, as is implied by the generic commodity model structure. Another modification is



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115 **Figure S1. Generic Commodity Model Structure and Representations/Modifications to Model U.S. Dairy Supply Chain**

that milk production is not equivalent to the production rate that results in inventories in the generic commodity model, because the raw milk must be transformed into perishable and storable products—and there are multiple dairy products into which farm milk is transformed, not just the one implied in the generic commodity model. We also omit the supply line of inventory in process because most U.S. dairy products do not require long production periods (aged cheeses would be a notable exception, but our two aggregated cheese products to not admit this complication.) In the generic commodity model, product prices are determined by inventory holdings (relative to current consumption—the "inventory coverage ratio") and these in turn affect both expectations of profitability and short-term and long-term demand.

The generic commodity model indicates that "delays" are pervasive in the supply chain structure. One justification for this is that for a dynamic system to oscillate, it must consist of at least one negative feedback loop with a delay (Sterman, 2000; p. 114), and this loop must be strong enough to offset other feedback effects. A feedback loop comprises a series of causally-linked variables in which an initial change in one of the variables would ultimately affect the value of the variable that was initially changed. Feedback loop polarity is defined in control theory on the basis of the sign of the open-loop "gain" of the loop. More formally, the polarity is given by:

$$\text{Polarity of loop} = SGN\left(\frac{\partial x_1^O}{\partial x_1^I}\right),$$

where SGN equals +1 if the function is > 0 and -1 if the function is < 0, x_1^O comprises the values of the variable x_1 after one feedback loop process is completed, x_1^I indicates the initial change in that variable, and the function is evaluated using the chain rule for all intervening variables in the feedback loop (x_1, x_2, … x_n). Partial derivatives here express the idea that this is a *ceteris paribus* condition that could be affected by other variables not in this specific feedback loop. A negative feedback loop thus has a negative loop polarity and a positive feedback loop a positive loop polarity. In more qualitative terms, positive feedback loops are sometimes referred to as "reinforcing loops" because an initial change in a variable will be enhanced through feedback processes ("gain" is positive) and negative feedback loops as "balancing loops" because an initial change in a variable will be offset (at least to some extent) as the effects are propagated through the loop structure ("gain" is negative).

A second justification for the delays in the generic commodity model structure is that they are common in real-world supply chains, often representing institutional or information constraints that prevent instantaneous adjustment in response to changes in variables affecting decision making in the chain. For example, the delay indicated for adjusting capacity utilization in response to expected profitability of current operations captures the time required for data collection and analysis, decision-making and implementation (for example, hiring new employees to work additional shifts). Delays between price and expected profitability capture the time required for data collection and expectation formulation, and between expected profitability and capacity initiation, similar to capacity utilization adjustments, require time for data collection, decision-making and implementation. Delays between the price (relative value of the product) and demand are due to price expectation formulation, finding substitutes, redesigning products, replacing capital stocks depending on the commodity, or for the expiration or renegotiation of contractual obligations with suppliers. An example related to demand for mozzarella cheese in response to a price increase would be that pizza restaurant chains seek to renegotiate contracts or "redesign" products (pizzas that include less cheese and more of other ingredients).

The foregoing suggests that the generic commodity model incorporates fundamental elements of supply and demand for commodities, but does so in a manner that differs in some particulars from model formulations more typical in economics.

Model Mathematical Description

Consistent with step 3 of the modeling process above, we now describe selected components of the mathematical structure. The SD model comprises thousands of equations and a large number of parameters, key elements of the basic model structure for milk supply, dairy product demand and dairy product trade are described below. We provide greater detail on the milk supply response because this is the most important for assessment of the impacts of MPP-Dairy. All variables have implied time (month) and regional subscripts, which are generally omitted for the sake of simplifying the expressions.

Milk Supply Module

The milk supply module determines milk production in a given time period, and incorporates biological, economic and farm financial components. Milk production is calculated as:

$$\mathit{Milk\ Production} = \sum_{s} (\mathit{Cows\ Per\ Farm}_s)(\mathit{Farms}_s)(\mathit{Milk\ Per\ Cow}_s) \qquad [1]$$

where s is the farm size category (8 in the model: small, medium, large, and extra large for each of two U.S. regions, California and the Rest of U.S.), and *Farms* is the number of farms in a size category. Each of the components of this equation are described in greater detail below.

Cows Per Farm

$$\mathit{Cows\ Per\ Farm}_s = \mathit{Cows}_s / \mathit{Farms}_s \qquad [2]$$

Cow numbers are a key stock ("accumulation", sometimes termed "state variable") and are based on an "aging chain" structure in which animals move through different stocks based on age. The two basic stock structures are for heifers and cows, with the number of the latter defined as:

$$Cows_s = \int_{t0}^{t} \left(HeifersEntering_s - CowsCulled_s \right) + Cows_0 \qquad [3]$$

Heifers Entering is specified as a 100-th order delay of heifer calves born and retained on farms in a given size category. A first-order delay has the mathematical structure:

$$\textit{Outflow from Stock} = \textit{Value of Stock} \,/\, \textit{Average Delay Time} \qquad [4]$$

where the average delay time is the average amount of time that a material remains in the stock before it exits (inflows are typically determined by other factors, but in SD models all stocks integrate the values of inflows and outflows). In a first-order delay, the outflow is directly proportional to the stock. A 100-th order delay links 100 of these first-order delay structures so that the outflow of one stock is the inflow of another stock. In this case, the 100 stocks represent the total number heifers maturing on farms and the total average delay time is the assumed time required for maturation, 27 months. The delay structure influences the distribution of outflows from a stock, and a 100-th order delay was appropriate in this case to represent a range of maturation values on U.S. dairy farms (i.e., the delay structure creates the equivalent of a probability distribution of heifer maturation dates around the mean 27-month value). More specifically:

$$\textit{Heifers Entering}_s = \textit{DELAY100}[\textit{Heifer Calves Born}_s]$$

$$\textit{Heifer Calves Born}_s = (\textit{Cows}_s \,/\, \textit{Calving Interval}_s) * \textit{Proportion Heifer Calves}_s \qquad [5]$$

The proportion of heifer calves assumes partial adoption of sexed semen technology on U.S. dairy farms so that the proportion of heifer calves reaches 60% by 2015. The average calving interval is assumed to be 14 months.

As noted above, culling decisions play a major role in determining cow numbers. Cow culling decisions are separated into "involuntary" and "voluntary" culling, as in:

$$\textit{Cows Culled}_s = \textit{Involuntary Culls}_s + \textit{Voluntary Culls}_s \qquad [6]$$

The former represents culling due to the age of the animal, its health or reproductive status, and is given as a fractional rate, with units of proportion of the herd culled/Month (equivalently, 1/Month). This fractional rate is determined by a base rate and by production stress, because animals that are fed to produce more milk are likely to reduce their body tissue reserves of energy (Nicholson et al., 1994) and therefore be more likely to have health or reproductive issues that would merit culling. The fractional involuntary cull rate is specified as:

$$\textit{Involuntary Cull Rate}_s = (\textit{Base Involuntary Cull Rate}_s)(\textit{Effect of Production Stress on Involuntary Culling}_s) \qquad [7]$$

where the Base Involuntary Cull Rate was 0.15 per year (0.0125 of current cow stock/month) based on Pagel (2005). The "Effect of Production Stress…" is defined as:

$$\textit{Effect of Production Stress on Involuntary Culling}_s = \textit{DELAY1}(\textit{Effect of Milk-Feed Price Ratio on Milk Per Cow}_s, \textit{Time for Cows to Exhaust Energy Reserves in Response to Production Stress}) \qquad [8]$$

Production stress is assumed to be a first-order delay of milk production increases or decreases in response to ration changes, with an average delay time ("Time for Cows to Exhaust Energy Reserves…") equal to three months. (A first-order delay implies that 95% of the effect of a change in feed production will be experienced within three times the value of the average delay, or 9 months—a typical lactation length—in this case.)

We assume that milk and feed prices affect milk per cow (which in turn affects involuntary cull rates) as follows:

$$\textit{Effect of Milk-Feed Price Ratio on Milk Per Cow}_s = \left[(\textit{Milk Prices}/\textit{Feed Costs})/(\textit{Reference Milk Price}/\textit{Reference Feed Prices})\right]^{\alpha} \quad [9]$$

The ratio of current milk price to farm-size-specific feed costs relative to reference values (2011 values) and α is a parameter indicating the responsiveness of milk per cow to changes in the ratio of milk and feed prices. The value of $\alpha = 0.15$ based on Pagel (2005) and reflects biological the limits on making changes to milk production per cow through ration modification, especially in mid-lactation.

The voluntary cull rate reflects management decisions about changing the herd size (capacity), and is more responsive to expectations of profitability than is the involuntary cull rate. The voluntary cull rate (proportion culled per month) is given by:

$$\textit{Voluntary Culls}_s = (\textit{Base Voluntary Cull Rate}_s)(\textit{Current Cows}_s / \textit{Desired Cows}_s)^{\beta} \quad [10]$$

The *Base Voluntary Cull Rate* is calculated based on the initial rate at which heifers would enter the herd based on breeding decisions, less the *Base Involuntary Cull Rate*. This assumes that at the Base Voluntary and Involuntary Cull Rates, the U.S. cow herd would be in a dynamic equilibrium, with inflows (heifers entering the cow herd) equal to outflows (cows culled). Thus, modifications of cow numbers will occur through adjustments in the rates of voluntary and involuntary culls, which are driven by economic factors. The base voluntary culling rate is modified based on the ratio of current to "desired" cows. The number of current cows is defined above as the integration of cow inflows and outflows and "desired cows" is discussed below. The β is a response parameter that varies with whether ratio of current to desired cows is >1 (value 1.25) or < 1 (value 8). Thus, the model assumes that the responsiveness of culling decisions to desired cows is asymmetric. As an example, if the ratio of current to desired cows = .95, the culling rate would be reduced to about 66% of the base culling rate. If the ratio of current to desired cows is 1.05, the culling rate would increase by about 6% compared to the base culling rate. These asymmetric values for β reflect opinions of industry professionals about the willingness of producers to cull animals in response to profitability, but also are the result of formal optimization procedures in Vensim Professional version software to replicate the observed period and amplitudes of the cyclical behavior in milk prices documented by Nicholson and Stephenson (2015). It is notable that in the absence of this asymmetry, the cyclical behavior of prices is significantly muted (and therefore is not realistic compared to actual price behavior). Although not a guarantee that these β values are "correct," our approach assures that at a minimum the values are consistent with the rest of the dynamic model structure and generate a dynamic behavioral pattern that the model must to be credible. We note in the evaluation section below that we undertook substantive assessments of the impacts of the β parameters on milk price behavior.

The desired cows are calculated using an "anchoring and adjustment" mechanism similar to that in Sterman for desired capacity in the generic commodity model (p. 807). Sterman notes that this is a commonly used heuristic in decision-making in which desired capacity is anchored on current capacity but adjusted up or down based on expected profitability.

$$\textit{Desired Cows}_s = (\textit{Current Cows}_s)\ (\textit{Expected NFOI}_s / \textit{Reference NFOI}_s)^{\gamma_s} \quad [11]$$

where *NFOI* is Net Farm Operating Income. The *Expected NFOI* uses the so-called TREND function (Sterman, pp. 634-638), which combines exponential smoothing of recent NFOI with and extrapolation of recent trends in NFOI. Sterman demonstrates that this function appears to reflect the underlying decision rules used in forecasts for energy consumption, cattle prices and inflation and other sectors (pp. 638-654). There are three time parameters for the TREND function: 1) Time to Perceive the Present Condition (TPPC), 2) Time Horizon for the Reference Condition (THRC) and 3) Time to Perceive the Trend (TPT). The TPPC reflects the time to assess the current status of NFOI and reporting delays and filtering of high-frequency "noise" often assumed in forecasts, and is assumed to equal 12 months. The THRC value determines the historical time horizon considered to be relevant in the decision-making process, here assumed to be 12 months (and 1/THRC is the rate at which past values of NFOI are discounted). The TPT value represents the time required for decision makers to recognize and accept a change in the trend and use it as a basis for their decisions, also assumed here to be 12 months. Expected NFOI for the next year therefore combines exponential smoothing of past NFOI values with an assessment of recent trends for each farm size category, and is given as:

$$\textit{Expected NFOI}_s = \textit{(Perceived Monthly Current NFOI)(1+Perceived Monthly Trend in NFOI)(12 months)} \quad [12]$$

where Perceived Monthly Current NFOI and Perceived Monthly Trend in NFOI are outputs from the TREND function structure. Expected NFOI for the next 12 months is compared to a Reference NFOI that reflects a farm size category's recent experience. The Reference NFOI is based on a first-order information delay (exponential smoothing) of NFOI, where:

$$\textit{Reference NFOI} = \int \textit{(Current NFOI} - \textit{Reference NFOI)/Adjustment Time} \quad [13]$$

where the NFOI values have units of \$/month/farm but are adjusted to an annual basis. This formulation allows for updating of a reference value of NFOI as a farm grows over time, rather than assuming that this value is constant.

The γ_s are parameter values the represent the responsiveness of desired cows numbers to changes in expectations regarding NFOI relative to their reference values. Similar to the β values, the γ values reflect opinions of industry professionals about the willingness and ability of producers of different farm sizes to increase or decrease cows in response to profitability signals, but also are the result of formal optimization procedures in Vensim Professional version software to replicate the observed period and amplitudes of the cyclical behavior in milk prices documented by Nicholson and Stephenson (2015). The values of γ were assumed to be the same for both regions, but varied by farm size as follows:

Small farm: 0.50

Medium farm: 0.75

Large farm: 1.25

Extra Large farm: 1.50

As for the β values, we conducted substantive sensitivity analysis of these γ values. If values did not increase with farm size, the observed cyclical pattern of milk price behavior did not occur (which invalidates that assumption, consistent with the model structure). However, for changes in the γ values of +/- 20% , there was no substantive impact on the cyclical price behavior generated by the model.

Farm Numbers

$$Farms_s = \int Farm\ Exits\ From\ Category_s + Farm\ Expansions\ Into\ Category_s \qquad [14]$$

except for the “small” farm size category, for which there are no expansions.

$$\textit{Farm Exits from Category}_s = f\,(\textit{Debt:Asset Ratio}_s, \textit{Non-Farm Income Opportunties}_s, \textit{Price Variation}_s) \quad [15]$$

$$\textit{Farm Expansions Into Category}_s = f(\textit{Debt:Asset Ratio}_s, \textit{Cash Flow Coverage}_s, \textit{NFOI in Next Largest Size Category}_{s,}) \quad [16]$$

That is, farms exit or expand based on a number of factors including current balance sheet indicators, non-farm employment opportunities, relative profitability, cash flow, and price variation.

Milk per Cow is adjusted over time for each farm size in response to technological change and endogenous economic factors.

$$\textit{Milk Per Cow}_s = (\textit{Milk Per Cow Potential}_s)(\textit{Fraction Potential Expressed}_s)(\textit{Seasonal}_s), \quad [17]$$

where Milk Per Cow Potential is the average genetic potential for milk production on farms of size s, which is assumed to increase 2% per year due to genetic improvement. The Fraction of Potential Expressed is given by:

$$\textit{Fraction of Potential Expressed}_s = (\textit{Reference Potential Expressed})(\textit{Effect of Milk-Feed Price Ratio on Milk Per Cow}_s), \quad [18]$$

where the Reference Potential Expressed values equals 1, and Effect of Milk-Feed Price Ratio on Milk Per Cow is as defined previously. Seasonality is incorporated by use of a sine function with an amplitude of 1% of the mean value, a period of 12 months and a peak month of 5 (May of each year).

Milk prices for the two regions are determined through the allocation of total milk production to various product uses, as influenced by the regulated pricing systems in FMMO areas and

California's state milk marketing order. We assume that 10% of total U.S. milk used for cheese is not pooled under regulated pricing (to account for locations such as Idaho), although the price of non-pooled milk is linked to the Class III price. The total value of milk (pooled and non-pooled) in each of the two regions plus over-order premiums that respond to market conditions is divided by the total milk quantity marketed in each region to determine a weighted average price. This provides the major component of revenues for dairy farms, but these also include sales of calves and culled animals as well as payments from dairy programs such as MILC or MPP-Dairy. Costs on the farms include feed, hired labor, replacements, assessments (such as those promotion programs) and combined all other costs (which includes such items as milk hauling and veterinary fees). NFOI is calculated as the difference between these revenues and costs, and is used as the basis for decision making, as noted above.

Discussion of Milk Supply Module Structure and Performance

The foregoing suggests that the model structure of milk supply response is more complex than the typical representation of milk supply in economic models, although the basic response of milk supply to changes in profitability (or prices) will be consistent with the direction of change in simpler economic models. It is useful to summarize the justifications for key assumptions and the overall complexity of the structure for milk supply, given the additional effort required to implement the structure and for a reader to understand it. First, the milk supply structure is consistent with the generic commodity model that provides the basic structures we adapted to represent the U.S. dairy supply chain. We modified the generic structure to allow the control of the outflow of "capacity" (cows) rather than the inflow ("capacity initiation"), but our approach is otherwise consistent with a widely-adapted commodity model. Moreover, this component of the structure contains the balancing feedback loops (*Profitability & Cows* and *Profitability & Productivity* loops in Figure 1) with relevant delays required for endogenous generation of oscillatory behavior in milk prices (and the MPP margin). It is important to note that this structure assumes boundedly-rational behavior on the part of U.S. dairy producers, also consistent with the behavioral assumptions in the generic commodity model. Dairy producers are not assumed to maximize profits by setting price equal to marginal cost. Rather, they respond to profitability incentives in a way that is consistent with bovine biology and observed oscillations in milk prices. Although this is not a common assumption in the agricultural economics literature, there is a precedent: Schiek (1994) assumed that regional producer supply responses were predicated on net farm income in his analysis of regional pricing changes in Federal Milk Marketing Orders. Further, industry participants and analysts found the structure and assumptions reasonable, and supported the inclusion of more industry-specific details (e.g., voluntary versus involuntary culling) than are typical in economic models of milk supply response. The use of NFOI rather than price to drive supply responses *per se* is also consonant with the design of MPP-Dairy itself, because MPP recognizes that a net quantity (margin, net of price) is an important farm-level performance indicator and may motivate producer decisions.

We recognize that this structure creates challenges for comparing our assumptions to those in other milk supply analyses. Our supply response is not easily reducible to a few equations, there is no explicit supply elasticity used in model computations, and the dynamic structure means that supply response will vary over time. However, it is possible to evaluate the milk supply response empirically based on the changes in total milk production over time in response to an exogenous price increase. We evaluated the impact of an exogenous 10% increase in the milk price at the beginning of January 2012 (month 12 of model simulation) and computed the percentage change in milk production during the following 36 months (Figure S2). This analysis suggests that the dynamic supply response in the model is inelastic, with a peak value of just under 0.5 about 21 months after initiation of the exogenous price increase, allowing for feedback effects. In addition, the dynamic impacts of the price increase imply that after about 30 months, milk production is lower than it would have been otherwise at that time, which results from the reductions in milk price that occur in response to increased milk supplies resulting from the initial price increase. This is consistent with the idea of a balancing feedback loop for milk supply. However, prolonged periods of increased milk prices (or profitability) and changes in milk prices observed during the past decade (many of which are larger than 10%) may result in larger changes than these in milk supplies over time—which is also consistent with cyclical behavior in milk prices and production.

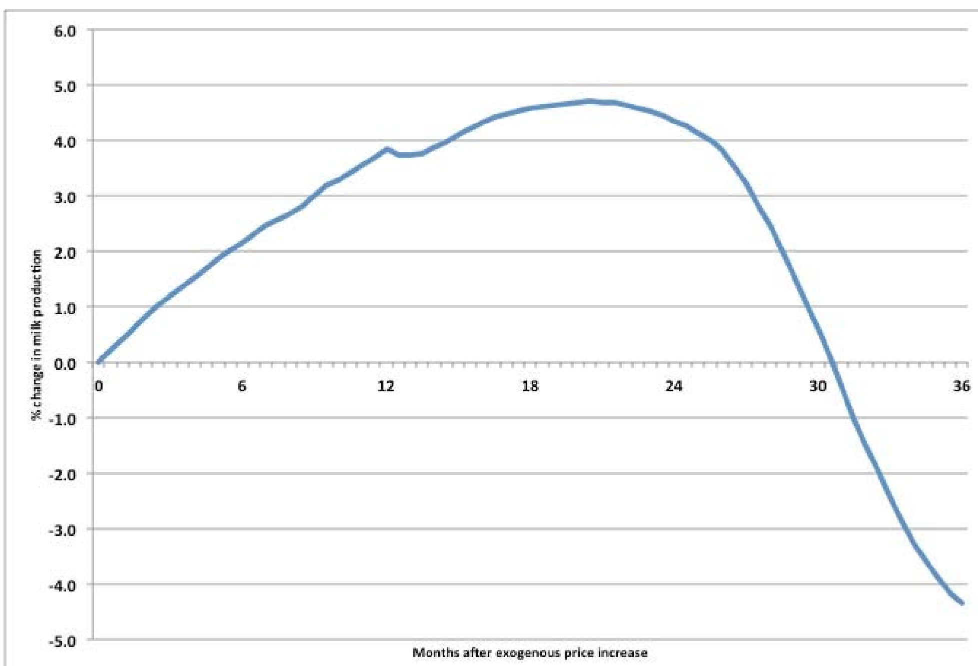


Figure S2. Simulated Impact of a One-Year Exogenous 10% Price Increase on Total Milk Supply, 0 to 36 Months After Price Increase

Dairy Product Demand, Inventories and Pricing Module

Domestic final demand functions are constant elasticity, and have the basic form:

$$QDI_p = QD_p^{REF} \cdot \left(1+\theta_p\right)\left(\frac{P_p}{P_p^{REF}}\right)^{\eta} \qquad [19]$$

where QDI_p is the "indicated" (desired demand if instantaneous change were possible) quantity demanded of product p, P is the relevant price per unit for product p ($/100 lbs), θ_p is a product specific monthly growth rate that accounts for shifts in demand over time, *REF* indicates a reference value used to initialize the model for *QD* and *P*, and η is the demand elasticity ($\eta < 0$). For some products, the demand also includes cross-product effects, which are modeled similarly to the effects of prices relative to a reference price. Actual demand QD_p is calculated using first-order exponential smoothing of QDI_p with a product-specific delay time to account for the time required for buyers to form price expectations, find substitutes, redesign products or for the expiration or renegotiation of contractual obligations with suppliers. For storable products,

$$P_p = f(Current\ Inventories_p / QD_p)^{\rho_p} \qquad [20]$$

Thus, prices for storable products are affected by their "relative inventory coverage" compared to current demand and a product-specific sensitivity parameter ρ_p. The values for ρ were developed based on empirical price and inventory relationships during 2000-2010. For storable products, current inventories integrate inflows and outflows of product, as follows:

$$Current\ Inventories_p = \int Production_p - QD_p - QI_p + Imports_p - Exports_p \qquad [21]$$

where QD is final demand, QI is intermediate demand and the other components are self-explanatory. Production of cheese (and therefore fluid whey) and other evaporated, condensed and dried products (e.g., whole milk powder, evaporated milk) is determined by the current production capacity and the degree of capacity utilization. Production capacity is specified for these seven products based on the generic commodity model and capacity initialization (inflows, investment) depends on the expected long-term profitability of new capacity. Utilization depends on the profitability relative to a reference profitability value. Fluid whey is allocated to the four whey products based on the relative profitability of each product up to total amount of available separated whey available for processing (which is based on cheese production).

For "non-storable" products (fluid milk, yogurt, cottage cheese, ice cream) that cannot be held in inventory for long periods of time, production in a month is assumed to equal demand during that month, or

$$Production_p = QD_p \quad [22]$$

Prices for non-storable products are determined based on materials costs (raw milk, dairy products or components), processing costs and a proportional product mark-up above these costs. Materials costs are endogenous to the model, but processing costs and proportional product mark-ups are based on data from cost of processing studies and analysis of margins from 2005 to 2011. Selected parameter values are provided for final products below (Table S1).

Production of NDM and butter provide the balancing of skim and cream available in raw milk in the model, ensuring mass balance (dairy component balance). In most dairy processing facilities, farm milk is initially separated into cream and skim milk and the recombined in appropriate proportions for the production of specific products. We assume the use of selected amounts of skim milk and cream (along with intermediate products in some cases, see below) in the manufacture of dairy products, and track the overall balance of cream and skim available. This is based on the quantity of farm milk and its composition, the latter of which influences yields and compositions of the two products. We assume that cream and skim not needed for other dairy product production is used to manufacture butter and NDM, respectively. One related assumption is that we do not explicitly model production capacity for NDM and butter in this model version. Although this is a generally realistic assumption, there have been some instances of some regions (e.g., California) facing constraints on butter and NDM processing capacity and shipping cream, skim or milk to other regions for processing. We do not represent these dynamics in this version of the model.

NDM, cream, skim, condensed skim, dried whey products, milk protein concentrates (MPC) and casein(ates) are commonly used in dairy manufacturing processes (e.g., NDM is added to cheese vats to enhance yields). The model allows for these "intermediate" product demands in addition the final product demands specified earlier, resulting in QI_p values. We simplify the decision process for the use of intermediate inputs by specifying a limited number of feasible combinations of intermediate inputs based on detailed product yield and product specification models. The least cost-combination of these feasible combinations is then selected endogenously as relative product prices evolve. This allows endogenous switching among intermediate product uses for yogurt, cheese, and ice cream. S

Table S1. Selected Demand-Related Parameter Assumptions for the U.S. Dairy Supply Chain Model

Final Product	Final Product Demand Elasticity	Proportional Mark-up	Annual Growth Rate, % (Demand Shifter)
Fluid milk	-0.2	1.8	0.5
Yogurt	-0.5	4.0	8.5
Ice cream	-0.5	2.5	-1.5
Cottage cheese	-0.5	4.0	0.0
American cheese	-0.5	--	1.5
Other cheese	-0.5	--	2.0
Whey products	-0.5	--	-2.0 to 6.5
NDM	-0.5	--	5.0
Butter	-0.25	--	2.0
Condensed skim	-0.5	--	0.0
Other ECD	-0.3	--	3.0

Dairy Product Trade

Dairy product imports for those with TRQ comprise those quantities under TRQ limits (with lower *ad valorem* and specific tariff rates) and those "over quota" with higher tariff rates. Thus, total imports

$$Imports_p = TRQ\ Imports_p + Over\text{-}Quota\ Imports_p \quad [23]$$

where TRQ imports are the minimum of Desired TRQ Imports based on relative U.S. and World dairy product prices and the TRQ amounts specified in total for U.S. imports (i.e., not country-specific). *Desired TRQ Imports*$_p$ are given as:

$$Desired\ TRQ\ Imports_p = (Reference\ TRQ\ Imports_p)\ [f(P_{US,p}/P_{LandedWorld,p})] \quad [24]$$

where "landed" world price is the price in international markets plus transportation costs and applicable U.S. tariffs, and the "reference" values of TRQ Imports adjusts over time (as another "anchoring and adjustment process"). Over-quota and non-quota (products without a TRQ, such as casein or milk protein concentrates) imports are determined similarly, but are based on different reference values, for example:

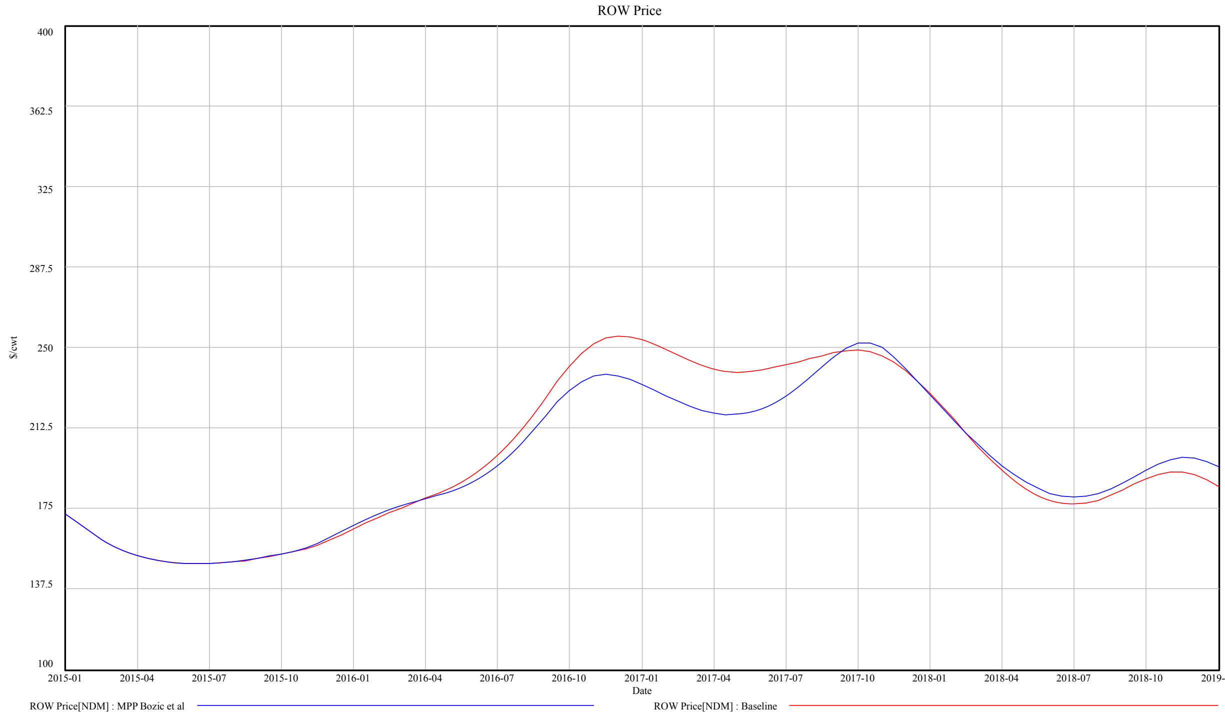
$$\textit{Non-Quota Imports}_p = (\textit{Reference Non-Quota Imports}_p)\ [f(P_{US,p}/P_{LandedWorld,p})] \qquad [25]$$

Dairy product exports also depend on reference values that are adjusted for relative U.S. and International prices:

$$\textit{Exports}_p = (\textit{Reference Exports}_p)\ [f(P_{USLanded,p}/P_{World,p})] \qquad [26]$$

where the U.S. "landed" price is the price in the U.S. plus transportation costs (but without specific consideration of generalized Rest of World tariff and non-tariff barriers).

This structure implies that if U.S. prices increase relative to world markets, U.S. exports will decreased and U.S. imports will increase, and vice versa if U.S. prices fall relative to world markets. In simulations, there is substantial price integration between U.S. and world markets. Rest of World prices and production for tradable products are determined endogenously with production capacity structures similar to that used for U.S. cheese markets and product inventory stocks that integrate ROW production, ROW demand, export demand (i.e., shipments to the U.S.) and import demand (shipments from the U.S.) The ROW production and demand components comprise a relatively simple structure that could be further developed, but they effectively integrate U.S. and world market prices for tradable dairy products to a significant extent, and allow an initial exploration of the directions and possible magnitudes of U.S. export or import quantities in response to policy change. The direction of impacts on the ROW prices and the volume and value U.S. exports of products due to MPP-Dairy are consistent with expectations (Figures S3, S4 and S5).



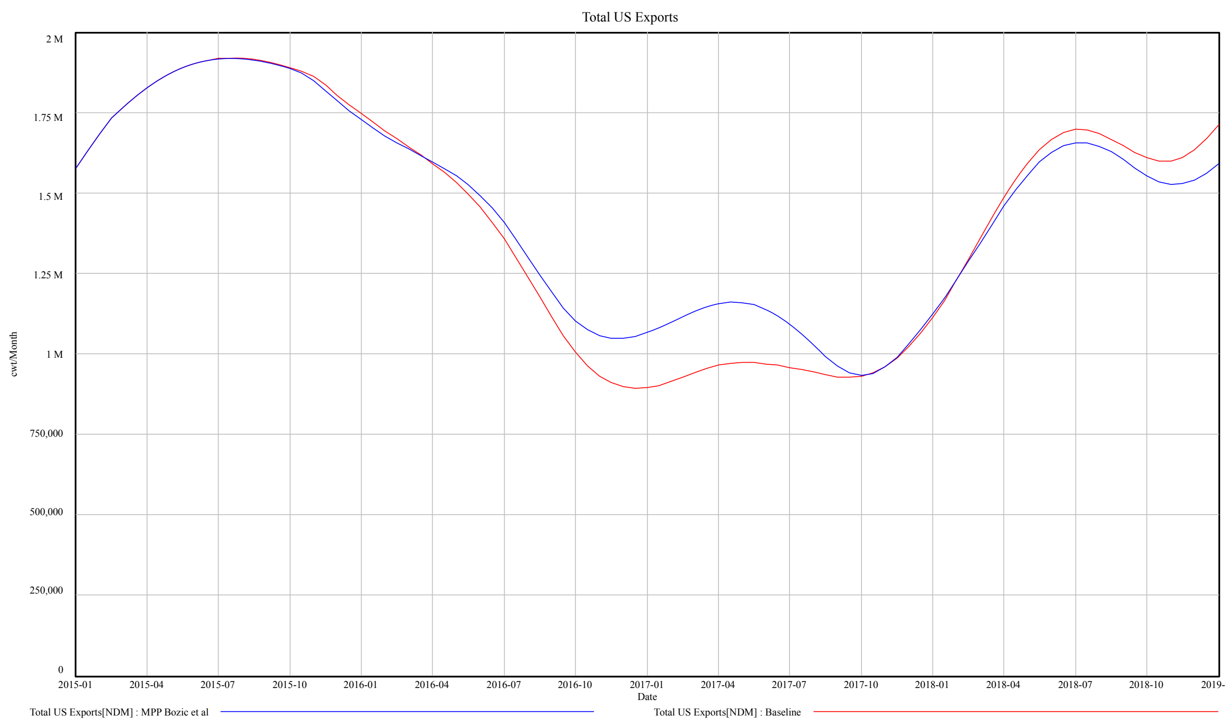
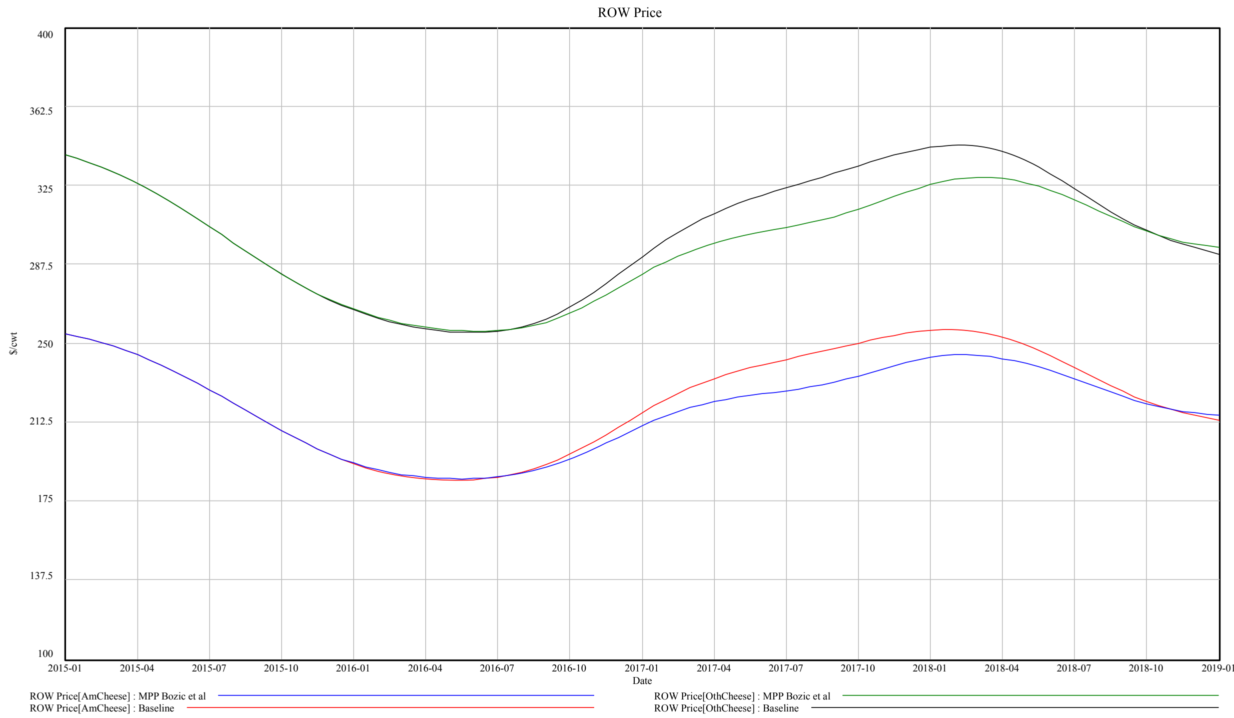


Figure S3. Simulated NDM ROW Price and Total U.S. Exports for Baseline and Bozic et al. MPP-Dairy Participation Scenarios, 2015 to 2018



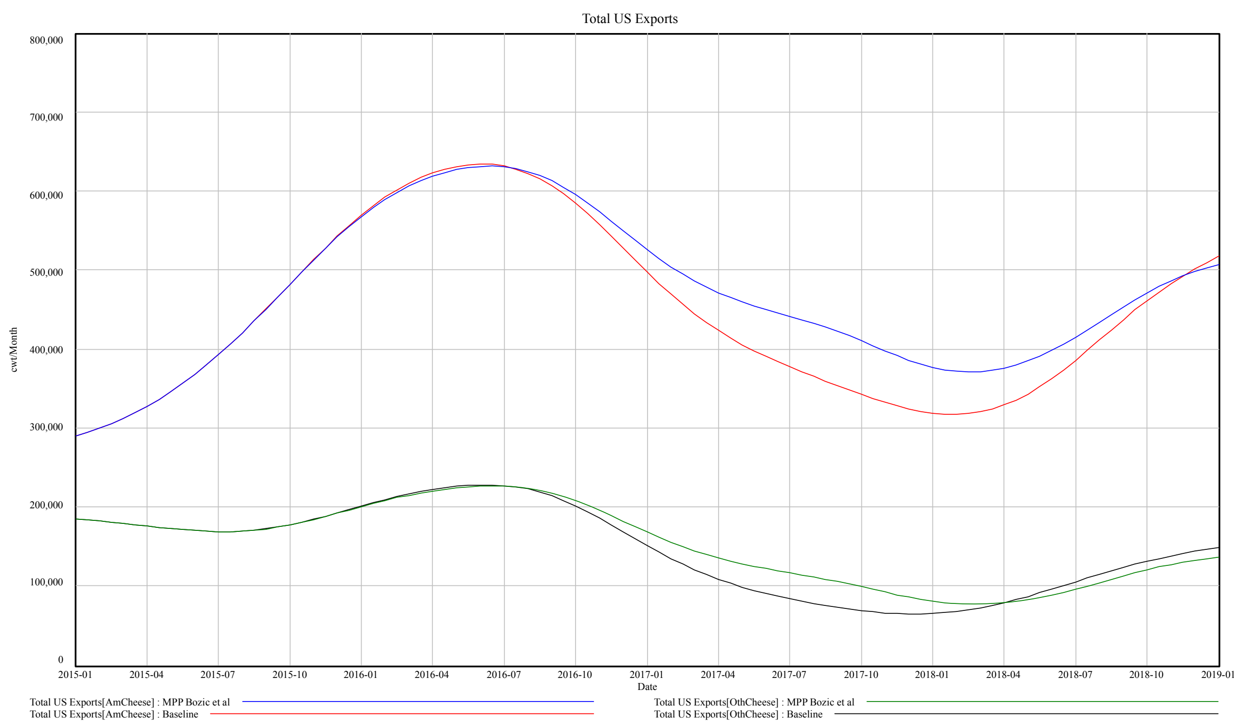


Figure S4. Simulated American and Other Cheese ROW Prices and Total U.S. Exports, Baseline and Bozic et al. MPP-Dairy Participation Scenarios, 2015 to 2018

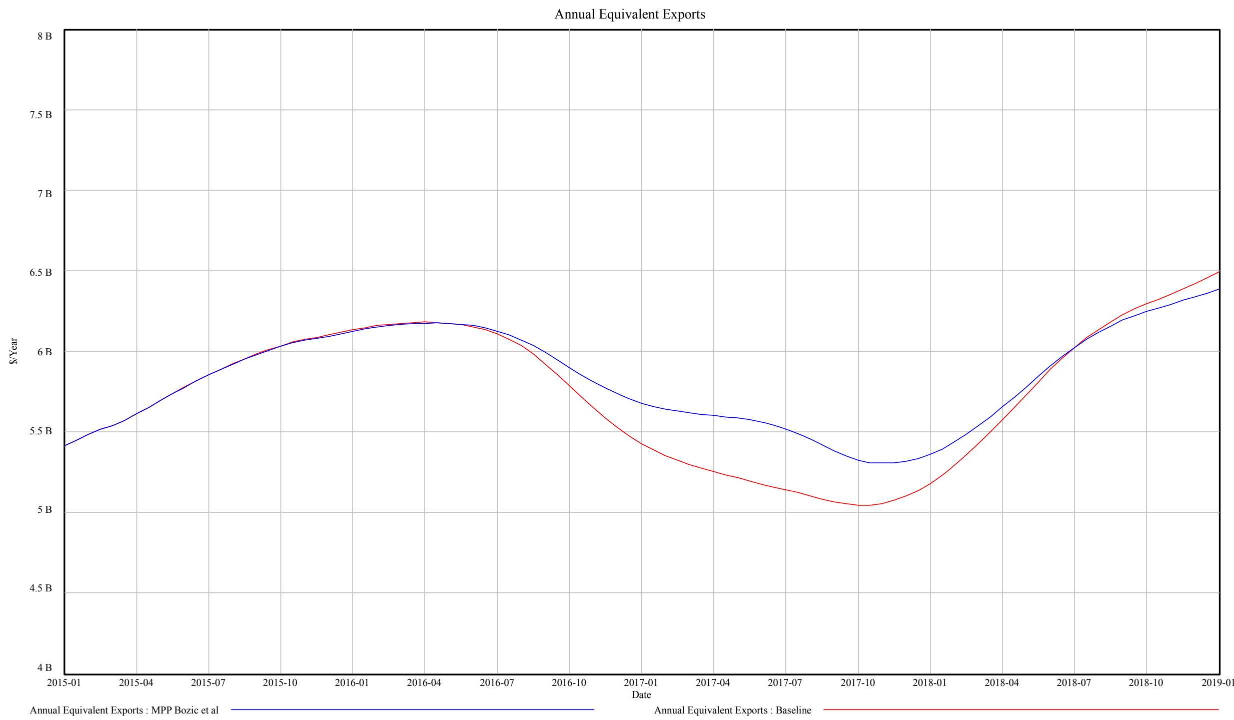


Figure S5. Simulated Total Annualized Value of U.S. Dairy Exports, Baseline and Bozic et al. MPP-Dairy Participation Scenarios, 2015 to 2018

MPP-Dairy Margin Expectation Formulation

For the *Conditional Expectations* participation scenario in which participation decisions depend on expected margins, we use the TREND function (described above for the influence of NFOI on expansion decisions) to define margin expectations. There are three time parameters for the TREND function: 1) Time to Perceive the Present Condition (TPPC), 2) Time Horizon for the Reference Condition (THRC) and 3) Time to Perceive the Trend (TPT). The TPPC reflects the time to assess the current status of NFOI and reporting delays and filtering of high-frequency "noise" often assumed in forecasts, and is assumed to equal 3 months. The THRC value determines the historical time horizon considered to be relevant in the decision-making process, here assumed to be 3 months (and 1/THRC is the rate at which past values of NFOI are discounted). The TPT value represents the time required for decision makers to recognize and accept a change in the trend and use it as a basis for their decisions, also assumed here to be 3 months. The forecast horizon is assumed to be 9 months given end-September sign-up deadlines for MPP-Dairy (after the 2014 and 2015 sign up periods), so participation decisions are based on the expected margin at the midpoint of the covered program year.

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 S2), with a brief discussion of their implementation in the U.S. dairy supply chain model.

Table S2. Summary of Model Evaluation Testing Procedures

Model Evaluation Test	Purpose and Description	Implementation in U.S. 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.
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 0.0625 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). Point prediction during 2012-2013 correctly assessed patterns and turning points in observed data (more below).

Model Evaluation Test	Purpose and Description	Implementation in U.S. 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.

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.

Model Behavioral Reviews with Industry Decision Makers and Analysts

As noted above, industry decision makers and analysts were consulted in an informal Group Model Building approach to provide input on key model structures and assumptions. In addition, on several occasions, a wide variety of industry decision makers reviewed model behaviors, typically in meetings in which the model was simulated in real time in response to inquiries or proposed assumptions/scenarios from these decision makers. A wide variety of model behaviors were explored in these meetings, including the relationship between Class III and IV prices under FMMO price regulation, impacts of changes in regulated pricing under FMMOs and the California state order, U.S. exports of cheese and NDM, the relationships between U.S. and international dairy product prices, cow numbers, milk production, milk prices and others. We never encountered a situation in which industry decision makers and analysts believed that the behavioral patterns generated by the model were unreasonable, and in most cases the orders of magnitude appeared reasonable to them. Although this is not a replacement for formalized model evaluation, it provides an additional point of contact between the model outputs and the reality of the U.S. dairy supply chain and builds confidence that the model is appropriate for its stated purpose.

Model Point Prediction During 2012 and 2013

Although not a test that is always appropriate for SD models, we also assessed the ability of the model to point-predict values of the MPP-Dairy margin during 2012 and 2013, using our assumed values of feed costs and initialization of the model using data from 2011. The model generated behaviors quite consistent with those observed during these two years, with a mean absolute percentage error of 26% (which would be considered quite good two years in advance by most dairy industry forecasters) and correctly predicting the turning points (Figure S3). The model also under-predicted the amplitude of cyclical behavior in this period, which could affect our assessment of the impacts of MPP-Dairy if this also occurred during 2015 to 2018.

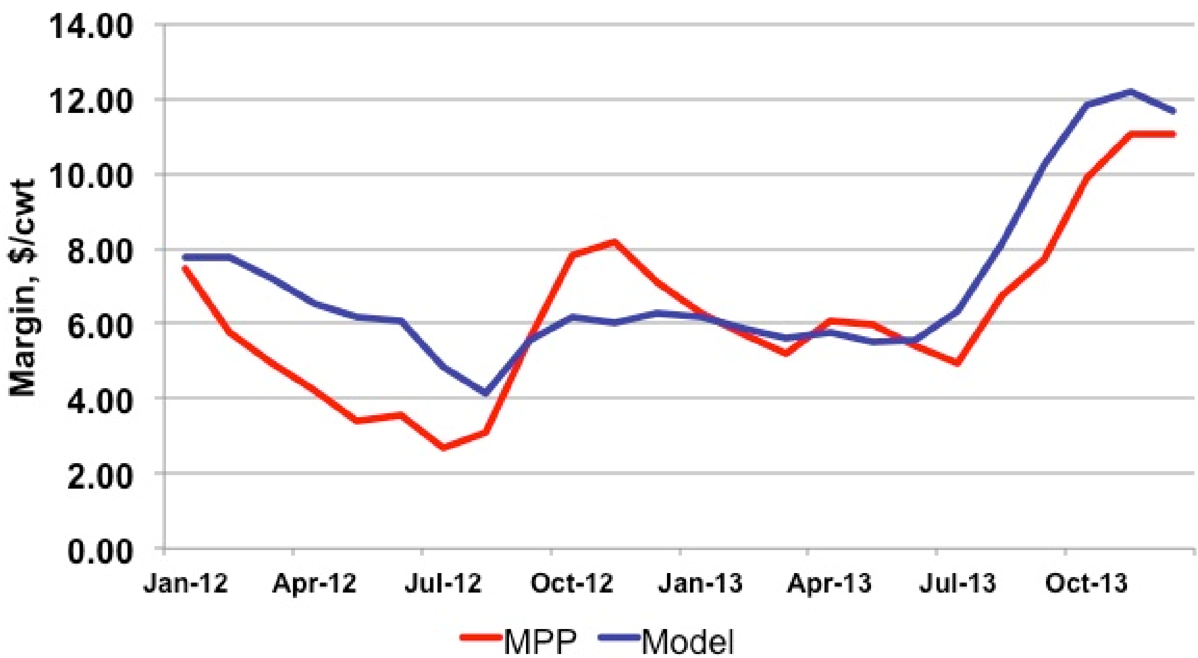


Figure S6: Actual MPP-Dairy Margin and U.S. Dairy Supply Chain Model Predictions for the MPP Margin, Monthly Values for 2012 and 2013

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