U.S. Federal Milk Marketing Orders: Impacts on the Geography of Milk Production and Processing, Inter-Regional Trade, and Welfare

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Abstract

This paper develops and calibrates a novel spatial model of the U.S. dairy supply chain to investigate the effects of longstanding milk pricing rules enforced by the eleven federal milk marketing orders on the geography of milk production and processing, inter-regional farm milk shipments, and welfare. While our simulation results comport with the standard finding that pricing rules transfer surplus from beverage milk consumers to dairy farms, measured welfare effects are small as a share of revenue, with notable regional differences. Shipments of farm milk increase slightly upon removal of the regional pricing rules, indicating that policy-induced market distortions are not the source of what might appear as excessive inter-regional milk trade.

JEL codes: C67, Q17, Q18
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1 Introduction

To what extent do agricultural policies shape the geographic footprint of agricultural and food production and commodity trade patterns? In developed countries such policies are often meant to benefit farmers, but at what cost to society? The present paper addresses these questions in the context of longstanding U.S. policy intended to increase regional returns to dairy farming through classified milk pricing—the practice of raising the price of farm milk when processed into

*The views expressed here are those of the authors and not necessarily those of the United States Department of Agriculture.

beverage milk, a product category with less elastic demand than other processed dairy products. To this end, we develop and calibrate a spatially-explicit structural economic model of the U.S. dairy supply chain tailored to address counterfactual questions related to milk pricing rules set by Federal Milk Marketing Orders (FMMOs) and provide transparent welfare impacts.

Our model structure borrows from the new quantitative trade model literature, as exemplified in Costinot, Donaldson, and Smith (2016) or Gouel and Laborde (2021), with important differences. Our focus on national and regional dairy policy impacts, rather than climate-induced global crop yield shocks, dictates a more parsimonious treatment of crops not directly used in dairy feed, a focus on inter-regional rather than global trade flows, and an explicit representation of crop production and transformation into raw milk, milk components, and consumer dairy products. A detailed representation of the dairy supply chain, both geographically and vertically, is warranted because the policy we study consists of regionally-determined price distortions for milk components—butterfat and nonfat milk solids—across industrial uses. That is, milk component prices differ according to their end use, and these differences further vary across space depending on the processing location. The general philosophy behind the policy-mandated price distortions is that milk components prices are set at higher levels for use in the production of fluid milk, whose local demand is more inelastic, than for use in more processed dairy products such as ice cream, yogurt, or milk powder. Milk producers receive a blend price that partially reflects the higher price generated by fluid milk sales. These distortions raise farm milk prices above the competitive level, increasing the total supply of farm milk and attendant demand for dairy cattle feed inputs and distorting the dairy product mix away from beverage milk.

An important feature of the dairy supply chain is that farm milk, certain dairy products such as beverage milk, and feed inputs such as corn silage are water-heavy and costly to transport, resulting in a spatially-scattered supply chain that reflects the size of regional consumer markets, in addition to comparative advantage in feed crop production, farm milk productivity, and regional processing efficiency. Another factor contributing to the spatial distribution of dairy production is the fact that some processed dairy products such as certain specialty cheeses may be differentiated by region of origin, preventing complete regional specialization.

Importantly for us, FMMO pricing policies may also act as a critical determinant of the geography of dairy production and the pattern of inter-regional milk and feed crop shipments. For instance, a higher average price for farm milk in a jurisdiction increases the size of local milk production and attendant feed crop supply from local and other sources and encourages farm milk shipments into it, distorting the geography of crop and milk production at the same time that it reduces local consumption of fluid milk. Indeed, our data indicate that 7.3% of the value of farm milk in the U.S. is shipped out of its production region.

The effects of FMMO pricing rules on milk production, shipments of farm milk between regions, and the value of dairy production could ideally be assessed by evaluating the change in each of these outcomes when changes to FMMO policy were implemented, controlling for the impacts of other factors that may have changed over time. However, since FMMO policies

change infrequently, the effectiveness of this approach would be limited. While policy reforms and consolidations of marketing order regions have occurred throughout the existence of FMMOs, with the most recent substantial changes implemented in 2000 and a currently ongoing regulatory process[1], the general structure of classified pricing and revenue pooling has remained unchanged since the 1930s. Additionally, many other factors have changed since classified pricing and revenue pooling were introduced, including substantial changes to the dairy industry and secular changes in consumer demand.

Therefore, instead of relying on an elusive econometric exercise, we adopt a structural approach to evaluate the changes in outcomes of interest, including welfare measures, in a scenario where FMMO pricing rules are removed. Because the dairy policy we study has been in place for almost a century, we use observed data to calibrate a baseline equilibrium model with explicit price distortions; our counterfactual then replicates the undistorted equilibrium that would prevail absent FMMO pricing rules.

Our model is calibrated using regional data on dairy product expenditures, milk shipments, and crop production and trade from a variety of sources as well as a set of behavioral parameters drawn from the literature. Demand parameters include the elasticity of demand for dairy products and elasticities of substitution between dairy product categories and, within categories, between origin regions. A separate set of demand parameters is used for export demand. Supply parameters include a parameter reflecting the heterogeneity of relevant regional crop yields and governing crop supply elasticities, elasticities of substitution between feed crops for use in dairy feed, and elasticities of substitution between milk components in dairy product manufacturing.

One of the benefits of our structural model is that it explicitly accounts for milk components demanded by dairy product manufacturers and supplied by milk producers. Milk derives its value from three main solid components: fat, protein, and other solids—primarily lactose and trace minerals. While these components are produced in approximately fixed proportions across regions, they are utilized in different ratios in dairy products. Because FMMO pricing rules pertain to components, rather than milk as a whole, it is important to model the regional supply and derived demand for these components. Classified pricing is implemented in our model by including a policy parameter that modulates the price paid for milk components depending on their end use.

Following the modeling frameworks of Costinot, Donaldson, and Smith (2016) and Gouel and Laborde (2021), land is assumed to be the limiting resource determining crop, milk, milk component, and dairy product supplies. The regional supply of milk is less than perfectly elastic because silage, an (effectively) essential part of dairy feed rations, is modeled as non-transportable across regions and high-quality silage is specific to the dairy sector. Silage crops compete for land with other crops. Consequently, the elasticity of regional farm milk supply is determined in our

[1]Milk in the Northeast and Other Marketing Areas; Proposed Amendments to Marketing Agreements and Orders, 89 Fed. Reg. 57580 (proposed July 15, 2024) (amending 7 CFR Parts 1000, 1001, 1005, 1006, 1007, 1030, 1032, 1033, 1051, 1124, 1126, and 1131).

model by the local acreage share of silage, the land intensity of local silage production, the silage intensity of the local feed ration, and the feed intensity of the local milk production technology, in addition to a shape parameter determining the extent of crop yield heterogeneity.

While we assume that farm milk is a homogeneous commodity, we allow for region-specific technologies to transform milk components into dairy products, including beverages, soft products, cheese, and butter-powder products. We allow for inter-regional trade in non-silage feed crops, farm milk, and dairy products. We also allow for international exports of feed crops and international trade in dairy products.

Our counterfactual analysis of the removal of regional milk component price differentials delivers three main results. First, although nothing in our model structure forces these differentials to raise regional beverage milk prices above the competitive level, our calibration data is consistent with the view that the component pricing rules (i) shift the product mix away from beverage milk and (ii) favor dairy producers to the detriment of domestic consumers. That is, upon removing the differentials, in all domestic regions the consumer price of beverage milk decreases while the consumer prices of other dairy products increase, resulting in a decrease of the overall dairy price index for U.S. consumers. In contrast, foreign consumers are hurt as they do not consume beverage milk of U.S. origin. In all regions, cropland, the residual claimant of dairy production value, decreases in value.

Second, the overall magnitude of these effects is small, revealing that the surplus transfer enabled by FMMO pricing rules, if present, has a low social cost. Upon removal of these rules, domestic welfare increases by a mere 0.12% relative to the overall value of the dairy market, while total welfare increases by 0.10%. More pronounced effects can be found at the regional level, however. For instance, land rents decrease by more than 2% in the Northeast region, which is responsible for 15% of domestic milk production value, and by 1.2% in the Southwest, which is responsible for 10% of domestic milk production value. The Southwest also experiences large decreases in milk production (-6.5%) and milk use (-4.8%). On the uses side, increases in consumer surplus relative to the regional value of consumption do not exceed 0.7% in any U.S. region.

Third, one cannot conclude that longstanding FMMO pricing rules have resulted in increased shipments of farm milk across regions. Indeed, overall shipments increase slightly upon removal of FMMO rules—by 0.22 percentage points, for a baseline share of production value shipped of 7.3%. That is, the overall volume of milk shipments at baseline is the result of market fundamentals, rather than an artefact of policy distortions. Still, upon FMMO removal, our model predicts a break-up of the farm milk market, which is integrated at baseline due to inter-regional milk trade, into two separate spatial markets—a block roughly to the West of the 110th meridian and the rest of the U.S.

Our analysis proceeds as follows. The next section describes the institutional setting. Sections 3, 4, and 5 are dedicated to model description, equilibrium definition, and parameter identification. Section 6 discusses the information used to determine the value of key shape parameters. Section 7 presents the results of our counterfactual exercise, and Section 8 concludes.

2 Institutional setting

Since the passage of the Agricultural Marketing Agreement Act of 1937 (AMAA), the FMMOs have overseen sales of milk within regions comprising the majority of milk production and processing in the U.S. The stated objective of the FMMOs is to support milk producers by establishing minimum prices for farm milk across end-use product classes and paying farmers a weighted average of the minimum class prices. To the extent that the price paid for farm milk is higher due to FMMO pricing rules than it otherwise would be, milk production is also higher. Dairy farmers clearly benefit from the system, and because pricing rules distort the competitive equilibrium, consumers must lose in aggregate despite the larger volume of milk processed into dairy products.

Marketing order pricing rules have two key elements: classified pricing and revenue pooling within marketing areas. The classified pricing system defines classes based on four end-use products and establishes minimum prices for milk used in those products. This allows for price discrimination across end-use markets, as prices for beverage products, whose regional demand is less elastic, are set at higher levels. Regional demand for beverage milk products is less elastic due to the relatively high cost to transport beverage milk, which establishes natural limits on competition from beverage milk products manufactured in other regions. Gains from price discrimination are redistributed to farmers through regional revenue pooling, establishing a "blend price" received by farmers that deliver milk to processors within a marketing order region.

Milk buyers, known as "handlers" in the FMMO authorizing legislation and regulations, include those who minimally process milk into beverage products and those who produce more heavily processed manufactured dairy products. Handlers are the regulated entities under FMMO pricing rules and are obligated to pay the minimum class prices if participating in an FMMO. In other words, milk producers may choose to sell milk to a handler in any region, but if a handler is located in and regulated by a specific marketing order region, then they are required to pay the order-regulated prices. This creates an incentive for farm milk to be moved between regions when milk producers can receive a higher (regulated minimum) price in another region, despite high transportation costs for farm milk relative to manufactured dairy products.

2.1 Historical background

The origins of the current FMMO system lie in the actions of milk marketing cooperatives in the early 20th century (Nourse, 1962). Milk marketing was highly localized since the lack of refrigeration technology limited the distance that fresh milk could travel before spoiling. With many milk producers in a local region interacting with a small number of milk processors, the processors benefited from market power (Ippolito and Masson, 1978).

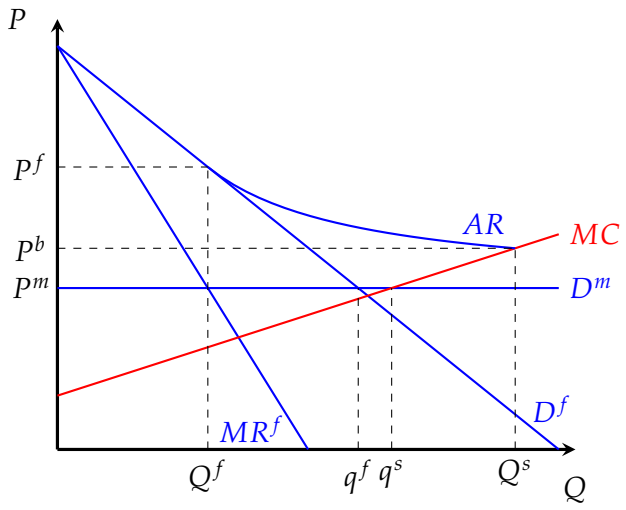
After the passage of the Capper-Volstead Act of 1922, agricultural cooperatives gained a degree of protection from antitrust challenges and producer cooperatives emerged in the dairy industry to counter the buyer power of processors (Erba and Novakovic, 1995). These marketing cooperatives began to implement a form of classified pricing by charging a higher price for milk used in beverage

products than the price for milk used in manufacturing. Cooperative members would then receive a blend price based on the share of cooperative-managed milk that was used in beverage products. However, an independent dairy farmer could bargain directly with a milk handler to sell milk at a price below the cooperative-set beverage milk price but above the blend price, thereby increasing their own revenue to the detriment of the cooperative and its members. Dairy farmers and producer cooperatives began calling for government intervention in the milk market during the Great Depression due to the perceived concentration of bargaining power among milk handlers and the inherent instability of the cooperative-based classified pricing system.

The AMAA was passed in 1937 and is the permanent legislation that authorizes Federal Milk Marketing Orders to this day. The AMAA declares it the policy of Congress to "establish and maintain such orderly marketing conditions for agricultural commodities in interstate commerce" through the use of marketing agreements and marketing orders (7 U.S.C. §602(1)). The requirements for milk marketing orders outlined in the AMAA reflect the pricing practices previously implemented by dairy cooperatives. Milk marketing orders require that milk be classified according to its end use, that handlers face the same minimum prices for each classified use, and that producers receive a uniform price (7 U.S.C. §608(5)). Producers may request the creation of a marketing order in a specific marketing area and handlers are then presented with the proposed order language. Handlers may accept or reject the proposal, but even if the proposal is rejected the Secretary of Agriculture may still implement the order if a sufficient number of producers vote to move forward. Since producers hold the final decision over whether to implement the proposed order, the milk marketing orders provide a mechanism for milk producers to impose regulation on milk handlers (Kessel, 1967).

Additionally, the AMAA establishes that marketing orders should ensure "an orderly flow of the supply [of an agricultural commodity] to market throughout its normal marketing season to avoid unreasonable fluctuations in supplies and prices" (7 U.S.C. §602(4)). This policy has generally been interpreted as ensuring a regular supply of milk for use in beverage products. Early implementations of the milk marketing order requirements of classified pricing and uniform producer prices involved a two-price system, with a higher price established for milk used in beverage products and a lower price for milk used in more processed dairy products, also known as manufactured products. The higher price for milk used in beverage products ensured that demand for beverage milk products was met first, with any remaining milk supplied to the market used in manufactured products. The price for milk used in beverage products was determined by adding a location-based differential to the minimum price for milk used in manufactured products. The size of the differential was based on the location where the milk was delivered, with a lower differential in regions where milk production was high relative to quantity demanded and a higher differential in areas with greater populations and more demand for beverage milk products. This pricing structure further incentivized movement of farm milk from regions with lower milk production costs to regions with less milk production.

Figure 1: Model of a Single Federal Milk Marketing Order from Kessel (1967)



Source: Authors' reproduction of Figure 1 from Kessel (1967).

2.2 Models of milk marketing order regulations

Kessel (1967) depicts a two-price system of classified pricing, reflecting the regulatory structure under early milk marketing orders. The model of a single milk marketing order assumes the local nature of the market for beverage milk results in downward-sloping demand while the national scope of the market for manufactured dairy products leads to infinitely elastic demand for manufacturing milk. Additionally, government purchase programs created support prices for major manufactured dairy products, which would be consistent with a demand function that is flat at the government support price.

Figure 1 depicts Kessel's model of an individual milk marketing order. Kessel defines two equilibrium conditions that determine the total quantity of milk supplied to the market, Q^s in Figure 1, and the quantity of milk used in beverage (or fluid) milk products, Q^f. The first condition states that the equilibrium quantity of milk supplied is determined where the average revenue is equal to the marginal cost of milk production. The second condition states that at the optimal allocation of milk between beverage and manufacturing products, the marginal revenue in the beverage and manufacturing milk markets must be equal (if milk is processed into both end products), or all milk must be transformed into beverage products. The AR curve defines the blend price received by milk producers for any level of output and approaches the manufacturing demand curve asymptotically as the quantity processed into beverage milk remains constant at Q^f for large enough quantities of milk processed. The equilibrium blend price, P^b, is a weighted average of the price paid for beverage milk, P^f, and the price paid for manufacturing milk, P^m, and results in a greater quantity of milk supplied to the market than in the absence of classified pricing and revenue pooling ($Q^s > q^s$). Compared to the competitive equilibrium, less milk is available to

consumers as fluid milk ($Q^f < q^f$) and more milk is used in manufacturing ($Q^s - Q^f > q^s - q^f$).

Kessel does not consider interactions between marketing orders or the sale of milk between regions. We extend his model to evaluate the impact of milk marketing order regulations on inter-regional trade in farm milk, milk and dairy feed production in each region, and consumer welfare.

3 Structural model of the dairy supply chain

Our model includes three production stages: crop production, milk production, and dairy product manufacturing, related vertically through technological relationships. Feed crops compete with other crops for a fixed land base, may be used outside of the dairy sector, and are converted into milk through the feeding of dairy cows. We do not model the supply of animals explicitly. Instead, we assume that herd size adjusts to the regional availability of dairy feed and the derived demand for farm milk. As such, our model is meant to capture long-run responses to policy, which is appropriate given the longstanding nature of the FMMO system.

Production, processing, and consumption activities are determined regionally and linked spatially through trade in dairy feed crops, farm milk, and dairy products. As the policy we study is also spatial in nature, the geographic resolution of our model captures that of FMMOs, resulting in 11 regulated regions and a residual domestic region representing areas not under FMMO jurisdiction. Regions are indexed from 0 (for "rest of the world," hereafter ROW) to $I = 12$ using the indices i or j.

Trade includes international exports of feed crops and international imports and exports of dairy products.[2] In our model, farm milk can only be traded between U.S. regions. Indeed, its high water content and the need for refrigeration make it very costly to transport, which explains why exports and imports of farm milk are negligible. Similarly, compared to the value of U.S. feed crop production and exports, the value of imported feed crops is very small, thus we simply subtract it from feed crop exports. In addition to trading farm milk, FMMO regions are allowed to trade feed crops (except dairy silage) and dairy products.

3.1 Demand for dairy products

Dairy products are indexed by $n = 1, \ldots, N$. Trade in dairy products across U.S. regions and internationally is subject to iceberg trade costs $\tau_{ij}^n \geq 1$, where i is the origin region and j the destination region, and $\tau_{ii}^n = 1$. That is, in order for one unit of dairy product n to arrive in region j, region i needs to ship τ_{ij}^n units. Iceberg trade costs also define price relationships between trading regions, since the price of product n in region j that is shipped from region i must be equal to the cost of procuring τ_{ij}^n units, namely $\tau_{ij}^n p_i^n$, where p_i^n is the price of product n in region i.

[2] In what follows, the terms "exports" and "imports" systematically refer to international trade flows.

Preferences in region $j \geq 1$ are represented by the following utility function:

$$U_j(C_j^0, C_j) = C_j^0 + (\beta_j)^{\frac{1}{\epsilon}} \frac{(C_j)^{1-\frac{1}{\epsilon}}}{1-\frac{1}{\epsilon}},$$

where $\beta_j > 0$, $0 < \epsilon < 1$ is the (absolute) elasticity of demand for dairy, C_j is a dairy product aggregate, and C_j^0 represents consumption of non-dairy foods and other goods. Thus, utility is quasilinear and demand for dairy is inelastic. The dairy aggregate C_j is further specified as a nested constant-elasticity-substitution (CES) aggregate, with the outer nest defined across dairy products $n = 1, \ldots, N$ as:

$$C_j \equiv \left[\sum_{n \geq 1} \left(\beta_j^n\right)^{\frac{1}{\kappa}} \left(C_j^n\right)^{\frac{\kappa-1}{\kappa}} \right]^{\frac{\kappa}{\kappa-1}},$$

where $\beta_j^n \geq 0$, $\sum_{n \geq 1} \beta_j^n = 1$, and $\kappa \in (0,1) \cup (1, \infty)$ represents the elasticity of substitution across products, assumed to be common to all U.S. regions. The inner nest, C_j^n, serves to aggregate over regional origins of product n:

$$C_j^n \equiv \left[\sum_{i \geq 0} \left(\beta_{ij}^n\right)^{\frac{1}{\sigma^n}} \left(C_{ij}^n\right)^{\frac{\sigma^n-1}{\sigma^n}} \right]^{\frac{\sigma^n}{\sigma^n-1}},$$

with $\beta_{ij}^n \geq 0$, $\sum_{i \geq 0} \beta_{ij}^n = 1$, and $\sigma^n \in (0,1) \cup (1, \infty)$.

The elasticity of substitution across origins, σ^n, referred to as an Armington elasticity (Armington, 1969), is allowed to vary across products because for some products, e.g., cheese, the region of origin may be a meaningful differentiating attribute while for others, e.g., butter, products are likely to be more homogeneous. However, for the sake of parsimony we assume that the elasticities of substitution are identical across consumption regions. We deem this restriction all the more acceptable as our consumption regions are regions of the U.S., as opposed to world countries.

Demand for U.S. dairy products by the ROW follows a similar structure, with the exception that demand for dairy products of foreign origin is not modeled explicitly (and thus is assumed to be part of the ROW's numeraire). This is tantamount to ignoring both income effects and substitution effects (other than those amongst products of U.S. origin) on the part of the ROW.[3] We also allow for differing substitution and demand elasticities, denoted σ_0^n, κ_0, and ϵ_0, in addition to differing values of the share parameters.

Utility maximization implies the following demand in region $j \geq 1$ for dairy product n coming from region $i \geq 0$:

$$C_{ij}^n = \beta_j \beta_j^n \beta_{ij}^n \left(P_j\right)^{\kappa-\epsilon} \left(P_j^n\right)^{\sigma^n-\kappa} \left(\tau_{ij}^n p_i^n\right)^{-\sigma^n}, \quad (1)$$

[3]If one were to introduce foreign consumption of foreign dairy products into the model, one would also need to introduce production of such products. Since the focus of this study is domestic U.S. dairy policy and its impacts on U.S. dairy production and welfare, the choice to abstract from world-level market-clearing mechanisms for dairy products of foreign origin seems appropriate.

where

$$P_j^n \equiv \left[\sum_{i\geq 0} \beta_{ij}^n \left(\tau_{ij}^n p_i^n\right)^{1-\sigma^n}\right]^{\frac{1}{1-\sigma^n}}$$

and

$$P_j \equiv \left[\sum_{n\geq 1} \beta_j^n \left(P_j^n\right)^{1-\kappa}\right]^{\frac{1}{1-\kappa}}$$

are CES price indices in region j for dairy product n and for all dairy products, respectively. Similarly, demand by the ROW for dairy product n originating from U.S. region $i \geq 1$ is

$$C_{i0}^n = \beta_0 \beta_0^n \beta_{i0}^n \left(P_0\right)^{\kappa_0-\epsilon_0} \left(P_0^n\right)^{\sigma_0^n-\kappa_0} \left(\tau_{i0}^n p_i^n\right)^{-\sigma_0^n} , \tag{2}$$

where

$$P_0^n \equiv \left[\sum_{i\geq 1} \beta_{i0}^n \left(\tau_{i0}^n p_i^n\right)^{1-\sigma_0^n}\right]^{\frac{1}{1-\sigma_0^n}}$$

and

$$P_0 \equiv \left[\sum_{n\geq 1} \beta_0^n \left(P_0^n\right)^{1-\kappa_0}\right]^{\frac{1}{1-\kappa_0}} .$$

We assume that the price of each dairy product sourced from international markets, p_0^n, is fixed. In contrast, the regional prices of U.S. dairy products, p_i^n $(i \geq 1)$, are determined endogenously.

3.2 Dairy product manufacturing and derived demand for milk components

Denote the quantity of dairy product n produced in region $i \geq 1$ as Q_i^n. Given trade costs, equilibrium in the dairy product market implies that:

$$Q_i^n = \sum_{j\geq 0} \tau_{ij}^n C_{ij}^n . \tag{3}$$

Dairy products are manufactured by combining milk components with other inputs. These other inputs are assumed to have fixed prices and are represented as a single aggregate. We assume that the production function for dairy product n in region i is:

$$Q_i^n = \min\left(Z_i^n, \frac{N_i^n}{\nu_i^n}\right) ,$$

where Z_i^n is the aggregate of milk components, N_i^n is the aggregate of other inputs, and ν_i^n thus represents the fixed amount of other inputs used per unit of output. Let milk components be

indexed by $k = 1, \ldots, K$. The milk component aggregate is then defined as follows:

$$Z_i^n \equiv \left[\sum_{k \geq 1} \left(\gamma_i^{nk} \right)^{\frac{1}{\varsigma^n}} \left(Z_i^{nk} \right)^{\frac{\varsigma^n - 1}{\varsigma^n}} \right]^{\frac{\varsigma^n}{\varsigma^n - 1}} ,$$

where $\gamma_i^{nk} \geq 0$, $\sum_{k \geq 1} \gamma_i^{nk} = 1$, and $\varsigma^n \in (0, 1) \cup (1, \infty)$ is the elasticity of substitution across milk components in the manufacturing of product n. This specification allows for component k not to be used in the manufacturing of product n by setting $\gamma_i^{nk} = 0$. While milk provides components in relatively fixed proportions, dairy manufacturing allows for substitution across components; our aggregates allow for differing component substitutability across dairy products.

In regions regulated by an FMMO, component prices are set according to the dairy product they are used to manufacture. Denoting v_i^k as the baseline price of component k in region i, $v_i^{nk} \equiv \delta_i^{nk} v_i^k$ is the regulated purchase price for component k when used in product n. Thus, $\delta_i^{nk} > 0$ represents the policy-driven price wedge between the "natural" price of component k in region i and its mandated price for use in dairy product n. As normalization, we set $\delta_i^{nk} = 1$ for butter and dry milk products, i.e., the Class IV uses.

Cost minimization implies that the output-conditional demand for milk component k used in product n in region i is:

$$Z_i^{nk} = Q_i^n \gamma_i^{nk} \left(V_i^n \right)^{\varsigma^n} \left(\delta_i^{nk} v_i^k \right)^{-\varsigma^n} , \tag{4}$$

where V_i^n is a CES price index representing the overall price of milk components used for product category n in region i, defined as

$$V_i^n \equiv \left[\sum_{k \geq 1} \gamma_i^{nk} \left(\delta_i^{nk} v_i^k \right)^{1 - \varsigma^n} \right]^{\frac{1}{1 - \varsigma^n}} .$$

We denote the fixed price of the other inputs by w.[4] The fixed-proportions dairy technology implies that the market price of dairy product n in region i exhausts its production cost, that is:

$$p_i^n = V_i^n + w v_i^n . \tag{5}$$

3.3 Use and trade of farm milk

Regional demand for milk components translates into derived demand for farm milk. We assume that farm milk provides components in fixed proportions that are independent of the region of production, and that farm milk is a tradable commodity across U.S. regions; thus its availability in any given region is given by local production plus net shipments from other U.S. regions. Denoting by M_{ji} the quantity of milk from region j used in the manufacturing of dairy products in region i

[4]Note that there is no benefit to allowing the price of the other inputs to depend on the region (or the dairy product for which they are used) since the input intensity v_i^n is already region- and product-dependent.

and by ζ^k the amount of component k present in one unit of farm milk, we must have:

$$\sum_{n\geq 1} Z_i^{nk} \quad = \zeta^k \sum_{j\geq 1} M_{ji} \quad \text{for all } k \geq 1 \,. \tag{6}$$

This set of equalities implies that in the processing region, the equilibrium product mix is such that all the milk components are exhausted. If not, the regional price of the leftover component would approach zero, and Equation (4) then implies that demand for that component across all dairy products in which it is used would increase.[5]

In equilibrium, the regional blend price of farm milk must exhaust the value of its components. Due to the component price wedges, the value of component k is itself a weighted average of its prices across products, namely $\frac{v_i^k \sum_{n\geq 1} \delta_i^{nk} Z_i^{nk}}{\sum_{n\geq 1} Z_i^{nk}}$, yielding the regional farm milk blend price:

$$m_i = \sum_{k\geq 1} \zeta^k v_i^k \left(\frac{\sum_{n\geq 1} \delta_i^{nk} Z_i^{nk}}{\sum_{n\geq 1} Z_i^{nk}} \right) \,.$$

Using equation (6), the blend price can also be expressed as:

$$m_i = \frac{\sum_{k\geq 1} v_i^k \sum_{n\geq 1} \delta_i^{nk} Z_i^{nk}}{\sum_{j\geq 1} M_{ji}} \,. \tag{7}$$

Equation (7) makes apparent the analogy between the equilibrium price of milk in our model and the FMMO blend price, since the total classified value of components used in region i is divided by the total quantity of milk used in that region, and there is no value to milk beyond that embedded in its components.

We assume that trade in farm milk between regions is subject to iceberg trade costs. Trade costs between origin region j and destination region i are denoted τ_{ji}, with $\tau_{ii} = 1$. Because farm milk is considered a homogeneous commodity, bilateral trade in farm milk is unidirectional, and milk prices between trading regions are related through trade costs. That is, denoting m_j the price of farm milk in region j, we have:

$$M_{ji} M_{ij} = 0 \quad \text{and} \quad \left\{ m_i = \tau_{ji} m_j \text{ whenever } M_{ji} > 0 \right\} \,.$$

The first equality states that if region j ships farm milk to region i, then region i does not ship farm milk to region j. The second condition states that under farm milk trade, the price of farm milk in the destination region exceeds that in the origin region by a factor equal to the bilateral trade cost. In terms of calibration, we handle observations of bidirectional trade in farm milk by computing net exports from one region to the other. We further reallocate milk shipments in the raw data so as

[5] In the real world, components may be carried over from year to year, perhaps because product mixes and recipes cannot be adjusted easily in the short run to absorb an excess of component. The nonzero substitution elasticities across components in our one-shot model are meant to reflect long-run adaptation processes.

to eliminate loops (milk being transferred back to a source region through a sequence of bilateral trades) and competing routes (milk being shipped from one region to another via more than one route). One may rationalize instances of bidirectional trade in farm milk and the presence of loops or competing routes by seasonality in local demand and supply conditions, a feature intentionally ignored in our analysis.

3.4 Milk production and derived demand for crops

Denoting by M_i the quantity of farm milk produced in region $i \geq 1$, equality between production and uses of farm milk implies that

$$M_i = \sum_{j \geq 1} \tau_{ij} M_{ij} \, . \tag{8}$$

We assume that milk is produced according to the following production function:

$$M_i = \min \left(F_i, \frac{N_i}{\nu_i} \right) ,$$

where F_i is a dairy feed crop aggregate, N_i is a composite of all non-feed inputs including livestock, and ν_i is the amount of non-feed inputs per unit of milk produced. Feed crops are indexed by $l = 1, \ldots, L$ and the dairy feed aggregate is defined as

$$F_i \equiv \left[\sum_{l \geq 1} \left(\omega_i^l \right)^{\frac{1}{\rho}} \left(F_i^l \right)^{\frac{\rho - 1}{\rho}} \right]^{\frac{\rho}{\rho - 1}} ,$$

where $\omega_i^l > 0$, $\sum_{l \geq 1} \omega_i^l = 1$, and $\rho \in (0, 1) \cup (1, \infty)$ is the elasticity of substitution between feed crops used as dairy feed. Except for silage, a crop too bulky to be shipped out of its production region in any meaningful quantity, feed crop l may be traded between regions, with iceberg trade cost τ_{ji}^l for a shipment from j to i.[6] The quantity of feed crop l used in the dairy industry in region i is also assumed to be an aggregate of physical quantities from different origins. This aggregate, F_i^l, is defined as

$$F_i^l \equiv \left[\sum_{j \geq 1} \left(\omega_{ji}^l \right)^{\frac{1}{\lambda}} \left(F_{ji}^l \right)^{\frac{\lambda - 1}{\lambda}} \right]^{\frac{\lambda}{\lambda - 1}} ,$$

where $\omega_{ji}^l > 0$, $\sum_{j \geq 1} \omega_{ji}^l = 1$, and $\lambda \in (0, 1) \cup (1, \infty)$ is the elasticity of substitution across feed crops from different origins. For expositional purposes, we assume that substitution across feed crops from different origin regions is identical for each feed crop, but, as we argue below, our market closure assumptions are such that the value of this elasticity is immaterial to the equilibrium.

[6] Note that despite the use of τ to represent iceberg trade costs at each stage of the dairy supply chain, the similarity in notation does not restrict the trade cost for feed crops to be identical to the trade costs for dairy products. That is, the cost to ship a unit of crop l from j to i, τ_{ji}^l, is not the same as the cost to ship a unit of dairy product n from j to i, τ_{ji}^n.

Denoting by w_j^l the price of crop l in region j, the milk-output-conditional demand, in region i, for crop l originating from region j is:

$$F_{ji}^l = M_i \omega_i^l \omega_{ji}^l \left(W_i\right)^\rho \left(W_i^l\right)^{\lambda-\rho} \left(\tau_{ji}^l w_j^l\right)^{-\lambda} , \tag{9}$$

where W_i and W_i^l are CES price indices. The price index for dairy feed crops in region i, W_i, is defined as

$$W_i \equiv \left[\sum_{l\geq 1} \omega_i^l \left(W_i^l\right)^{1-\rho}\right]^{\frac{1}{1-\rho}} ,$$

while the price index for dairy feed crop l in region i, W_i^l, is defined as

$$W_i^l \equiv \left[\sum_{j\geq 1} \omega_{ji}^l \left(\tau_{ji}^l w_j^l\right)^{1-\lambda}\right]^{\frac{1}{1-\lambda}} .$$

Perfect competition and the fixed-proportions milk production technology imply that the milk price in region i exhausts the production cost of farm milk, that is:

$$m_i = W_i + wv_i . \tag{10}$$

3.5 Crop trade and crop production

Feed crop l may be exported from region i to the ROW subject to iceberg trade cost $\tau_{i0}^l \geq 1$. We assume fixed world prices for feed crops, say w_0^l. Thus, if region i exports feed crop l internationally, the regional price of that crop is fixed at $w_i^l = \frac{w_0^l}{\tau_{i0}^l}$. Feed crops are not imported.

Feed crops may also be used in other animal sectors (cattle, poultry, etc.) or in the energy sector, and we assume fixed prices for crops in these sectors as well.[7] The quantities of feed crop l produced in region i that either reach the international market or are used outside of the U.S. dairy sector are aggregated together and denoted F_{i0}^l. Since grains and oilseeds are widely used in other livestock sectors, their prices in each region are fixed in the model. Given the relatively small share of these crops used by the dairy industry, this assumption seems reasonable. In contrast, a larger share of forage crops is used in the dairy industry and these crops are less likely to be exported internationally, so the regional prices of forage crops may be endogenous. Most hay is consumed locally, but a non-negligible share of it goes to sectors other than dairy, and in some cases it may also be exported internationally. Thus, we also treat the price of hay as exogenous.

The case of silage is less clear-cut. In many regions, silage is used mostly for dairy. Even where some silage is used in other sectors, dairy silage is often produced near dairies, non-dairy cattle

[7]Due to the assumption of fixed prices, if a region exports crop l internationally and also uses that crop in non-dairy sectors, the price obtained in these sectors, net of any transportation cost, must be equal to $\frac{w_0^l}{\tau_{i0}^l}$.

that are fed silage may be located far from dairies, and silage cannot be economically transported over long distances. That is, the market for dairy silage may be considered independent from other silage markets and thus regional dairy silage prices are treated as endogenous. Thus, in our model we define silage as silage used exclusively for dairy and treat silage used for other sectors as a different crop.

In addition to dairy feed crops, farmers may produce an alternative crop representing an aggregate of all other crops competing for land (including non-dairy silage). This crop is indexed by $l = 0$, and we assume that its regional price, w_i^0, is fixed.

Denoting by Y_i^l the quantity of crop l produced in region i, total production is related to crop uses through the following equality:

$$Y_i^l = \sum_{j \geq 0} \tau_{ij}^l F_{ij}^l \,. \tag{11}$$

Crops are produced using technologies combining land and other inputs. Each region i has a fixed land base $L_i > 0$ and a continuum of parcels denoted ω, with heterogeneous yields for crop l denoted $A_i^l(\omega)$. Crop yields follow a Fréchet distribution with shape parameter $\theta > 1$ and unconditional crop yield $A_i^l > 0$.[8] As in Gouel and Laborde (2021), the output from parcel ω when grown in crop $l \geq 0$ is given by the following production function:

$$Y_i^l(\omega) = \min\left(A_i^l(\omega), \frac{N_i^l(\omega)}{\nu_i^l}\right) ,$$

where $N_i^l(\omega)$ is the quantity of inputs other than land and is chosen by farmers, unlike $A_i^l(\omega)$. The parameter ν_i^l thus represents the other inputs required per unit of crop output and is allowed to vary across regions and crops. In other words, the quantity of crop l produced on a given parcel ω is determined by the amount of inputs chosen by farmers, but it cannot exceed the natural yield of the parcel, $A_i^l(\omega)$.

Profit maximization implies that, conditional on growing crop l, $N_i^l(\omega) = \nu_i^l Y_i^l(\omega) = \nu_i^l A_i^l(\omega)$, therefore the rent per unit of crop l output is:

$$r_i^l \equiv w_i^l - w\nu_i^l \,. \tag{12}$$

Given our distributional assumption regarding crop yields, the share of region i's cropland dedi-

[8]Specifically, the joint probability distribution for crop yields in region i is:

$$\Pr\left(A_i^l(\omega) \leq a^l, l = 1, \ldots, L\right) = \exp\left[-\gamma \sum_{l=1}^{L} \left(\frac{a^l}{A_i^l}\right)^{-\theta}\right] ,$$

where the parameter γ is set so that $\mathbb{E}\left[A_i^l(\omega)\right] = A_i^l$ for all $l = 1, \ldots, L$. See Costinot, Donaldson, and Smith (2016) for details.

cated to crop l can then be expressed as

$$\pi_i^l = \frac{\left(r_i^l A_i^l\right)^\theta}{\sum_{l' \geq 0} \left(r_i^{l'} A_i^{l'}\right)^\theta} \,, \tag{13}$$

where the summation at the denominator is over all crops, including non-feed crops. The regional supply of crop l can further be expressed as

$$Y_i^l = L_i A_i^l \left(\pi_i^l\right)^{1-\frac{1}{\theta}} \,, \tag{14}$$

making apparent that the conditional yield of crop l is $A_i^l \left(\pi_i^l\right)^{-\frac{1}{\theta}} > A_i^l$.

4 Equilibrium in relative changes

We now derive the equilibrium in relative changes, which will help identify the most parsimonious set of data necessary to generate the counterfactual of interest. Added parsimony comes from the fact that although every parameter and variable considered previously has a clear empirical interpretation, not every one of them requires independent calibration to identify counterfactual effects (Donaldson, 2022). The algebra behind the derivation of the equilibrium in relative changes is standard and follows the approach utilized by Gouel and Laborde (2021) or Mérel, Qin, and Sexton (2023).

4.1 Changes in prices and quantities

Due to the longstanding nature of FMMOs, share parameters calibrated using observed data reflect an equilibrium that includes component price distortions (Lucas Jr, 1976). Our main policy counterfactual involves the removal of all such wedges in all FMMO regions. That is, $\delta_i^{nk} \neq 1$ for some (i, n, k) combinations in the baseline, whereas $\delta_i^{nk} = 1$ for all (i, n, k) in the counterfactual. The relative change in the price wedge, which is exogenous, is denoted $\hat{\delta}_i^{nk}$ and represents the ratio of the new to the old wedge.

The equilibrium in relative changes relates the change in the price wedges to the endogenous change in prices and quantities, also denoted with hats and representing the ratio of the new to the old values. The equilibrium is defined by a system of equations presented below, going from downstream dairy product markets to upstream feed crop markets.

The following equations relate to dairy product consumption in the U.S. and the ROW:

$$\hat{C}_{ij}^n = \left(\hat{P}_j\right)^{\kappa-\epsilon}\left(\hat{P}_j^n\right)^{\sigma^n-\kappa}\left(\hat{p}_i^n\right)^{-\sigma^n} \qquad i=0,\ldots,I, \quad j=1,\ldots,I, \quad n=1,\ldots,N \tag{15}$$

$$\hat{P}_j = \left[\sum_{n\geq 1} b_j^n\left(\hat{P}_j^n\right)^{1-\kappa}\right]^{\frac{1}{1-\kappa}} \qquad j=1,\ldots,I \tag{16}$$

$$\hat{P}_j^n = \left[\sum_{i\geq 0} b_{ij}^n\left(\hat{p}_i^n\right)^{1-\sigma^n}\right]^{\frac{1}{1-\sigma^n}} \qquad j=1,\ldots,I, \quad n=1,\ldots,N \tag{17}$$

$$\hat{C}_{i0}^n = \left(\hat{P}_0\right)^{\kappa_0-\epsilon_0}\left(\hat{P}_0^n\right)^{\sigma_0^n-\kappa_0}\left(\hat{p}_i^n\right)^{-\sigma_0^n} \qquad i=1,\ldots,I, \quad n=1,\ldots,N \tag{18}$$

$$\hat{P}_0 = \left[\sum_{n\geq 1} b_0^n\left(\hat{P}_0^n\right)^{1-\kappa_0}\right]^{\frac{1}{1-\kappa_0}} \tag{19}$$

$$\hat{P}_0^n = \left[\sum_{i\geq 1} b_{i0}^n\left(\hat{p}_i^n\right)^{1-\sigma_0^n}\right]^{\frac{1}{1-\sigma_0^n}} \qquad n=1,\ldots,N\,. \tag{20}$$

The following equations relate to dairy product manufacturing and the use of milk components:

$$\hat{Q}_i^n = \sum_{j\geq 0} a_{ij}^n \hat{C}_{ij}^n \qquad i=1,\ldots,I, \quad n=1,\ldots,N \tag{21}$$

$$\hat{Z}_i^{nk} = \hat{Q}_i^n\left(\hat{V}_i^n\right)^{\varsigma^n}\left(\hat{\delta}_i^{nk}\hat{v}_i^k\right)^{-\varsigma^n} \qquad i=1,\ldots,I, \quad n=1,\ldots,N, \quad k=1,\ldots,K \tag{22}$$

$$\hat{V}_i^n = \left[\sum_{k\geq 1} c_i^{nk}\left(\hat{\delta}_i^{nk}\hat{v}_i^k\right)^{1-\varsigma^n}\right]^{\frac{1}{1-\varsigma^n}} \qquad i=1,\ldots,I, \quad n=1,\ldots,N \tag{23}$$

$$\hat{p}_i^n = \psi_i^n\hat{V}_i^n + 1 - \psi_i^n \qquad i=1,\ldots,I, \quad n=1,\ldots,N\,. \tag{24}$$

The following equations relate to regional milk demand and milk prices:

$$\sum_{n\geq 1}\chi_i^{nk}\hat{Z}_i^{nk} = \sum_{j\geq 1}\mu_{ji}\hat{M}_{ji} \qquad i=1,\ldots,I \quad k=1,\ldots,K \tag{25}$$

$$\hat{m}_i\sum_{j\geq 1}\mu_{ji}\hat{M}_{ji} = \sum_{k\geq 1}\theta_i^k\hat{v}_i^k\sum_{n\geq 1}\theta_i^{nk}\hat{\delta}_i^{nk}\hat{Z}_i^{nk} \qquad i=1,\ldots,I \tag{26}$$

$$\hat{m}_j - \hat{m}_i \geq 0 \text{ and } \left(\hat{m}_j - \hat{m}_i\right)\hat{M}_{ji} = 0 \text{ if } \mu_{ji} > 0 \qquad i=1,\ldots,I, \quad j=1,\ldots,I\,. \tag{27}$$

The following equations relate to regional production of milk and the use of feed crops:

$$\hat{M}_i = \sum_{j \geq 1} a_{ij} \hat{M}_{ij} \qquad i = 1, \ldots, I \tag{28}$$

$$\hat{F}_{ji}^l = \hat{M}_i \left(\hat{W}_i\right)^{\rho} \left(\hat{W}_i^l\right)^{\lambda - \rho} \left(\hat{w}_j^l\right)^{-\lambda} \qquad j = 1, \ldots, I, \quad i = 1, \ldots, I, \quad l = 1, \ldots, L \tag{29}$$

$$\hat{W}_i = \left[\sum_{l \geq 1} \xi_i^l \left(\hat{W}_i^l\right)^{1-\rho}\right]^{\frac{1}{1-\rho}} \qquad i = 1, \ldots, I \tag{30}$$

$$\hat{W}_i^l = \left[\sum_{j \geq 1} \xi_{ji}^l \left(\hat{w}_j^l\right)^{1-\lambda}\right]^{\frac{1}{1-\lambda}} \qquad i = 1, \ldots, I, \quad l = 1, \ldots, L \tag{31}$$

$$\hat{m}_i = \phi_i \hat{W}_i + 1 - \phi_i \qquad i = 1, \ldots, I\,. \tag{32}$$

The next set of equations relate to regional crop production:

$$\hat{Y}_i^l = \sum_{j \geq 0} \rho_{ij}^l \hat{F}_{ij}^l \qquad i = 1, \ldots, I, \quad l = 1, \ldots, L \tag{33}$$

$$\hat{Y}_i^l = \frac{\left(\hat{r}_i^l\right)^{\theta - 1}}{\left[\sum_{l' \geq 0} \pi_i^{l'} \left(\hat{r}_i^{l'}\right)^{\theta}\right]^{\frac{\theta - 1}{\theta}}} \qquad i = 1, \ldots, I, \quad l = 0, \ldots, L \tag{34}$$

$$\hat{w}_i^l = \varphi_i^l \hat{r}_i^l + 1 - \varphi_i^l \qquad i = 1, \ldots, I, \quad l = 1, \ldots, L\,. \tag{35}$$

The final equations represent market closure conditions for commodities with exogenous prices, namely foreign dairy products and crops traded internationally and/or used in non-dairy sectors:

$$\hat{p}_0^n = 1 \qquad n = 1, \ldots, N \tag{36}$$

$$\hat{w}_i^l - 1 \geq 0 \text{ and } \left(\hat{w}_i^l - 1\right) \hat{F}_{i0}^l = 0 \text{ if } \rho_{i0}^l > 0 \qquad i = 1, \ldots, I, \quad l = 1, \ldots, L \tag{37}$$

$$\hat{r}_i^0 = 1 \qquad i = 1, \ldots, I\,. \tag{38}$$

In addition to the shape and elasticity parameters introduced in Section 3, Equations (15)–(38) feature a series of share parameters. At the dairy product level, $b_j^n \equiv \frac{P_j^n C_j^n}{P_j C_j}$ is the budget share of product n in total dairy consumption in region j; $b_{ij}^n \equiv \frac{\tau_{ij}^n p_i^n C_{ij}^n}{P_j^n C_j^n}$ is the share of product n from region i in total consumption of n in region j; and $a_{ij}^n \equiv \frac{\tau_{ij}^n p_i^n C_{ij}^n}{p_i^n Q_i^n} = \frac{\tau_{ij}^n C_{ij}^n}{Q_i^n}$ is the share of region i's production value of product n shipped to region j.

At the milk processing stage, $c_i^{nk} \equiv \frac{\delta_i^{nk} v_i^k Z_i^{nk}}{V_i^n Z_i^n}$ is the share of component k in the cost of milk components in product n in region i; $\chi_i^{nk} \equiv \frac{Z_i^{nk}}{\sum_{n'} Z_i^{n'k}}$ is the share of product n in the use of component k in region i (in volume); $\theta_i^k \equiv \frac{\zeta^k v_i^k \left(\frac{\sum_{n \geq 1} \delta_i^{nk} Z_i^{nk}}{\sum_{n \geq 1} Z_i^{nk}}\right)}{m_i}$ is the share of component k in total milk value in

region i; and $\theta_i^{nk} \equiv \frac{\delta_i^{nk} v_i^k Z_i^{nk}}{\sum_{n'} \delta_i^{n'k} v_i^k Z_i^{n'k}} = \frac{\delta_i^{nk} Z_i^{nk}}{\sum_{n'} \delta_i^{n'k} Z_i^{n'k}}$ is the share of product n in the value of component k in region i, which would be equal to χ_i^{nk} if not for the policy distortion.

At the farm milk production stage, $a_{ij} \equiv \frac{\tau_{ij} m_i M_{ij}}{m_i M_i} = \frac{\tau_{ij} M_{ij}}{M_i}$ is the share of region i's milk value shipped to region j and $\mu_{ji} \equiv \frac{M_{ji}}{\sum_{j'} M_{j'i}}$ is the share of milk used in region i originating from region j. Note that due to the trade costs in farm milk, we must have $a_{ij} a_{ji} = 0$ and $\mu_{ij} \mu_{ji} = 0$. In addition, $\xi_i^l \equiv \frac{W_i^l F_i^l}{W_i F_i}$ is the share of crop l in total expenditure on dairy feed crops in region i, while $\xi_{ji}^l \equiv \frac{\tau_{ji}^l w_j^l F_{ji}^l}{W_i^l F_i^l}$ is the share of crop l originating in region j in total expenditure on crop l in region i.

At the crop production stage, $\rho_{ij}^l \equiv \frac{\tau_{ij}^l w_i^l F_{ij}^l}{w_i^l Y_i^l} = \frac{\tau_{ij}^l F_{ij}^l}{Y_i^l}$ is the share of region i's production of crop l that is shipped to region j, with $j = 0$ denoting the international market or the feed market for animals other than dairy cattle.

Finally, cost shares at each state of production are defined as follows: $\varphi_i^l \equiv \frac{r_i^l}{w_i^l} = \frac{w_i^l - w v_i^l}{w_i^l}$ is the land rent relative to the producer price of feed crop l in region i, that is, the regional land share of the crop l dollar; $\phi_i \equiv \frac{W_i}{m_i} = \frac{m_i - w v_i}{m_i}$ is the expenditure on feed crops relative to the value of milk produced in region i, that is, the regional crop share of the milk dollar; and $\psi_i^n \equiv \frac{V_i^n}{p_i^n} = \frac{p_i^n - w v_i^n}{p_i^n}$ is the expenditure on milk components as a share of the price of dairy product n in region i, that is, the regional milk share of the dairy product n dollar.

Because we assume that the prices of grains, oilseeds, and hay are fixed ($\hat{w}_i^l = 1$), Equation (31) implies that $\hat{W}_i^l = 1$ for these crops. The remaining feed crop, namely silage, is not traded or used in other sectors, therefore $\xi_{ii}^l = 1$ and Equation (31) implies that $\hat{W}_i^l = \hat{w}_i^l$. But then, (29) with $j = i$ implies that $\hat{F}_{ii}^l = \hat{M}_i \left(\hat{W}_i\right)^{\rho} \left(\hat{w}_i^l\right)^{-\rho}$, so λ disappears from the equilibrium conditions. Therefore, a consequence of our model closure is that the Armington elasticity λ is irrelevant to the equilibrium concept, as are the values of the ξ_{ji}^l parameters for traded feed crops.

4.2 Counterfactual welfare effects

Consider the representative consumer in region $j \geq 1$. The change in utility is calculated as the difference between utility in the counterfactual scenario, U_j', and utility in the baseline, U_j:

$$\Delta U_j \equiv U_j' - U_j = \frac{P_j C_j}{1 - \epsilon} \left(1 - \hat{P}_j^{1-\epsilon}\right) .$$

Quasi-linearity implies that the change in utility is equivalent to the change in consumer surplus, the equivalent variation, and the compensating variation due to the change in dairy product prices. Similarly, the effect on consumer surplus in the ROW for dairy products of U.S. origin is:

$$\Delta U_0 \equiv U_0' - U_0 = \frac{P_0 C_0}{1 - \epsilon_0} \left(1 - \hat{P}_0^{1-\epsilon_0}\right) ,$$

where $P_0 C_0$ represents the value of exported dairy products.

We define total dairy product value in the market as

$$PC \equiv \sum_{j\geq 1} P_j C_j + P_0 C_0 \ .$$

Let $b_j \equiv \frac{P_j C_j}{PC}$ denote the share of total dairy product value that is consumed in region $j \geq 0$. One may then express the change in domestic consumer surplus relative to the value of domestic consumption as

$$\frac{\sum_{j\geq 1} \Delta U_j}{\sum_{j\geq 1} P_j C_j} = \frac{\sum_{j\geq 1} \frac{b_j}{1-\epsilon}\left(1-\hat{P}_j^{1-\epsilon}\right)}{\sum_{j\geq 1} b_j} \ ,$$

and the total change in consumer surplus relative to total dairy product value as

$$\frac{\sum_{j\geq 0} \Delta U_j}{PC} = \frac{b_0}{1-\epsilon_0}\left(1-\hat{P}_0^{1-\epsilon_0}\right) + \sum_{j\geq 1} \frac{b_j}{1-\epsilon}\left(1-\hat{P}_j^{1-\epsilon}\right) \ .$$

Since we assume constant returns to scale in dairy, milk, and crop production, profit in our model is limited to rents accruing to landowners, the residual claimants of crop value. The land rent in region $i \geq 1$ is equal to $\Pi_i \equiv \sum_{l\geq 0} r_i^l Y_i^l$. The change in the regional land rent is:

$$\Delta\Pi_i \equiv \Pi_i' - \Pi_i = \sum_{l\geq 0} r_i^l Y_i^l \left(\hat{r}_i^l \hat{Y}_i^l - 1\right) \ ,$$

and the relative change in the regional land rent is then:

$$\frac{\Delta\Pi_i}{\Pi_i} = \sum_{l\geq 0} \frac{\varphi_i^l \rho_i^l}{\varphi_i}\left(\hat{r}_i^l \hat{Y}_i^l - 1\right) \ ,$$

where $\rho_i^l \equiv \frac{w_i^l Y_i^l}{\sum_{l'\geq 0} w_i^{l'} Y_i^{l'}}$ is the share of crop $l \geq 0$ in the value of crop production in region $i \geq 1$, and $\varphi_i \equiv \frac{\sum_{l\geq 0} r_i^l Y_i^l}{\sum_{l\geq 0} w_i^l Y_i^l} = \sum_{l\geq 0} \varphi_i^l \rho_i^l$ is the value of cropland relative to the total value of crop production in region i, that is, the regional land share of the crop dollar.

The total land rent impact, $\Delta\Pi \equiv \sum_{i\geq 1} \Delta\Pi_i$, can then be expressed relative to the aggregate land rent as

$$\frac{\Delta\Pi}{\sum_{i\geq 1} \Pi_i} = \frac{\sum_{i\geq 1} \rho_i \sum_{l\geq 0} \varphi_i^l \rho_i^l \left(\hat{r}_i^l \hat{Y}_i^l - 1\right)}{\sum_{i\geq 1} \varphi_i \rho_i} \ ,$$

where $\rho_i \equiv \frac{\sum_{l\geq 0} w_i^l Y_i^l}{\sum_{i'\geq 1}\sum_{l\geq 0} w_{i'}^l Y_{i'}^l}$ is the share of region i in the total value of crop production. For comparability with consumer effects and to compute social welfare effects, one may also express

the change in land rent relative to the total dairy product value:

$$\frac{\Delta\Pi}{PC} = \frac{a\psi\phi}{(1-\rho^0)(1-\xi_0)} \sum_{i\geq 1} \rho_i \sum_{l\geq 0} \varphi_i^l \rho_i^l \left(\hat{r}_i^l \hat{Y}_i^l - 1\right) , \tag{39}$$

where $a \equiv \frac{\sum_{i\geq 1}\sum_{n\geq 1} p_i^n Q_i^n}{PC}$ is the share of domestic production in total dairy product value, $\psi \equiv \frac{\sum_{i\geq 1} m_i M_i}{\sum_{i\geq 1}\sum_{n\geq 1} p_i^n Q_i^n}$ is the milk share of domestic dairy product revenue, $\phi \equiv \frac{\sum_{i\geq 1} W_i F_i}{\sum_{i\geq 1} m_i M_i}$ is the overall feed crop share of milk revenue, $\rho^0 \equiv \frac{\sum_{i\geq 1} w_i^0 Y_i^0}{\sum_{l\geq 0}\sum_{i\geq 1} w_i^l Y_i^l}$ is the overall share of the non-feed crop in the value of total crop production, and $\xi_0 \equiv \frac{\sum_{j\geq 1}\sum_{l\geq 1} \tau_{j0}^l w_j^l F_{j0}^l}{\sum_{j\geq 1}\sum_{l\geq 1} w_j^l Y_j^l}$ is the share of total feed crop value used outside the dairy industry or exported.

5 Minimum calibration requirements

Conditional on model structure, the shape and share parameters in Equations (15)–(39) completely determine the price, quantity, and welfare effects of modifying the regional FMMO component price wedges. Many of the share parameters can be calculated from available data, yet mechanistic relationships exist between them, considerably reducing the amount of independent information necessary for calibration. In what follows, we make these relationships explicit.

5.1 Dairy product expenditure and shipment shares

Because we do not model the ROW's consumption of non-U.S. dairy products, total dairy product value, PC, is equal to the value of domestic consumption plus the value of exports. PC must also be equal to the value of dairy products manufactured in the U.S. plus the value of imported dairy products. Therefore, we have:

$$\sum_{j\geq 1} P_j C_j + P_0 C_0 = \sum_{i\geq 1}\sum_{n\geq 1} p_i^n Q_i^n + \sum_{j\geq 1}\sum_{n\geq 1} \tau_{0j}^n p_0^n C_{0j}^n .$$

Consequently, the expenditure shares by origin, b_{ij}^n, are related to the shares of production value by destination, a_{ij}^n, namely:

$$b_j b_j^n b_{ij}^n = a a_i a_i^n a_{ij}^n \qquad n \geq 1, i \geq 1, j \geq 0 \tag{40}$$

$$b_j b_j^n b_{0j}^n = (1-a) a_0^n a_{0j}^n \qquad n \geq 1, j \geq 1 , \tag{41}$$

where $a_i \equiv \frac{\sum_n p_i^n Q_i^n}{\sum_{i'\geq 1}\sum_n p_{i'}^n Q_{i'}^n}$ is the share of region i in the domestic value of dairy product manufacturing, $a_i^n \equiv \frac{p_i^n Q_i^n}{\sum_{n'} p_i^{n'} Q_i^{n'}} = \frac{\sum_{j\geq 0} \tau_{ij}^n p_i^n C_{ij}^n}{\sum_{n'}\sum_{j\geq 0} \tau_{ij}^{n'} p_i^{n'} C_{ij}^{n'}}$ is the share of product n in the value of dairy product manufacturing in region i, $a_0^n \equiv \frac{\sum_{j\geq 1} \tau_{0j}^n p_0^n C_{0j}^n}{\sum_{n'}\sum_{j\geq 1} \tau_{0j}^{n'} p_0^{n'} C_{0j}^{n'}}$ is the share of product n in the total value of dairy

imports, and $a_{0j}^n \equiv \frac{\tau_{0j}^n p_0^n C_{0j}^n}{\sum_{j' \geq 1} \tau_{0j'}^n p_0^n C_{0j'}^n} = \frac{\tau_{0j}^n C_{0j}^n}{\sum_{j' \geq 1} \tau_{0j'}^n C_{0j'}^n}$ is the share of region j in the value of imports of dairy product n.

Summing Equations (40) and (41) over origin regions $i \geq 0$ yields:

$$b_j b_j^n = a \sum_{i \geq 1} a_i a_i^n a_{ij}^n + (1-a) a_0^n a_{0j}^n \qquad j \geq 0, n \geq 1 \tag{42}$$

with the convention that $a_{00}^n = 0$. Summing Equation (42) over dairy products $n \geq 1$ then yields:

$$b_j = a \sum_{i \geq 1} a_i \sum_{n \geq 1} a_i^n a_{ij}^n + (1-a) \sum_{n \geq 1} a_0^n a_{0j}^n \qquad j \geq 0 \, . \tag{43}$$

Therefore, if one knows a, a_i, a_i^n, and a_{ij}^n, one can deduce recursively the values of b_j, b_j^n, and b_{ij}^n.

5.2 Dairy component cost shares and dairy product value shares

The share of component k in the cost of dairy components for dairy product n in region i is given by c_i^{nk}, while the contribution of product n to the value of component k in that region is given by θ_i^{nk}. The relationship between these shares can be expressed as

$$a_i^n \psi_i^n c_i^{nk} = \theta_i \theta_i^k \theta_i^{nk} \qquad i \geq 1, n \geq 1, k \geq 1 \, , \tag{44}$$

where $\theta_i \equiv \frac{m_i \sum_{j \geq 1} M_{ji}}{\sum_{n \geq 1} p_i^n Q_i^n}$ is the value of milk used in region i relative to the value of processed dairy products in i.

Summing Equation (44) over components k leads to

$$a_i^n \psi_i^n = \theta_i \sum_{k \geq 1} \theta_i^k \theta_i^{nk} \qquad i \geq 1, n \geq 1 \, . \tag{45}$$

Thus, if the parameters θ_i, θ_i^k, θ_i^{nk}, and a_i^n are known, (45) can be used to deduce ψ_i^n. One may then use (44) to deduce c_i^{nk}.

5.3 Farm milk trade shares

Regarding the movement of farm milk across U.S. regions, shipment shares by destination (a_{ij}) and availability shares by origin (μ_{ij}) are related through the relationship

$$\psi \mu_i a_{ij} = a_j \theta_j \mu_{ij} \qquad i, j \geq 1 \, , \tag{46}$$

where $\mu_i \equiv \frac{m_i M_i}{\sum_{i' \geq 1} m_{i'} M_{i'}}$ is region i's share of the total value of U.S. milk production. Summing Equation (46) over destination regions j leads to

$$\psi \mu_i = \sum_{j \geq 1} a_j \theta_j \mu_{ij} \qquad\qquad i \geq 1 \; . \tag{47}$$

Summing Equation (47) over origin regions i leads to

$$\psi = \sum_{j \geq 1} a_j \theta_j \; . \tag{48}$$

Thus, if one knows a_j, θ_j, and μ_{ij}, one may first use (48) to infer the value of ψ, then (47) to deduce the value of μ_i, and then (46) to deduce the value of a_{ij}.

5.4 Feed crop availability and shipment shares

The total value of feed crops is equal to the value of feed crops used in the domestic dairy industry plus the value of feed crops exported or used in other livestock sectors. Since there are no net imports of feed crops, this value must be equal to the total value of feed crops produced across U.S. regions, namely:

$$\sum_{i \geq 1} W_i F_i + \sum_{l \geq 1} \sum_{j \geq 1} \tau^l_{j0} w^l_j F^l_{j0} = \sum_{j \geq 1} \sum_{l \geq 1} w^l_j Y^l_j \; .$$

Define ξ_i, the share of total feed crop value that is used in the dairy industry in region $i \geq 1$, as

$$\xi_i \equiv \frac{W_i F_i}{\sum_{j \geq 1} \sum_{l \geq 1} w^l_j Y^l_j} \; .$$

Using this parameter and the parameter ξ_0 defined previously, one can establish the key relationship between feed crop regional consumption (ξ^l_{ij}) and production (ρ^l_{ij}) shares:

$$(1 - \rho^0) \xi_i \xi^l_i \xi^l_{ji} = \rho_j \rho^l_j \rho^l_{ji} \qquad\qquad i \geq 0, j \geq 1, l \geq 1 \; , \tag{49}$$

where $\xi^l_0 \equiv \frac{\sum_{j \geq 1} \tau^l_{j0} w^l_j F^l_{j0}}{\sum_{l' \geq 1} \sum_{j \geq 1} \tau^{l'}_{j0} w^{l'}_j F^{l'}_{j0}}$ is the share of feed crop l in the total value of feed crops exported or used in non-dairy sectors, and $\xi^l_{j0} \equiv \frac{\tau^l_{j0} w^l_j F^l_{j0}}{\sum_{j' \geq 1} \tau^l_{j'0} w^l_{j'} F^l_{j'0}}$ is the share of origin $j \geq 1$ in the value of exports/non-dairy uses of crop l.

Equation (49) implies further parameter restrictions. First, summing over origin regions $j \geq 1$ leads to

$$(1 - \rho^0) \xi_i \xi^l_i = \sum_{j \geq 1} \rho_j \rho^l_j \rho^l_{ji} \qquad\qquad i \geq 0, l \geq 1 \; . \tag{50}$$

Then, summing over feed crops $l \geq 1$ yields

$$(1-\rho^0)\xi_i = \sum_{j\geq 1} \rho_j \sum_{l\geq 1} \rho_j^l \rho_{ji}^l \qquad i \geq 0\,. \tag{51}$$

Therefore, if one knows the values of the parameters ρ^0, ρ_j, ρ_j^l, and ρ_{ji}^l, one may recover the parameters ξ_i, ξ_i^l, and ξ_{ji}^l recursively.

5.5 Crop share of milk revenue and land share of crop revenue

The regional feed crop share of milk revenue, ϕ_i, can be deduced from the overall feed crop share of milk revenue across regions, ϕ, the regional share of milk production value, μ_i, and the share of total feed crop value used by the dairy industry in region i, ξ_i, using the following relationship:

$$\phi_i = \frac{\phi \xi_i}{(1-\xi_0)\,\mu_i} \qquad i \geq 1\,, \tag{52}$$

where $1-\xi_0$ represents the share of the total value of feed crop production that is utilized by the domestic dairy industry.

Equations (13) and (14) imply that the regional share of land used for crop l, π_i^l, is related to the land share of crop revenue φ_i^l and the share of crop l in total crop value ρ_i^l through the equality

$$\pi_i^l = \frac{\varphi_i^l \rho_i^l}{\sum_{l'\geq 0} \varphi_i^{l'} \rho_i^{l'}} \qquad i \geq 1, l \geq 0\,.$$

One could consider calibrating the parameters $\varphi_i^l = \frac{r_i^l}{w_i^l}$ using region-specific information on crop budgets. Instead, using the regional land share of the crop dollar $\varphi_i = \sum_{l\geq 0} \varphi_i^l \rho_i^l$, we have:

$$\varphi_i^l = \frac{\pi_i^l \varphi_i}{\rho_i^l} \qquad i \geq 1, l \geq 0\,. \tag{53}$$

Thus, to the extent that the parameters π_i^l, φ_i, and ρ_i^l can be calculated from available data, this expression determines the value of φ_i^l, making it clear that the regional land share of crop revenue is implicitly revealed by the observed land and value shares.

5.6 Baseline component price distortions

The baseline price wedge factors δ_i^{nk} can be deduced from comparing the share parameters θ_i^{nk} and χ_i^{nk}, which represent regional shares of product category n in the value and the quantity of component k, respectively. We set the reference component prices for butter-powder in all regions, so that all component prices are measured relative to the component price for use in butter-powder.

Denoting $n = 4$ the index for butter-powder products, we thus have

$$\delta_i^{nk} = \frac{\theta_i^{nk}/\chi_i^{nk}}{\theta_i^{4k}/\chi_i^{4k}} \qquad i \geq 1, n \geq 1, k \geq 1 \,. \tag{54}$$

The price wedges δ_i^{nk} are used to construct the policy counterfactuals. In the counterfactual where all wedges are removed, the exogenous shock to our equilibrium is given by $\hat{\delta}_i^{nk} = \frac{1}{\delta_i^{nk}}$.

6 Calibration information

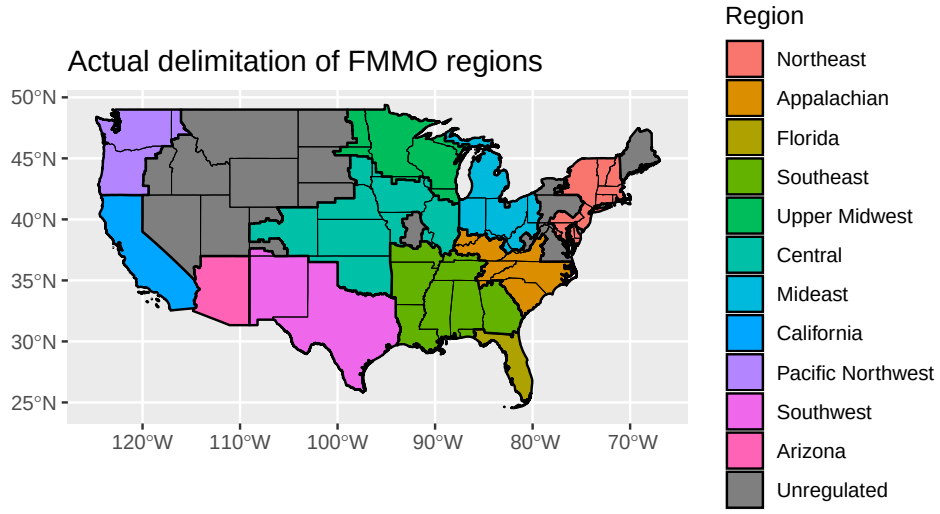
Our model of the U.S. dairy supply chain features $I = 12$ domestic regions corresponding to the 11 FMMO regions and a residual unregulated region. The regions utilized in our model are composed of U.S. states that approximate the official boundaries of FMMO marketing areas, which rely on state boundaries but also county and in some cases township or city boundaries. Table A.1 in Appendix A provides the list of states included in each FMMO region. Aggregation at the state level is necessary due to data limitations, notably regarding the Commodity Flow Survey of the U.S. Census Bureau, which is only available publicly at the state level. Nonetheless, we believe that our delineation does a good job of capturing most of the economically relevant differences in milk pricing across space. For example, several counties in Idaho are included in the boundaries of the Pacific Northwest marketing area, but the majority of Idaho's milk and crop production are located in the portion of the state which is not part of the marketing area. Most of the milk produced in Idaho being unregulated, it seems appropriate to include Idaho in the unregulated region. In contrast, Maine is not included in any defined marketing area, but the vast majority of milk produced in Maine is regulated by the Northeast FMMO. We thus include Maine in the Northeast region of our model to reflect this natural association. The actual FMMO regions, as well as the state-based delineations used in our model, are depicted in Figure 2.

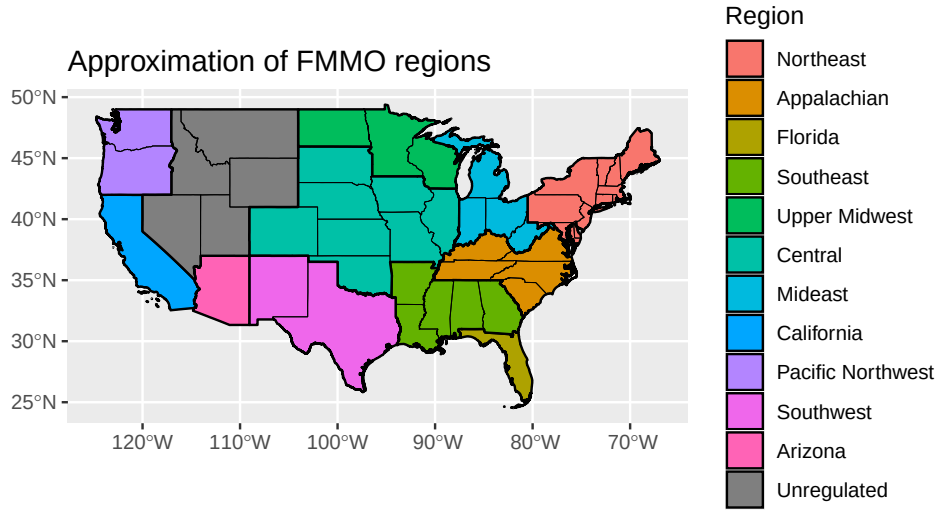
We consider $N = 4$ dairy product categories corresponding to the four classes of milk specified in FMMO regulations, namely beverages, softs, cheese, and butter-powder products. Given the facts that we model demand for dairy products at wholesale and that our policy counterfactuals involve changes in pricing rules for milk components across classes, we believe this choice to be appropriate.[9] Similarly, we consider the $K = 3$ components specified by FMMOs, namely butterfat, protein, and other solids. The $L = 4$ feed crops considered in the land allocation model—in addition to the non-feed crop—are grains, oilseeds, hay, and silage. Among those, only silage is assumed to be non-tradable across regions or internationally.

Table 1 summarizes the set of baseline share parameters, indicating whether they are directly calibrated against available data or whether their value is deducible from that of other parameters according to the relationships laid out in Section 5. The last column of the table indicates the

[9]One drawback is that most available estimates of demand elasticities for dairy products have been estimated for consumer- rather than industry-oriented categories.

Figure 2: FMMO regions





source of the calibrating information. Appendix B describes the procedures and assumptions used to compute the share parameters directly calibrated against empirical data. Most calibration data pertain to the year 2017.

6.1 Component price wedges (δ_i^{nk})

To provide an idea of the extent and the pattern of the component price distortions generated by the FMMO system, Table 2 shows the price wedge factors for protein and other solids in the beverage and cheese product categories, relative to the default butter-powder products. Unlike the price of the fat component, the prices of the other components tend to be heavily distorted, typically so in these two product categories. Table 2 suggests that relative wedges can be substantial for both protein and other solids, with factors sometimes in excess of 2 or below 0.5. It also suggests that the wedge factors are far from being uniform across jurisdictions. For example, the Appalachian, Florida, Southeast, and Arizona regions have higher protein price wedge factors in beverages than in cheese, but the opposite holds for the Northeast, Central, Mideast, or Pacific Northwest regions. Finally, price distortions for protein and other solids are identical for beverages, but not necessarily for cheese.

6.2 Elasticities of demand for dairy products (ϵ, κ)

Two shape parameters govern the elasticities of dairy product demand: ϵ, the price elasticity of demand for the dairy product aggregate, and κ, the elasticity of substitution across dairy products. Specifically, the elasticity of demand for dairy product n in region j is:

$$\frac{\partial \ln C_j^n}{\partial \ln P_j^n} = (\kappa - \epsilon)\, b_j^n - \kappa. \tag{55}$$

Equation (55) implies that the absolute elasticity is bounded between ϵ (if $b_j^n \to 1$) and κ (if $b_j^n \to 0$). We would expect that $\kappa > \epsilon$ so that a product with a larger budget share has less elastic demand. Additionally, it makes sense for demand for dairy as a whole to be less elastic than demand for specific dairy products, and for products to be net substitutes, which happens whenever $\kappa > \epsilon$.

Gouel and Laborde (2021) refer to elasticities for food categories from a meta-analysis by Andreyeva, Long, and Brownell (2010). That study includes cheese, milk, and other dairy products among the food categories for which demand elasticities were evaluated, with 26 studies reporting demand elasticities for milk, 20 for cheese, and 13 for dairy products in general. The mean demand elasticity for dairy products was 0.65 in absolute value, with 95% of the observations between 0.46 and 0.84. These estimates are pulled from studies that considered the elasticity of demand for dairy products as a group, so this information could be used to suggest a range of values for ϵ. However, the mean value of 0.65 was higher than the elasticities reported for milk and cheese, contrary to the expectation that the dairy aggregate should be more inelastic than individual product categories. For beverage milk, the mean absolute elasticity was 0.59 and the 95% range was 0.40 to 0.79. Cheese

Table 1: Share parameters and calibration sources

Share	Index range	Definition	Source
a		share of domestic production in total dairy product revenue	observed: Census Bureau, USDA/NASS
a_i	$i \geq 1$	share of region i in value of domestic dairy production	observed: Census Bureau
a_i^n	$i \geq 1, n \geq 1$	share of product n in value of dairy production in region i	observed: Census Bureau
a_{ij}^n	$i \geq 0, j \geq 0, n \geq 1$	share of region i's production of n shipped to region j	observed: Census Bureau
μ_{ij}	$i \geq 1, j \geq 1$	share of milk used in region j shipped from region i	observed: USDA/AMS
θ_i	$i \geq 1$	overall cost share of milk in dairy products made in region i	observed: Census Bureau; USDA/AMS
θ_i^k	$i \geq 1, k \geq 1$	share of comp. k in total milk value in region i	observed: USDA/AMS
θ_i^{nk}	$i \geq 1, n \geq 1, k \geq 1$	share of product n in value of comp. k in region i	observed: USDA/AMS
χ_i^{nk}	$i \geq 1, n \geq 1, k \geq 1$	share of product n in volume of comp. k in region i	observed: USDA/AMS
ρ^0		share of non-feed crop in value of domestic crop production	observed: USDA/NASS
ρ_i	$i \geq 1$	share of region i in value of domestic crop production	observed: USDA/NASS
ρ_i^l	$i \geq 1, l \geq 0$	share of crop l in region i's value of crop production	observed: USDA/NASS
ρ_{ij}^l	$i \geq 1, j \geq 0, l \geq 1$	share of region i's production of crop l shipped to region j	observed: USDA/NASS
φ_i	$i \geq 1$	land share of crop revenue in region i	observed: USDA/NASS
ϕ		feed crop share of milk revenue	observed: Census Bureau; USDA/NASS
π_i^l	$i \geq 1, l \geq 0$	share of crop l in region i's total cropland	observed: USDA/NASS
b_j	$j \geq 0$	exp. share of region j in total dairy consumption	deduced from (43)
b_j^n	$j \geq 0, n \geq 1$	exp. share of product n in region j's dairy consumption	deduced from (42)
b_{ij}^n	$i \geq 0, j \geq 0, n \geq 1$	exp. share of origin i in region j's consumption of product n	deduced from (40) and (41)
ψ_i^n	$i \geq 1$	cost share of milk comp. for product n in region i	deduced from (45)
c_i^{nk}	$i \geq 1, n \geq 1, k \geq 1$	cost share of k (out of milk comp.) for product n in region i	deduced from (44)
ψ		milk share of (domestic) dairy product revenue	deduced from (48)
μ_i	$i \geq 1$	share of region i in value of domestic milk production	deduced from (47)
a_{ij}	$i \geq 1, j \geq 1$	share of region i's milk value shipped to region j	deduced from (46)
ξ_i	$i \geq 0$	share of total feed crop value used in region i	deduced from (51)
ξ_i^l	$i \geq 0, l \geq 1$	share of crop l in value of region i's use of feed crops	deduced from (50)
ξ_{ji}^l	$i \geq 0, j \geq 1, l \geq 1$	share of origin j in value of region i's use of crop l	deduced from (49)
ϕ_i	$i \geq 1$	feed crop share of milk revenue in region i	deduced from (52)
φ_i^l	$i \geq 1, l \geq 1$	land share of crop revenue for crop l in region i	deduced from (53)
δ_i^{nk}	$i \geq 1, n \geq 1, k \geq 1$	comp. price wedge relative to butter-powder product use	deduced from (54)

Note: Share parameters are those appearing in Equations (15)–(39) as well as ancillary share parameters defined in Section 5.

Table 2: Selected price wedge factors

Region	Protein		Other Solids	
	Beverages	Cheese	Beverages	Cheese
Northeast	1.71	2.68	1.71	0.37
Appalachian	1.81	1.15	1.81	1.15
Florida	2.24	1.22	2.24	1.22
Southeast	1.95	1.23	1.95	1.23
Upper Midwest	1.48	2.29	1.48	0.52
Central	1.50	2.16	1.50	0.57
Mideast	1.51	2.55	1.51	0.42
California	1.39	1.10	1.39	1.16
Pacific Northwest	1.47	2.14	1.47	0.57
Southwest	1.65	2.02	1.65	0.62
Arizona	1.57	1.09	1.57	1.09

Source: Authors' calculations using Equation (54). Wedges are relative to component use in Butter-Powder. The Unregulated region has no component price wedges and is not shown.

was found to be slightly more inelastic, with a mean absolute elasticity of 0.44 and a 95% range of 0.25 to 0.63.

Okrent and Alston (2011) also survey the food demand literature to determine the range of elasticity estimates for food categories. The authors focus on the difference between food consumed at home and away from home, and discuss the differences in estimated elasticities from studies that differentiate between these purchases and studies that do not. In research that does not differentiate between food at home and food away from home, they find an average elasticity of demand for dairy products of -0.10, with a range from -0.04 to -0.19, suggesting much more inelastic demand than discussed in Andreyeva, Long, and Brownell (2010). Additionally, Okrent and Alston (2011) report mean demand elasticities of -0.42 for cheese, -0.30 for fluid milk, and -0.32 for ice cream.

Chouinard et al. (2010) estimate demand elasticities for a wider range of dairy products, including beverage milk products differentiated by fat content. The own-price elasticity estimates for reduced fat, skim, and whole milk lie between -0.63 and -0.74, while demand for low-fat milk is found to be much more elastic at -2.05. The low-fat milk elasticity may be an outlier, but the authors argue that due to substitution, disaggregating across beverage milk products should produce demand elasticity estimates larger in absolute value than that for beverage milk as a whole. Since we are interested in targeting the elasticity of demand for beverage milk as a product category, we may want to target a more inelastic value, as reported in the meta-analysis by Andreyeva, Long, and Brownell (2010). Additionally, Chouinard et al. (2010) provide own-price elasticity estimates for cream and other soft products (between -0.41 and -0.91), for cheese products (between -0.40 and -0.73), and for butter (-0.30).

Table 3: Elasticities of demand for dairy products by region

Region	Beverages	Softs	Cheese	Butter-Powder
Northeast	-0.43	-0.39	-0.41	-0.47
Appalachian	-0.41	-0.41	-0.42	-0.46
Florida	-0.36	-0.44	-0.42	-0.48
Southeast	-0.38	-0.41	-0.44	-0.47
Upper Midwest	-0.47	-0.46	-0.29	-0.47
Central	-0.43	-0.40	-0.40	-0.47
Mideast	-0.44	-0.38	-0.41	-0.47
California	-0.41	-0.42	-0.43	-0.44
Pacific Northwest	-0.36	-0.44	-0.42	-0.48
Southwest	-0.40	-0.38	-0.44	-0.48
Arizona	-0.36	-0.45	-0.42	-0.47
Unregulated	-0.42	-0.44	-0.37	-0.47
Rest of the World	–	-1.71	-1.56	-1.62

Source: Authors' calculations using Equation (55) with $\epsilon = 0.2$, $\kappa = 0.5$, $\epsilon_0 = 1.3$, and $\kappa_0 = 1.8$.

These studies provide a target range for elasticities of demand for the four dairy product categories used in our model. Choosing values of $\epsilon = 0.2$ and $\kappa = 0.5$ produces elasticities of demand for each product category across regions that are within the target ranges. The resulting demand elasticities are reported in Table 3.

6.3 Armington elasticity (σ^n)

In combination with the elasticities ϵ and κ, the Armington elasticity σ^n determines the elasticity of demand in region j for dairy product category n originating from region i:

$$\frac{\partial \ln C_{ij}^n}{\partial \ln p_i^n} = (\kappa - \epsilon) b_j^n b_{ij}^n + (\sigma^n - \kappa) b_{ij}^n - \sigma^n \ . \tag{56}$$

Substituting Equation (55) into Equation (56) makes apparent that the regional product demand elasticity is bounded between the overall elasticity of demand for product category n (if $b_{ij}^n \to 1$) and the regional elasticity of substitution σ^n (if $b_{ij}^n \to 0$):

$$\begin{aligned}\frac{\partial \ln C_{ij}^n}{\partial \ln p_i^n} &= \left(\frac{\partial \ln C_j^n}{\partial \ln P_j^n} + \kappa\right) b_{ij}^n + (\sigma^n - \kappa) b_{ij}^n - \sigma^n, \\ &= \left(\frac{\partial \ln C_j^n}{\partial \ln P_j^n} + \sigma^n\right) b_{ij}^n - \sigma^n \ .\end{aligned}$$

Armington-style models often feature two nested levels of aggregation: one between domestic

goods and overall imports, and another one across imports of different origins. This structure entails two elasticities of substitution, the first reflecting substitution between domestic and imported products and the second reflecting substitution across imports from different origins (Hillberry and Hummels, 2013). In our model, the parameter σ^n is the elasticity of substitution across all possible origins of product n, i.e., the various domestic regions and the ROW. Studies that estimate trade elasticities may focus on either the domestic-import elasticity of substitution or the elasticity of substitution across origins of imports, and the appropriate σ^n may lie between these values.

Several widely-cited studies use a time-series approach to estimate trade elasticities and tend to find relatively inelastic values. Reinert and Roland-Holst (1992) estimate domestic-import elasticities of substitution across a wide range of sectors. For dairy product categories, they estimate elasticities of substitution of 0.67 for fluid milk, 1.00 for butter, and 1.99 for cheese. Gallaway, McDaniel, and Rivera (2003) utilize a similar approach but separately estimate short-run and long-run domestic-import substitution elasticities, depending on available data. They find that long-run elasticities of substitution are generally twice as large as short-run elasticities. They estimate elasticities of substitution of 1.00 for cheese in the short run and 1.35 in the long run and find identical estimates of 1.70 for butter in both the short and long run. For condensed milk and ice cream the authors can only estimate short-run elasticities, finding 0.59 for condensed milk and 0.50 for ice cream; they do not find a statistically significant estimate for fluid milk.

The time-series estimation approach used in these studies has been criticized for producing elasticities of substitution that are biased downward due to measurement error and simultaneity issues (Hillberry and Hummels, 2013; Hertel et al., 2007). Additionally, the domestic-import substitution elasticities are different from import-origin substitution elasticities and the σ^n parameters used in our model. Hertel et al. (2007) describe the assumption used in the Global Trade Analysis Project model, which uses a value for the import-origin substitution elasticity that is twice as large as the domestic-import elasticity. Additionally, Hertel et al. (2007) estimate the import-origin elasticity of substitution across a range of sectors using cross-sectional variation in trade costs, including transportation costs and tariffs, across pairs of importers and exporters. For dairy products as an aggregate category, they estimate a mean elasticity of 7.3 with a standard deviation of 0.8.

Broda and Weinstein (2006) utilize a technique developed by Feenstra (1994) to estimate a wide range of import-origin elasticities for products at a highly disaggregated level. For soft products, elasticity estimates range from 1.81 to 7.76 with a median value of 4.03 and an average of 4.31. Substitution elasticities for cheeses and related products range from 1.55 to 12.32 with a median value of 6.34 and an average of 5.56. The estimated substitution elasticity for butter is 4.13, with dry and concentrated milk products elasticities ranging from 1.55 to 10.5 with a median of 3.6 and an average of 4.82. For milk and cream as an aggregate category, the elasticity estimate is 2.7. More generally, Broda and Weinstein find that estimated substitution elasticities are lower for more aggregate categories, and larger for products that could be considered homogeneous commodities rather than differentiated products.

While these studies provide a range of substitution elasticities applicable in an international trade context, far fewer studies consider trade elasticities applicable for regional analysis. In many cases regional trade models utilize trade elasticities from the international trade literature, with acknowledgement that such elasticities could be lower bounds for regional trade elasticities (Giesecke and Madden, 2013). To the extent that inter-regional trade faces fewer barriers than international trade, and transportation costs are often a smaller share of total costs for products traded regionally, the degree of substitution could be higher in a regional context as consumers are more price sensitive (Partridge and Rickman, 2010). However, Bilgic et al. (2002) find this not necessarily the case, with estimates of elasticities of substitution for regional trade that are comparable or even smaller than international trade elasticities. Bilgic et al. argue that regions may produce a wider set of products for domestic consumption than for the export market, therefore resulting in more differentiation across regions and more inelastic substitution across origins.

With respect to dairy products traded within the U.S., it is likely that a wider variety of products are available to domestic consumers whereas commodity products reach the export market. Product variety is more likely to have an impact for the soft products and cheese categories, while butter and dry milk products are commodity products even within the U.S. Additionally, since the four product categories used in our model are highly aggregated, the findings in Broda and Weinstein would suggest more inelastic substitution. Therefore, we use 2.5 as the elasticity of substitution for beverage products, 4.0 as the elasticity for soft products and cheeses, and 7.0 as the elasticity for butter and dry milk products. These elasticities reflect the ranges suggested by Broda and Weinstein (2006), while the higher elasticity for butter and dry milk products is closer to the elasticity suggested by Hertel et al. (2007).

6.4 Elasticities of foreign demand (ϵ^0, κ_0, σ_0^n)

In parallel to U.S. regional demand for dairy products of all origins, we parameterize the demand for U.S.-origin dairy products from the ROW. Since foreign consumers may substitute U.S. products with products originating from other parts of the world, foreign demand can be expected to be much more elastic than domestic demand.

Song and Kaiser (2016) evaluate the effectiveness of export promotion programs for dairy products and in doing so estimate import demand for U.S. dairy products across 10 importing regions. They estimate a demand elasticity for U.S. dairy products of -1.058, suggesting foreign demand is near unit elastic. However, this value is more inelastic than estimated foreign demand for other agricultural products. For instance, Reimer, Zheng, and Gehlhar (2012) estimate long-run elasticities of demand for U.S. crops of -1.64 for corn, -1.45 for soybeans, and -1.25 for wheat using data from 2001 through 2011. The U.S. share of the world dairy market is smaller than the U.S. share of the world corn or soybean markets, but dairy products are more heterogeneous than grains and oilseeds. Therefore, Reimer, Zheng, and Gehlhar may provide a reasonable range of elasticities to target, though the choices of the parameters ϵ_0 and κ_0 deserve further attention

through sensitivity analysis.

With this in mind, we choose a more elastic value than that suggested by Song and Kaiser (2016) and set $\epsilon_0 = 1.3$. Choosing $\kappa_0 = 1.8$ implies elasticities of foreign demand for U.S. dairy products ranging from -1.71 for soft products to -1.56 for cheese, values that are in line with those suggested by Reimer, Zheng, and Gehlhar (2012). These elasticities are reported in the last row of Table 3.

As discussed in the previous section, dairy products reaching the export market are likely to be less differentiated than those traded inter-regionally. Therefore, the values chosen for σ_0^n should be larger than the corresponding σ^n values. Following the result in Hertel et al. (2007), we choose an origin substitution elasticity of 8 for soft products and cheeses and 10 for butter and dry milk powder products.

6.5 Elasticity of substitution across milk components in dairy production (ς^n)

The three milk components, namely butterfat, protein, and other solids, are used by dairy product manufacturers in various combinations. Depending on what product is being produced the combination may be close to fixed proportions. For example, most butter produced in the U.S. is 80% butterfat, but some higher-fat butter may also be produced.

It is common for researchers to assume fixed proportions when specifying production of dairy products. Chavas and Kim (2005) study hedonic pricing of American cheese, butter, and nonfat dry milk and assume that milk components are used in fixed proportions. However, since the authors study three specific products, fixed proportions may be a reasonable assumption. Coggins and Hammond (1994) specify a cheese yield formula based on the butterfat and protein content in milk but allow for a flexible functional form using a Box-Cox transformation. They test both a linear or perfect substitutes specification and a Cobb-Douglas specification, rejecting both functional forms. Coggins and Hammond do not specifically test a fixed-proportions specification, but these results suggest that substitution between milk components in cheese production is relatively inelastic. Gillmeister, Yonkers, and Dunn (1996) argue that milk component marginal product curves are inelastic, and that even if the production technology is not fixed-proportions, it is likely that the elasticities of substitution are small.

Given the variety of dairy product categories considered in our model, it is important to allow for different component substitution elasticities. For cheese and butter-powder products we set $\varsigma^n = 0.2$, allowing for a limited degree of substitution between milk components. While component substitutability in cheese production is limited due to the required protein and fat content in products, the butter-powder category includes products with widely different levels of required milk components, suggesting a high level of substitutability across components. Nonetheless, butter and powder products are often produced together in a given plant, since farm milk, which is the main input into the plant, is split into butterfat for use in butter and nonfat solids to be dried into nonfat dry milk. As a result, in practice substitution would be limited as plants would not specialize in either butter or powder products depending on relative prices, but rather produce a

mix of both.

Beverage products range in fat content from skim milk to whole milk, with even higher fat beverage products commonly available. While the nonfat solids in beverage products are often at a similar level across various fat contents, the mix of products suggests that some substitution between components is possible. Hence, we set $\varsigma^n = 0.3$ for beverage products.

The soft products category includes the broadest set of dairy products, such as ice cream, yogurt, cream cheese, and infant formula, and therefore covers a broad set of product specifications. Manufacturers of specific products in this category may require milk components in fixed proportions due to plant restrictions, but across the product category milk components may be substituted more readily since different products are produced. Therefore, we set $\varsigma^n = 0.8$.

6.6 Elasticities of substitution across feed crops (ρ, λ)

As explained in Section 4.1, the value of the elasticity of substitution across feed crop origins, λ, is irrelevant to the equilibrium concept.

The elasticity of substitution between feed crops in dairy cattle feed, ρ, determines the regional output-constant elasticity of demand for feed crops:

$$\frac{\partial \ln F_i^l}{\partial \ln W_i^l} = -\rho \left(1 - \xi_i^l\right). \tag{57}$$

For crops representing a large share of feed expenditure ($\xi_i^l \to 1$), the elasticity of demand will be close to zero, whereas for feed crops with a small share ($\xi_i^l \to 0$) that elasticity will be close to $-\rho$.

Gouel and Laborde (2021) note that the literature on estimation of feed demand is limited, and studies that focus on feed demand by the dairy industry specifically are even less common. Rude and Meilke (2000) estimate feed demand in the European Union and find own-price demand elasticities for coarse grains and protein feeds of -0.70 and -0.32. Beckman, Keeney, and Tyner (2011) estimate U.S. feed demands in the context of substitution with biofuel by-products, estimating feed demand from the beef industry and finding elasticities of demand for energy feeds of -0.12 and for protein feeds of -0.05. Buccola and Iizuka (1997) use a hedonic cost modeling approach to evaluate the marginal cost of milk component production for U.S. dairy farms, estimating an elasticity of substitution of 0.25 between forage and feed concentrates, with corresponding own-price demand elasticities of -0.11 for feed concentrates and -0.13 for forages. In a study of the Spanish dairy industry, Casasnovas-Oliva and Aldanondo-Ochoa (2014) estimate a short-run feed demand elasticity of -0.23 and a long-run elasticity of -0.51.

These studies may provide some guidance on the value of ρ, but the substitutability between feed crops is also an important determinant of the implied elasticity of milk supply (along with the heterogeneity parameter θ). Therefore, ρ should ideally be chosen to target both the elasticity of feed demand and the elasticity of milk supply, which is discussed in further detail in the next section. Using $\rho = 0.2$ results in a range of feed demand elasticities that are in line with

Table 4: Regional feed crop demand elasticities

Region	Grains	Oilseeds	Hay	Silage
Northeast	-0.16	-0.18	-0.16	-0.10
Appalachian	-0.17	-0.18	-0.16	-0.09
Florida	-0.15	-0.17	-0.15	-0.13
Southeast	-0.16	-0.18	-0.15	-0.11
Upper Midwest	-0.15	-0.17	-0.15	-0.12
Central	-0.14	-0.17	-0.14	-0.16
Mideast	-0.16	-0.17	-0.15	-0.12
California	-0.15	-0.17	-0.14	-0.14
Pacific Northwest	-0.15	-0.17	-0.15	-0.13
Southwest	-0.14	-0.16	-0.13	-0.16
Arizona	-0.14	-0.17	-0.14	-0.16
Unregulated	-0.15	-0.17	-0.14	-0.14

Source: Authors' calculations using Equation (57) with $\rho = 0.2$.

those suggested by Beckman, Keeney, and Tyner (2011) yet have lower magnitude than those in Casasnovas-Oliva and Aldanondo-Ochoa (2014). These elasticities are shown in Table 4. Note that Gouel and Laborde (2021) set $\rho = 0.9$, leading to more elastic demand for feed crops. However, they consider demand for feed from all livestock sectors, so a greater degree of substitutability between feed crops is to be expected in that context. Given that Buccola and Iizuka (1997) focus on the dairy industry, their estimate of 0.25 for the elasticity of substitution between forage and feed concentrates is a better reference value for our model.

6.7 Land heterogeneity parameter (θ)

The shape parameter of the Fréchet crop yield distribution, θ, determines crop acreage elasticities:

$$\frac{\partial \ln \pi_i^l}{\partial \ln w_i^l} = \frac{\theta(1-\pi_i^l)}{\varphi_i^l} \,, \tag{58}$$

and, given Equation (14), it also determines the crop output elasticities:

$$\frac{\partial \ln Y_i^l}{\partial \ln w_i^l} = \left(1 - \frac{1}{\theta}\right) \frac{\partial \ln \pi_i^l}{\partial \ln w_i^l} = \frac{(\theta-1)(1-\pi_i^l)}{\varphi_i^l} \,. \tag{59}$$

Equation (58) shows that the crop acreage elasticity is decreasing in the regional acreage, which is intuitive as crops occupying a large share of available land have less room for expansion. The φ_i^l parameter is the ratio of land rent to crop price and is bounded between zero and one, with the acreage elasticity decreasing with a higher land share of the crop dollar. This is also intuitive as land is supplied inelastically in the aggregate whereas the labor input is assumed to be supplied

Table 5: Regional crop acreage and output elasticities

Region	Grains		Oilseeds		Hay		Silage		Other Crops	
Northeast	[5.86]	0.28	[5.45]	0.26	[4.48]	0.21	[4.60]	0.22	[38.32]	1.82
Appalachian	[4.13]	0.20	[3.15]	0.15	[2.40]	0.11	[2.94]	0.14	[17.89]	0.85
Florida	[5.56]	0.26	[4.66]	0.22	[2.84]	0.14	[3.38]	0.16	[7.12]	0.34
Southeast	[5.84]	0.28	[3.12]	0.15	[1.97]	0.09	[3.18]	0.15	[6.44]	0.31
Upper Midwest	[2.41]	0.11	[2.44]	0.12	[1.84]	0.09	[2.67]	0.13	[2.81]	0.13
Central	[1.90]	0.09	[2.46]	0.12	[1.55]	0.07	[1.29]	0.06	[0.94]	0.04
Mideast	[2.47]	0.12	[1.87]	0.09	[2.23]	0.11	[2.41]	0.11	[7.97]	0.38
California	[3.05]	0.15	[6.19]	0.29	[2.25]	0.11	[1.98]	0.09	[5.40]	0.26
Pacific Northwest	[1.40]	0.07	[17.12]	0.82	[3.23]	0.15	[3.18]	0.15	[3.80]	0.18
Southwest	[5.59]	0.27	[8.43]	0.40	[5.51]	0.26	[7.42]	0.35	[7.59]	0.36
Arizona	[3.57]	0.17	[4.06]	0.19	[3.99]	0.19	[2.43]	0.12	[11.85]	0.56
Unregulated	[2.81]	0.13	[31.95]	1.52	[4.17]	0.20	[8.93]	0.43	[2.92]	0.14

Source: Authors' calculations using Equations (58) and (59) with $\theta = 1.05$. Acreage elasticities are shown in square brackets. Output elasticities are shown without brackets.

perfectly elastically.

In addition, the structure of the model imposes that the ratio of the crop output to the crop acreage elasticities be equal to $\frac{\theta-1}{\theta}$. Given that most applications consider value of θ close to one, the crop output elasticities are, by construction, much smaller than their acreage counterpart.

Many studies focus on U.S. acreage elasticities for corn and soybeans. In the context of crop rotation practices, Hendricks, Smith, and Sumner (2014) estimate long-run acreage elasticities for corn and soybeans of 0.29 and 0.26, respectively. Miao, Khanna, and Huang (2016) estimate U.S. corn and soybean acreage under alternative climate conditions and find acreage elasticities of 0.448 for corn and 0.625 for soybeans. These studies provide a range to target for the elasticities of grains and oilseeds.

We choose $\theta = 1.05$ as our baseline value. Gouel and Laborde (2021) set $\theta = 1.1$ in their analysis based on a spatial unit of analysis representing a one-degree of latitude/longitude grid cell. There are hundred such cells across the continental U.S., thus it is reasonable to assume higher heterogeneity in yields in our model, which treats the entire country as one single cell.

The implied crop supply elasticities are shown in Table 5. Choosing $\theta = 1.05$ as a baseline value produces crop output supply elasticities for grains and oilseeds that are slightly lower than the values for acreage elasticities in Hendricks, Smith, and Sumner (2014), though these elasticities vary across regions to a greater extent due to the differences in acreage shares. For example, oilseed crops occupy a small share of acres in the Pacific Northwest, leading to a calculated oilseed supply elasticity of 1.19. As expected, acreage elasticities are much larger in magnitude than the output supply elasticities, and they exceed the values in both Hendricks, Smith, and Sumner (2014) and Miao, Khanna, and Huang (2016). This clearly is a limitation of the Fréchet specification: lower

values of θ reduce the acreage elasticity (though it is still be bounded from below by $\frac{1-\pi_i^l}{\varphi_i^l}$, a ratio that often already exceeds the target values), but at the cost of further lowering the implied output elasticities. In addition, the lowering of the supply elasticities when reducing the value of θ is much more dramatic than that of the acreage elasticities. For example, moving from $\theta = 1.05$ to $\theta = 1.01$ would multiply the acreage elasticities by a factor of about 0.96 and the output elasticities by a factor of 0.20. The reason why the output elasticity may be much smaller than the acreage elasticity in this model is due to the assumption of heterogenous yields, which imply that any increase in acreage results in a decrease in average yield. Reducing the responsiveness of acreage to price implies assuming more heterogenous yields, which further reduces the output responsiveness to price.

6.8 Milk supply elasticity

Our equilibrium model does not yield a closed-form expression for regional milk supply elasticities. Nonetheless, one may compute numerical values by using the supply-side of the model consisting of Equations (29)–(35) and (37)–(38) and treating the relative change in regional milk prices, $\hat{m}_i$, as exogenous. We thus assume simultaneous and equiproportional changes across regions and solve for the regional changes in farm milk supply, $\hat{M}_i$. The implied regional milk supply elasticity is then given by:

$$\frac{\%\Delta M_i}{\%\Delta m_i} = \frac{\frac{\Delta M_i}{M_i}}{\frac{\Delta m_i}{m_i}} = \frac{\hat{M}_i - 1}{\hat{m}_i - 1} \,.$$

The shape parameters directly affecting regional milk supply are the land heterogeneity parameter θ and the substitution elasticity across feed crops ρ.

Milk supply estimation has a long history, albeit with less focus in the recent literature. Since we are interested in simulating the long-term response to removal of FMMO pricing rules, we focus on long-run elasticities of milk supply. Chavas and Klemme (1986) develop a dynamic model of milk production based on herd composition, estimating a range of own-price elasticities for milk production over several time horizons. Their estimates of the long-run milk supply elasticity range from 2.46 at a 10-year horizon to 6.69 over a 30-year horizon. As an extension to this study, Chavas, Kraus, and Jesse (1990) considers regional milk production and herd sizes and estimates regional milk supply elasticities. While the regions used by Chavas, Kraus, and Jesse do not directly correspond to the marketing order regions used in this study, and milk production dynamics have changed over time in some regions, the regional elasticity estimates provide some insight into differences in supply elasticities across regions. Their overall estimate of the U.S. milk supply elasticity ranges from 1.53 at 10 years to 4.79 at 29 years. Regional milk supply elasticities at the 10-year horizon range from 0.35 in the South Atlantic to 3.65 in the Pacific region. Bozic, Kanter, and Gould (2012) update the Chavas and Klemme study with data from 2006–2010 and bootstrapped confidence intervals, estimating an aggregate U.S. milk supply elasticity at a 10-year

Table 6: Regional milk supply elasticities

Region	Elasticity
Northeast	1.46
Appalachian	0.80
Florida	3.06
Southeast	1.51
Upper Midwest	1.91
Central	3.73
Mideast	1.84
California	3.04
Pacific Northwest	2.65
Southwest	12.60
Arizona	4.67
Unregulated	5.87
Total	3.63

Source: Authors' numerical simulation of an equiproportional increase in regional milk prices.

horizon of 0.89 with a range from 0.68 to 1.14 and at a 25-year horizon of 2.33 with a range of 1.73 to 3.08.

Choosing values for ρ and θ that jointly meet the target elasticity ranges for the elasticity of feed demand, elasticity of crop supply, and elasticity of milk supply presents a challenge. Setting $\rho = 0.2$ and $\theta = 1.05$ as we have done here produces elasticities of milk supply that appear quite reasonable on average, albeit with significant regional variation. The aggregate milk supply elasticity is 3.63. The implied milk supply elasticities are shown in Table 6.

Given that land is the only productive factor supplied inelastically in our model, regional variation in implied milk supply elasticities can be explained by differences in the land intensity of milk production, itself a function of the feed crop share of the milk dollar, ϕ_i, the silage share of dairy feed expenditure, ξ_i^{silage}, the land share of the crop dollar for silage, $\varphi_i^{\text{silage}}$ (silage being the only feed crop with an endogenous price in the model), and the acreage share of silage, π_i^{silage}. For instance, the Southwest region, which has the largest milk supply elasticity, has the lowest feed crop share of the milk dollar, the lowest silage share of dairy feed expenditure, and the second lowest land share of the silage crop dollar. In contrast, the Appalachian region, which has the lowest milk supply elasticity, has the largest feed crop share of the milk dollar and the largest silage share of dairy feed expenditure. The Northeast, which has the second-lowest milk supply elasticity, has an unusually large acreage share for silage, about 22%, in addition to having the second-highest feed crop share of the milk dollar and the second-highest silage share of feed expenditure. Interestingly, the Southwest region is one of the fastest growing milk-producing regions, with multiple dairy product manufacturing plants added or planned in Texas. It is reassuring that our calculations show the largest milk supply elasticity for that region.

6.9 Demand for milk components by end use

The canonical model of price discrimination across end uses of milk is due to Kessel (1967). For a single marketing order and two representative end uses, beverage milk and manufacturing milk, Kessel (1967) argues that a profit-maximizing marketing order will determine the blend price by equating the marginal revenue from milk in the inelastic market (beverage) with that from milk in the elastic market (manufacturing). According to this model, removal of the FMMO would result in less milk produced, more milk used for beverage, and less milk used for manufacturing.

Although our calibrating information does not directly force this particular pattern of differentiated derived demand elasticities across end uses of farm milk, we can check that the implied elasticities in our structural model are congruent with the stylized fact that derived demand for beverage milk at the regional level should be more inelastic than derived demand for manufacturing products, particularly those that can be more easily shipped like cheese and butter-powder.

One complicating factor, besides the fact that we must consider multiple FMMOs, is that the derived demand by end use pertains to components rather than farm milk. Thus, we report the regional elasticity of derived demand for milk components in product n, Z_i^n, with respect to its own milk component price index, V_i^n, holding constant the component price indices for other dairy products in region i and those for all dairy products in other regions. To compute these elasticities, we use the demand side of our model as represented by Equations (15)–(21), (24), and (36), treating the changes in component price indices $\hat{V}_i^n$ as exogenous. We increase the price of milk components for one dairy product in one region at a time, holding all other milk component prices constant, and compute the implied elasticity as:

$$\frac{\%\Delta Z_i^n}{\%\Delta V_i^n} = \frac{\hat{Q}_i^n - 1}{\hat{V}_i^n - 1} \,.$$

The resulting elasticities are reported in Table 7 and confirm that milk component demand for use in beverage products is generally much less elastic than that for use in other products, particularly butter-powder. This result arises because of the larger substitution elasticity across origins for butter-powder products and the fact that all regions ship these products to the international market, where prices are fixed. The one exception is the Appalachian region, where the inelastic derived demand for milk components in butter-powder products can be traced to a particularly low cost share of milk components relative to other inputs.

7 Results and discussion

We now explore a counterfactual scenario whereby the price differentials in each FMMO region are simultaneously removed. From a modeling standpoint, we set the value of the price differential relative to butter-powder products equal to one, so that component prices are equated across classes. That is, the relative change in the price wedge for component k in product n in region i is

Table 7: Regional milk component demand elasticities

Region	Beverages	Softs	Cheese	Butter-Powder
Northeast	-0.14	-0.24	-0.32	-0.70
Appalachian	-0.36	-0.56	-0.36	-0.25
Florida	-0.13	-0.63	-0.07	-1.06
Southeast	-0.92	-1.26	-1.20	-3.63
Upper Midwest	-0.31	-0.38	-0.63	-0.83
Central	-0.17	-0.27	-0.63	-1.52
Mideast	-0.31	-0.17	-0.74	-4.59
California	-0.11	-0.23	-0.87	-1.55
Pacific Northwest	-0.09	-0.36	-1.00	-3.41
Southwest	-0.17	-0.30	-2.11	-2.03
Arizona	-0.17	-1.49	-1.54	-1.26
Unregulated	-0.12	-0.38	-0.98	-2.42

Source: Authors' numerical simulations of increases in regional milk component prices.

set to $\hat{\delta}_i^{nk} = 1/\delta_i^{nk}$.

Anticipated effects are decreases in the milk price and regional milk production (and attendant silage production), changes in the pattern of milk shipments between regions, and an overall decrease in the value of dairy product manufacturing and exports. As expected, domestic consumers benefit from the removal of FMMO pricing rules initially designed to exploit inelastic demand for beverage products, although the gain is modest in relation to the value of the dairy product market. Foreign consumers lose as they do not benefit from the lower prices of U.S. beverage products and are hurt by the higher prices of the majority of other U.S. dairy products.

7.1 Changes in farm milk prices, production, shipments, and use

Table 8 summarizes regional changes in the farm milk market. Removing the FMMO pricing rules reduces the price received by milk producers, which decreases the quantity of milk produced. Depending on the region, the milk price decreases by either 0.4% or 0.2%. Recall that relative changes in regional prices are linked through milk shipments. In the baseline, milk shipments are such that each region is linked to every other, directly or indirectly, implying that the farm milk market is fully integrated spatially across the U.S. (Due to transportation costs, this should not be construed as implying that the milk price is equated across regions, however.) In the counterfactual, this overall spatial connectivity breaks down as milk shipments from the Unregulated region towards the Southwest are eliminated, giving rise to two separate milk markets, one comprising the Western portion of the U.S. (California, Pacific Northwest, Unregulated, and Arizona) where the milk price decreases by 0.2%, and the other comprising the other regions where the milk price decreases by 0.4%. Although shipments from the Unregulated region to the Southwest disappear and those towards California, its other destination region, are reduced substantially, it does not

Table 8: Change in farm milk indicators

Region	Milk production value		Milk price	Milk produced	Milk used	Share of production value shipped out		Share of use value shipped in	
	(%)	(%)	(%)	(%)	(%)	(% pt.)	(%)	(% pt.)	(%)
Northeast	-0.93	[15.23]	-0.37	-0.56	-1.49	0.86	[8.17]	–	[0.00]
Appalachian	-0.67	[2.34]	-0.37	-0.30	-0.94	23.69	[23.44]	18.18	[40.40]
Florida	-1.55	[1.35]	-0.37	-1.18	-3.61	–	[0.00]	-2.39	[5.06]
Southeast	-0.94	[1.05]	-0.37	-0.57	-5.02	-3.36	[6.87]	-3.03	[64.21]
Upper Midwest	-1.09	[18.65]	-0.37	-0.72	0.64	–	[0.00]	1.29	[4.65]
Central	-1.78	[9.60]	-0.37	-1.42	-0.90	-4.53	[22.01]	-4.33	[17.71]
Mideast	-1.06	[10.08]	-0.37	-0.69	-4.72	5.38	[12.05]	1.88	[12.31]
California	-0.73	[17.61]	-0.18	-0.56	-0.05	-0.26	[0.36]	0.25	[1.48]
Pacific Northwest	-0.67	[4.35]	-0.18	-0.49	-3.85	3.38	[0.14]	–	[0.00]
Southwest	-6.84	[9.63]	-0.37	-6.49	-4.81	-3.34	[16.74]	-2.12	[2.12]
Arizona	-1.04	[2.23]	-0.18	-0.86	-2.80	–	[0.00]	-1.94	[2.73]
Unregulated	-1.31	[7.88]	-0.18	-1.13	2.51	-3.48	[5.47]	–	[0.00]
Total	-1.61	[100]	–	–	–	0.22	[7.3]	0.22	[7.3]

Notes: Total effects are only reported for indicators of value. For milk production value, regional shares of total value are indicated in square brackets. For changes in shipment shares, baseline shares are indicated in square brackets. The Unregulated region has a zero share of milk use value shipped in in the baseline and in the counterfactual. The overall value share of production shipped out is equal to the overall value share of use shipped in.

fully move to autarky. The other notable change in milk shipments is the large increase from the Appalachian region to the Southeast, its only destination market at baseline, although this increase is partially offset by an increase in shipments from the Mideast, which ships about 12% of its milk to Appalachia in the baseline.

Importantly, overall farm milk shipments increase by 0.22 percentage points in value, a very modest increase relative to a baseline share of 7.3%. Therefore, surprisingly perhaps, it is not possible to impute the observed inter-regional shipments of farm milk at baseline to the component price distortions created by FMMO pricing rules. Rather, such shipments reflect market fundamentals related to comparative advantage in production and usage of milk. That is, regions with a comparative advantage in production, due for instance to forage availability, will tend to be net exporters of farm milk, while regions with a comparative advantage in milk transformation, either due to technological advantage or consumer preferences for geographical origin, will tend to be net importers.

Regional milk production decreases in all regions, with reductions ranging from 0.3% in the Appalachian region to 6.5% in the Southwest, by far the most affected region in terms of milk output. This is expected as the Southwest has the largest milk supply elasticity (see Table 6).

Overall, the value of milk production across the U.S. decreases by 1.6%.[10] This simulated decline in milk production value is consistent with the results of Chavas, Cox, and Jesse (1998), who consider scenarios where the FMMO pricing rules and price support programs are removed. Chavas, Cox, and Jesse find that U.S. milk production would fall by 1.8% when both programs are removed, with milk production falling across all regions they consider except California. Reductions in regional milk output translate into reductions in the regional land area dedicated to silage, to the benefit of other crops. These reductions, which are not reported here, are modest, typically less than 1%, except in the Southwest where the silage area decreases by 5%.

Milk utilization falls in all regions except the Upper Midwest and the Unregulated region, while utilization in California falls by a negligible amount. The regions experiencing the largest declines in milk use are the Southeast, the Southwest, the Mideast, and the Pacific Northwest, with decreases in the order of 5%.

7.2 Changes in Component Prices and Costs

With classified pricing, components tend to be priced higher for use in products other than butter and powder (see Table 2). Upon removing price differentials, we would expect the component price to converge to a value that lies between that in butter-powder products and those in other products. Since component prices are measured relative to butter-powder products, we expect the component prices to increase.

The first set of results in Table 9 shows the percentage change in component prices across regions. All three component prices increase in most regions, consistent with new equilibrium prices that lie between the highest- and lowest-cost uses. The component prices most affected by the removal of FMMO pricing are those for protein and other solids, which is expected as these are the components for which initial price wedges are the most sizable (see Table 2). The price of other solids actually decreases in the Upper Midwest, the Central region, and the Pacific Northwest. These regions are among those where wedges for cheese products happened to be lower than 1 at baseline, putting downward pressure on the equilibrium price once the wedges are removed.

In contrast, the protein price increases in every region, which is expected as the protein price wedge is larger than one for beverages, soft products and cheese in all regions except the Unregulated region. As expected, the Unregulated region, in which no component price differentials are in place at baseline, experiences the smallest changes in milk component prices.

Dairy products are manufactured from milk components in variable proportions, thus Table 9 also displays the change in the component cost index, V_i^n, which combines the individual changes in the prices of butterfat, protein, and other solids to reflect the overall change in the cost of milk components when used in each product category. The first column shows that the cost of components used in beverage products falls by between 8.7 and 18.7% across FMMO regions. The

[10]Strictly speaking, our model cannot be used to decipher the change in the overall quantity of milk produced because regional milk shares are defined by value, not by volume.

Table 9: Change in component prices and cost indices

Region	Component price			Component cost index			
	Butterfat (%)	Protein (%)	Other Solids (%)	Beverage (%)	Softs (%)	Cheese (%)	Butter-Powder (%)
Northeast	4.32	44.55	11.08	-17.88	4.99	1.49	11.47
Appalachian	5.45	47.32	47.33	-11.10	10.98	12.82	18.21
Florida	6.56	93.51	93.51	-8.07	15.26	27.40	22.38
Southeast	-2.20	72.39	72.39	-8.73	7.52	17.34	13.01
Upper Midwest	2.10	86.44	-29.53	-18.68	-0.64	-0.09	3.13
Central	2.21	50.48	-3.53	-15.17	1.77	1.33	6.28
Mideast	2.02	48.40	4.07	-13.34	2.48	-0.11	7.74
California	-0.22	11.83	13.85	-11.50	-0.57	-0.35	4.43
Pacific Northwest	1.28	50.52	-5.17	-14.66	0.56	0.31	5.53
Southwest	2.47	52.43	0.06	-18.34	2.36	3.19	9.48
Arizona	1.16	14.72	14.72	-17.39	2.93	2.18	11.47
Unregulated	-1.28	1.64	1.58	0.27	-0.18	-0.42	0.17

Notes: The component price v_i^k is defined with respect to use in Butter-Powder products. The component cost index is defined by Equation (23) and reflects the cost of the milk component mix used in each product category.

beverage product component cost increases by about 0.3% in the Unregulated region, reflecting a general increase in derived demand for components in beverage products in that region.[11]

Component costs generally increase across the other dairy product categories, with cost increases generally lower for soft products and cheese and higher for butter and powder products. The largest component cost increases for non-beverage products are found in Florida, Appalachia, and the Southeast. These are also the FMMO regions experiencing the most moderate decreases in the beverage component cost.

7.3 Changes in dairy product value and exports

The change in regional dairy product prices follows the change in the regional component cost index for each category shown in Table 9, though the change in component costs is not fully passed through to the product prices due to the complementary processing input. Therefore, the price of beverage products generally falls while softs, cheese, and butter-powder products generally become more expensive. Table 10 shows changes in the quantities of each dairy product produced regionally, in total production value, and in the value of dairy products exported internationally. Following the decline in component costs for beverage products, most regions see an increase in beverage product output. Florida, the Pacific Northwest, and the Unregulated region are the

[11]This increase in demand is consistent with the increase in equilibrium milk use in that region, see Table 8.

Table 10: Change in dairy product quantity, value and export value

Region	Production quantity				Total production value		International export value	
	Beverage (%)	Softs (%)	Cheese (%)	Butter-Powder (%)	(%)	(%)	(%)	(%)
Northeast	1.20	-0.76	-0.27	-2.89	-0.49	[20.27]	-0.30	[9.22]
Appalachian	1.01	-5.14	-3.95	4.31	0.12	[4.03]	-3.29	[2.28]
Florida	-0.61	-8.21	-1.22	-10.28	-2.23	[2.33]	-6.12	[5.49]
Southeast	5.00	-8.07	-17.86	-30.77	-4.25	[1.23]	-18.23	[1.13]
Upper Midwest	3.77	1.06	0.47	6.37	1.29	[15.74]	4.83	[12.48]
Central	0.29	0.32	-0.54	-0.71	-0.24	[11.30]	1.44	[9.68]
Mideast	1.88	0.45	0.51	-23.35	-0.32	[13.04]	0.29	[5.26]
California	0.25	0.61	0.86	-1.53	0.18	[13.90]	1.45	[30.86]
Pacific Northwest	-0.20	0.11	-0.04	-10.44	-1.23	[4.07]	-7.07	[7.05]
Southwest	1.31	-0.13	-6.26	-9.83	-1.77	[6.70]	-8.91	[8.24]
Arizona	1.71	-3.61	-2.94	-5.19	-1.76	[1.64]	-4.95	[1.39]
Unregulated	-2.07	0.69	0.92	7.37	1.06	[5.75]	6.95	[6.92]
Total	–	–	–	–	-0.18	[100]	-0.26	[100]

Notes: Because dairy products are differentiated by origin region, total effects can only be reported for indicators of value. Baseline regional shares of total dairy production and export values are indicated in square brackets.

only regions to experience a decline in beverage production, but with larger increases in output elsewhere, more beverage products are being shipped to those regions. For example, the large increase in beverage production in the Southeast (+5%) coincides with more shipments of beverage products to Florida (+7.2%), the Pacific Northwest (+7.3%), and the Unregulated region (+8.5%).[12]

In most regions, production of butter and powder products declines, consistent with the decline in overall milk production seen across all regions, the overall shift towards beverage product manufacturing, and the increase in the cost of components for butter-powder use documented in Table 9. Production of soft products and cheese declines in many but not all regions, with the most pronounced reductions happening in the Southeast and Southwest for cheese and the Southeast and Florida for soft products.

In order to aggregate across dairy product categories and across regions, we also report the change in the value of dairy products. The change in production value ranges from a decline of 4.3% in the Southeast to an increase of 1.3% in the Upper Midwest, the only region to experience an increase in output of all dairy products categories. Overall, the value of U.S. dairy products falls by about 0.2%, meaning that the increases in production value in some regions barely offset the declines in others.

Table 10 also shows that the value of dairy product exports declines by about 0.3% for the

[12]Changes in dairy product inter-regional shipments are not reported in Table 10.

Table 11: Changes in consumer surplus, land rents, and social welfare

Region	Consumer surplus		Land rents		Social welfare	
	(%)	($ mn)	(%)	($ mn)	(%)	($ mn)
Northeast	0.17	[80]	-2.16	[-21]	0.028	[59]
Appalachian	0.17	[21]	-0.15	[-3]	0.009	[18]
Florida	0.22	[16]	-0.65	[-2]	0.007	[14]
Southeast	0.42	[33]	-0.06	[-1]	0.015	[32]
Upper Midwest	0.12	[27]	-0.37	[-25]	0.001	[2]
Central	0.20	[55]	-0.06	[-13]	0.020	[42]
Mideast	0.18	[33]	-0.27	[-14]	0.009	[19]
California	0.02	[6]	-0.37	[-12]	-0.003	[-6]
Pacific Northwest	0.30	[23]	-0.13	[-3]	0.010	[20]
Southwest	0.33	[50]	-1.22	[-13]	0.018	[37]
Arizona	0.63	[20]	-0.52	[-1]	0.009	[18]
Unregulated	0.06	[5]	-0.29	[-5]	0.000	[0]
United States	0.18	[369]	-0.23	[-113]	0.122	[256]
Rest of the World	-0.87	[-46]	–	–	-0.022	[-46]
Total	0.15	[322]	-0.05	[-113]	0.100	[210]

Notes: Percentage changes in regional consumer surplus (including for the U.S. as a whole and the ROW) are relative to the regional value of dairy market consumption, $P_i C_i$. Percentage changes in regional land rents (including for the U.S. as a whole) are relative to the regional land rent, $\sum_{l \geq 0} r_i^l Y_i^l$. Percentage changes in social welfare as well as percentage changes for Total are all relative to the total value of the dairy market, PC. Absolute changes in million USD are indicated in square brackets.

U.S. as a whole. Exports fall by a large amount for some regions, up to 18% in the Southeast, which however represents the smallest share of exports at baseline across all regions (1.1%). These declines are partially offset by increases in regions responsible for a larger share of exports. For instance, exports from the Upper Midwest increase by 4.8% and exports from California increase by 1.5%. Both regions are major exporters of dairy products in the baseline.

7.4 Welfare effects

Table 11 indicates that removing the FMMO pricing rules would increase total social welfare by $210 million, a mere 0.1% improvement relative to the total value of the dairy market, PC. Domestic consumer surplus would increase by $369 million largely due to the overall decrease in the price of beverage milk,[13] while foreign consumer surplus would fall by $46 million due the overall increase in the prices of other dairy products. Domestic land rents would decrease by $113 million due to the reduction in farm milk prices.

[13]The price of beverage milk decreases in all domestic regions, except the Unregulated region.

Domestic social welfare would increase by the difference between consumer surplus and land rent changes, namely $256 million, a figure similar to FMMO welfare impacts calculated in previous research. Specifically, Ippolito and Masson (1978) calculate the total social cost of Federal Order regulations as a sum of impacts that affect producers, costs due to transportation adjustment, and administrative costs, finding a total of $60 million, or about $285 million in 2022 dollars. However, it is important to note that Ippolito and Masson's calculation includes impacts to dairy producers while our calculation is driven by changes in consumer surplus and land rents. Chouinard et al. (2010) summarize several studies that estimate impacts of FMMO regulations on consumer surplus ranging between $225 million and $1.6 billion in 2022 dollars. Our simulation results lie towards the lower end of that range, but this suggests that the calculated $369 million increase in domestic consumer surplus is plausible.

As in previous results, the impacts on individual regions are important to consider, with some regions faring better than others in the counterfactual. The Northeast, Central, and Southwest regions see the largest gains in welfare, with increases of about $59 million, $42 million, and $37 million, respectively. Only one region, California, experiences a loss in social welfare due to decreases in land rents exceeding the increase in consumer surplus, with a $6 million loss in net welfare. The Unregulated region breaks even from a social welfare perspective. The simulated increase in consumer surplus in these two regions is relatively small. In California, this is due to a combination of a relatively small decrease in the price of local beverage products (1.2% as opposed to 2–3% for beverages manufactured in other regions[14]) combined with a particularly high baseline expenditure share on butter-powder products (18.9%), the price of which rises by 1.9%. As for the Unregulated region, it experiences very small changes in local dairy product prices, leading to moderate overall consumer effects as locally manufactured products also dominate consumption in that region.

Land rents fall across all domestic regions along with farm milk and silage prices, with losses ranging from $1 million in the Southeast and Arizona to $25 million in the Upper Midwest. Relative to baseline land rents, the largest effects are found in the Northeast with a loss in excess of 2%, and in the Southwest with a 1.2% loss. The reasons for these relatively large effects differ between the two regions: the Southwest experiences the largest decrease in the price of dairy silage (9%), while the effect in the Northeast is due to an unusually large share of cropland dedicated to dairy silage (22.4%, as opposed to less than 10%, and often less than 5%, in other regions).

8 Conclusion

In this paper, we develop and calibrate an equilibrium model of the U.S. dairy supply chain to investigate the impacts of longstanding regional FMMO pricing rules on the geography of milk production and processing, inter-regional trade across U.S. regions and internationally, and the

[14]Most beverages consumed in California are sourced locally as the expenditure share on local beverages reaches 85.5%. The beverage price index for beverage milk decreases only by 1.3% in California.

availability of dairy products to U.S. and foreign consumers.

Although our model is detailed in its geographical resolution and its representation of the production process, our calibrating information comports with stylized representations of FMMO pricing developed in previous work: price differentials tend to raise the cost of supplying dairy products with the more inelastic demand, resulting in an increase in the price of beverage milk, a decrease in that of other dairy products, and an overall increase in milk production and the farm milk blend price. While the qualitative effects of this policy are well understood, at least in the aggregate, our structural supply chain model affords a comprehensive quantitative treatment of it, including transparent welfare effects as well as impacts on inter-regional trade, which may otherwise have gone unaddressed.

In summary, we find that the impacts of removing the FMMO pricing rules on farm milk production would be small at the national level. The Southwest, the region most affected in percentage terms, would experience a 6.5% decrease in milk production and a 4.8% decrease in milk use. U.S. milk value would fall by -1.6%. By comparison, Ippolito and Masson (1978) estimate that Federal Order regulations lead to a 1.3% increase in milk production. However, they estimate that the price received by milk producers increases by 3.7%, a value much different from the 0.2–0.4% changes in milk price found in our simulation. This is due to the much larger long-run milk supply elasticity in our model—3.63 for the U.S. as a whole. A notable effect of removing component price differentials is the split of a previously spatially integrated market into two separate U.S. markets, one roughly comprising the Western portion of the U.S. and the other its Central and Eastern portions.

Downstream, we find that changes in the value of dairy product manufacturing and exports may be sizable at the regional level, yet impacts are small in the aggregate, typically less than a third of a percent, due to offsetting effects across regions.

To the extent that the change in the component cost index for beverage products can be compared to a change in the Class I price, the declines in component costs are similar in magnitude to the increase in Class I price estimated by Ippolito and Masson (1978). They estimate that FMMO regulations result in an increase in the Class I price of 9.3% and a decline in the price of manufacturing milk of 5.6%. Ippolito and Masson also estimate a decline in the consumption of beverage (Class I) products by 1.9% and an increase in the consumption of other dairy products of 9.6%. Considering the changes in the production of dairy products across regions, our simulation results appear consistent with Ippolito and Masson's findings.

Our simulation shows that dairy product buyers in the U.S. would gain $369 million in consumer surplus as a result of the changes in dairy product prices if FMMO pricing rules were removed, while export buyers of U.S. dairy products would lose $46 million because prices of export products rise slightly. Due to the decline in milk production, and corresponding decline in demand for feed crops from the dairy industry, crop producers would lose $113 million. Overall, net welfare for the U.S. would increase by $256 million. At the regional level, net welfare would increase in most regions except California and the Unregulated region.

Further research should evaluate whether perfect competition in the market for farm milk remains an appropriate approximation for the counterfactual scenario. To simplify the analysis, this study largely ignores the role of farmer-owned processing cooperatives in the dairy industry. The size and national scope of the major dairy cooperatives, such as Dairy Farmers of America, could allow them to exercise some degree of market power, especially seller power in the market for dairy products. It is also common for a large number of dairy producers to deliver to a small number of processors, creating a potential for buyer power in regions with few processing plants. One argument in favor of the FMMOs is that they balance market power between milk producers and milk buyers. Extending the model to allow for bilateral market power could determine whether the welfare impacts of the FMMO pricing rules are offset by the loss of welfare due to imperfect competition in the counterfactual.

A more detailed representation of foreign dairy markets would be a natural extension of this work. While we include dairy product imports from the rest of the world and exports of U.S. dairy products to the international market in our simulation, international prices are treated as exogenous to reduce complexity. Explicitly considering the equilibrium in the international market for dairy products would allow us to analyze the extent to which the U.S. affects international prices and the impact of various domestic dairy policies, e.g. supply management in Canada, on international trade flows.

FMMOs provide benefits to dairy farmers not accounted for in the present study, such as testing milk samples, market information, and product promotion efforts. Notwithstanding these benefits, our research shows that classified pricing and revenue pooling distort dairy market outcomes across the milk supply chain, though impacts are found to be small in the aggregate.

References

Andreyeva, T., M.W. Long, and K.D. Brownell. 2010. "The Impact of Food Prices on Consumption: A Systematic Review of Research on the Price Elasticity of Demand for Food." *American Journal of Public Health* 100:216–222.

Armington, P.S. 1969. "A Theory of Demand for Products Distinguished by Place of Production." *International Monetary Fund Staff Papers* 16:159–178.

Beckman, J., R. Keeney, and W. Tyner. 2011. "Feed Demands and Coproduct Substitution in the Biofuel Era." *Agribusiness* 27:1–18.

Bilgic, A., S. King, A. Lusby, and D.F. Schreiner. 2002. "Estimates of U.S. Regional Commodity Trade Elasticities of Substitution." *Journal of Regional Analysis and Policy* 32:79–98.

Bozic, M., C.A. Kanter, and B.W. Gould. 2012. "Tracing the evolution of the aggregate U.S. milk supply elasticity using a herd dynamics model." *Agricultural Economics* 43:515–530.

Broda, C., and D.E. Weinstein. 2006. "Globalization and the Gains from Variety." *Quarterly Journal of Economics* 121:541–585.

Buccola, S., and Y. Iizuka. 1997. "Hedonic Cost Models and the Pricing of Milk Components." *American Journal of Agricultural Economicsc* 79:452–462.

Casasnovas-Oliva, V.L., and A.M. Aldanondo-Ochoa. 2014. "Feed prices and production costs on Spanish dairy farms." *Spanish Journal of Agricultural Research* 12:291–304.

Chavas, J., T.L. Cox, and E. Jesse. 1998. "Spatial allocation and the shadow pricing of product characteristics." *Agricultural Economics* 18:1–19.

Chavas, J.P., and K. Kim. 2005. "Cointegration relationships and hedonic pricing of differentiated commodities: an application to price dynamics in the US dairy sector." *Applied Economics* 37:1813–1827.

Chavas, J.P., and R.M. Klemme. 1986. "Aggregate Milk Supply Response and Investment Behavior on U.S. Dairy Farms." *American Journal of Agricultural Economics* 68:55–66.

Chavas, J.P., A.F. Kraus, and E.V. Jesse. 1990. "A Regional Analysis of Milk Supply Response in the United States." *Applied Economic Perspectives and Policy* 12:149–164.

Chouinard, H.H., D.E. Davis, J.T. LaFrance, and J.M. Perloff. 2010. "Milk marketing order winners and losers." *Applied Economic Perspectives and Policy* 32:59–76.

Coggins, J.S., and J.W. Hammond. 1994. "Component Values for Milk Used in Cheddar Cheese." *Review of Agricultural Economics* 16:203–213.

Conley, D.M., R.G.A. Nagesh, and E.J. Salame. 2012. "Supply and Utilization of Corn in the United States, by State, 2004-2010." Working paper, University of Nebraska-Lincoln, Lincoln, Nebraska.

Costinot, A., D. Donaldson, and C. Smith. 2016. "Evolving comparative advantage and the impact of climate change in agricultural markets: Evidence from 1.7 million fields around the world." *Journal of Political Economy* 124:205–248.

Donaldson, D. 2022. "Blending Theory and Data: A Space Odyssey." *Journal of Economic Perspectives* 36(3):185–210.

Erba, E.M., and A.M. Novakovic. 1995. "The Evolution of Milk Pricing and Government Intervention in Dairy Markets." Working paper, Cornell University, Ithaca, NY.

Feenstra, R.C. 1994. "New Product Varieties and the Measurement of International Prices." *American Economic Review* 84:157–177.

Gallaway, M.P., C.A. McDaniel, and S.A. Rivera. 2003. "Short-run and long-run industry-level estimates of U.S. Armington elasticities." *North American Journal of Economics and Finance* 14:49–68.

Giesecke, J.A., and J.R. Madden. 2013. *Regional Computable General Equilibrium Modeling*, P. B. Dixon and D. W. Jorgenson, eds., vol. 1. Elsevier.

Gillmeister, W.J., R.D. Yonkers, and J.W. Dunn. 1996. "Hedonic Pricing of Milk Components at the Farm Level." *Review of Agricultural Economics* 18:181–192.

Gouel, C., and D. Laborde. 2021. "The crucial role of domestic and international market-mediated adaptation to climate change." *Journal of Environmental Economics and Management* 106:102408.

Hendricks, N.P., A. Smith, and D.A. Sumner. 2014. "Crop Supply Dynamics and the Illusion of Partial Adjustment." *American Journal of Agricultural Economics* 96:1469–1491.

Hertel, T., D. Hummels, M. Ivanic, and R. Keeney. 2007. "How confident can we be of CGE-based assessments of Free Trade Agreements?" *Economic Modeling* 24:611–635.

Hillberry, R., and D. Hummels. 2013. *Trade Elasticity Parameters for a Computable General Equilibrium Model*, P. B. Dixon and D. W. Jorgenson, eds., vol. 1. Elsevier.

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

Kessel, R.A. 1967. "Economic Effects of Federal Regulation of Milk Markets." *The Journal of Law and Economics* 10:51–78.

Lucas Jr, R.E. 1976. "Econometric policy evaluation: A critique." In *Carnegie-Rochester conference series on public policy*. North-Holland, vol. 1, pp. 19–46.

Mérel, P., Z. Qin, and R.J. Sexton. 2023. "Policy-Induced Expansion of Organic Farmland: Implications for Food Prices and Welfare." *European Review of Agricultural Economics* 50:1583–1631.

Miao, R., M. Khanna, and H. Huang. 2016. "Responsiveness of Crop Yield and Acreage to Prices and Climate." *American Journal of Agricultural Economics* 98:191–211.

Nourse, E.G. 1962. "Report to the Secretary of Agriculture by the Federal Milk Order Study Committee." Working paper, U.S. Department of Agriculture, Washington, DC.

Okrent, A.M., and J.M. Alston. 2011. "Demand for Food in the United States: A Review of Literature, Evaluation of Previous Estimates, and Presentation of New Estimates of Demand." Working paper, Giannini Foundation of Agricultural Economics, Berkeley, CA.

Partridge, M.D., and D.S. Rickman. 2010. "Computable General Equilibrium (CGE) Modelling for Regional Economic Development Analysis." *Regional Studies* 44:1311–1328.

Reimer, J.J., X. Zheng, and M.J. Gehlhar. 2012. "Export Demand Elasticity Estimation for Major U.S. Crops." *Journal of Agricultural and Applied Economics* 44:501–515.

Reinert, K.A., and D.W. Roland-Holst. 1992. "Armington Elasticities for United States Manufacturing Sectors." *Journal of Policy Modeling* 14:631–639.

Rude, J., and K. Meilke. 2000. "Implications of CAP Reform for the European Union's Feed Sector." *Canadian Journal of Agricultural Economics* 48:411–420.

Song, L., and H.M. Kaiser. 2016. "An economic evaluation of market development programmes for US dairy products." *Applied Economics* 48:212–221.

Appendices

A State-based delineation of FMMO regions

Table A.1: States used to approximate FMMO regions

Region	Component States
Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Washington D.C.
Appalachian	Kentucky, North Carolina, South Carolina, Tennessee, Virginia
Florida	Florida
Southeast	Alabama, Arkansas, Georgia, Louisiana, Mississippi
Upper Midwest	Minnesota, North Dakota, Wisconsin
Central	Colorado, Illinois, Iowa, Kansas, Missouri, Nebraska, Oklahoma, South Dakota
Mideast	Indiana, Michigan, Ohio, West Virginia
California	California
Pacific Northwest	Oregon, Washington
Southwest	New Mexico, Texas
Arizona	Arizona
Unregulated	Idaho, Montana, Nevada, Utah, Wyoming

Source: Authors' determinations based on official FMMO marketing areas.

B Calibration of share parameters

Note: This appendix to be completed later.

B.1 Regional land share of the crop dollar

The regional land share of the crop dollar is computed from state-level data on cropland rental rates, total cropland, cropland acres by crop, and the value of crop production by crop. All these data are from USDA/NASS Quick Stats. Data on total cropland, cropland acres, and value of crop production pertain to the reference year 2017. Because cropland rental values by state are based on surveys, and the set of rented acres may vary from year to year, we average reported values over the years 2015–2019.

Regional cropland rental values are computed by multiplying state-level cropland rental rates by state total cropland, summing over states in the region, and then dividing by the sum of state total cropland in the region.

The sum of crop areas for the crops represented in our model (these crops are used to compute the value of crop production and the crop-specific land shares) is lower than the total reported cropland area, but it is generally close. To compute the regional land share of the crop dollar, we multiply the regional cropland rental value calculated above by the sum of the areas of the crops modeled across states in the region, and then divide by the sum of the production values for these same crops across states in the region.

B.2 Milk pooling and utilization data in FMMO regions

Each FMMO reports the quantities of milk received and utilized by handlers who participate in revenue pooling. These data are compiled and published by USDA/AMS and provide the underlying observations to compute the share parameters related to milk production, trade, utilization, and value.

The data source for milk shipments between regions, M_{ij}, is the *Producer Milk Pooled by State of Origin* report for 2017. The report breaks down the total quantity of milk pooled in each FMMO by the state where the milk originated. We assign each origin state to an FMMO region and sum to the origin level to generate a table of M_{ij} values. Since our model assumes unidirectional milk trade flows, we calculate net flows in cases where bidirectional shipments between regions are observed. The report summarizes all milk shipments in a year, so if the direction of milk shipments between regions changes on a seasonal basis then this would appear as bidirectional trade on an annual basis. Additionally, we reallocate milk shipments whenever a no-arbitrage condition could be violated by the observed trade flows. There are two types of shipment scenarios one should be concerned about: loops (some volume of milk being shipped back indirectly to a source region through a sequence of trades) and competing routes (one source region shipping milk to another region through more than one trade route). In each case, these scenarios are resolved by removing the smallest trade flow and reallocating shipments so that for each region, (i) the total volume of milk produced and (ii) the total volume of milk used remain the same as in the raw data. For example, if region A ships milk to region B and region C, but region B also ships milk to region C, then we would look at the magnitude of each shipment and eliminate whichever is smallest. If the shipment from A to C is smaller than the shipment from A to B and the shipment from B to C, then we would eliminate the shipment from A to C. The quantity of milk initially shipped from A to C would be reallocated to the shipment from A to B. This same quantity would then be subtracted from the shipment from B to itself and added to the shipment from B to C. After accounting for net flows and removing loops and competing routes, we calculate the share of milk received in region j that originated in region i, μ_{ij}.

USDA/AMS also publishes a *Utilization of Producer Milk* report for each product class, which includes the quantity of milk used in products from each class, the share of total milk pooled that

was used in each class, and the component percentage of milk pooled in each class. Since the reported quantity of milk pooled in each class may differ from the quantity of milk available in each region, we use the share of total milk pooled by class from the *Utilization* reports to calculate the quantity of milk used in each class of products. We then use the component shares and the milk quantities by class to calculate the quantity of component k used in product n, Z_i^{nk}. Note that milk component shares across classes may differ from farm milk component shares based on their use in the products associated with each class. For example, beverage milk products average around 2% butterfat, so Class I milk has a 2% butterfat share. The additional butterfat from farm milk is often used to produce cream, which is a Class II product. Therefore, the Class I butterfat share is typically lower than the farm milk butterfat share while the Class II butterfat share is typically higher, so component shares may differ across classes but all components in farm milk are utilized in one of the four classes.

To impute the utilization of milk not pooled, we use two pieces of data from the monthly *Utilization of Producer Milk* reports from AMS: the utilization share for each class, the percent of all milk pooled in a given month that was utilized in each class, and the quantity of milk pooled in each month. First, using the utilization shares, we calculate the annual average utilization share by class and the deviations between the monthly utilization share and the annual average. Then, we divide the quantity of milk pooled by the number of days in the month to determine the average daily milk pooled. Since we are calculating deviations from average, this step ensures that we can compare January and February without the number of days impacting the comparison. We then multiply the average daily milk pooled by the utilization shares to determine the average daily milk utilized in each class, and again calculate the annual average and deviations from that average.

We assume that milk is depooled from a specific class in a given month if the deviations from the average utilization share and the average daily milk utilized are negative. For example, in the Central Federal Order about 40% of milk pooled was used for Class III products on average in 2017. However, in October, November, and December the utilization share fell to between 20 and 30%, suggesting that milk that would be used in cheese production was depooled in those months. We then take the sum of the deviations of average daily milk utilized across the months that were identified as depooled for that class. Since pooling Class I milk is mandatory, we calculate these sums for Class II, Class III, and Class IV. Using the total deviations for Classes II, III, and IV, we calculate the share of the depooled quantity attributable to each class. In the Central Federal Order about 70% of the quantity deviations were from Class III, so we assume that 70% of depooled milk from the Central region was used in cheese manufacturing. Table B.1 reports the imputed utilization shares for each class and each region.

The value of milk produced and used is calculated using the *Final Class and Component Price* reports. These reports include each of the minimum class prices on a standardized component basis and the component prices by marketing order. We use the Class IV component prices as the baseline values for v_i^k, with the component prices for each other class equal to $\delta_i^{nk} v_i^k$. The

Table B.1: Imputed utilization shares for milk not pooled (%)

Order	Softs	Cheese	Butter-Powder
Northeast	30	11	60
Appalachian	22	14	65
Florida	28	41	31
Southeast	6	62	32
Upper Midwest	11	82	6
Central	9	72	19
Mideast	30	53	17
California	0	100	0
Pacific Northwest	3	95	3
Southwest	3	83	14
Arizona	4	37	58

Source: Authors' calculations using data from USDA AMS reports, *Producer Milk Pooled by State of Origin* and *Utilization of Producer Milk*.
Note: The California Milk Marketing Order enforced mandatory pooling for all Grade A milk and was still in effect in 2017. Any milk not pooled in California (which would be Grade B) was assumed to be used for cheese production. The Unregulated region is not included in this table because milk utilization in the Unregulated region is calculated separately.

component minimum prices are used in combination with the *Utilization* reports to calculate $(\delta_i^{nk} v_i^k) Z_i^{nk}$ for each order, class, and component. The total value of the components used across the for product classes, $\sum_n \sum_k (\delta_i^{nk} v_i^k) Z_i^{nk}$, is the value of milk used in region i.

Calculating the value of components involves some differences across marketing orders. Most of the current FMMOs use component-based pricing across Classes II, III, and IV, where minimum component prices are set for each class and used to calculate the classified value of milk. Class III is the only class in which prices are used for fat, protein, and other solids, while Classes II and IV use a fat price and a nonfat solids price. In each of these cases the classified value is easily calculated as the product of the component prices and the quantity of components used in each class. Four FMMOs, Appalachia, Florida, Southeast, and Arizona, use a skim-fat pricing method where a minimum price is set for fat and skim milk. Additionally, all FMMOs use this method for Class I milk use. The value of fat used in each class is calculated in the same way as the component-priced orders, but then the quantity of skim milk used in calculated from the difference between milk use and fat use. Using the skim milk price for each class, we compute the value of skim milk and then apportion this value between protein and other solids. Note that using the whole quantity of skim milk in this calculation implicitly values the water in milk. However, by attributing the skim milk value to protein and other solids, we are assigning no explicit value to water. We assign the skim milk value to protein at a ratio of 3.1:9 and other solids at a ratio of 5.9:9. These ratios come from the FMMO regulations used to define the Class III skim milk price, so they represent the method

that USDA/AMS uses to assign individual component values to skim milk.

B.3 Milk Use in the Unregulated Region

Milk that is produced in the unregulated region and has not been shipped to an FMMO region is difficult to assign to product categories. Since we assume the component prices are not distorted across product categories, we know the total value of components used in the unregulated region, $v_i^k \sum_n Z_i^{nk}$, but without further information one cannot determine the value in each category, $v_i^k Z_i^{nk}$.

NASS publishes the *Dairy Products Annual Summary*, which reports production quantities for several major dairy products. Production is reported for the United States, three regions (Atlantic, Central, and West), and a selection of states for each product. Unfortunately, NASS groups states into an "Other States" category if a state has less than 3 plants manufacturing a given product or if the observation would identify a specific operation. Therefore, we must use the known state observations and the residual production in each region to deduce state level production that is not reported.

For example, total cheese production is reported for California, Idaho, and Oregon as individual states from the West region. These three states produced about 3.7 billion pounds of cheese in 2017, or about 70% of the 5.2 billion pounds produced in the West region. The remaining cheese produced in the West must be produced in the other West region states, and we use the share of milk production among the remaining states to assign cheese production values. Among the states without specifically-reported cheese production, 34% of milk production is in Washington, therefore we assume about 260 million pounds of cheese was produced in Washington.

Once production values have been deduced for each state, we use conversion factors used by the USDA Economics Research Service to convert dairy product production values into milk component use by product.[15] we then sum across the states in the unregulated region to determine the share of each component used in the manufactured dairy product categories.

This process allows us to approximate the share of components used in manufactured dairy products, but we also need to include components used in beverage milk products. We use data published by ERS on fluid milk consumption per capita and state-level population to compute beverage milk consumption by state, and again sum across states in the unregulated region.

B.4 Dairy Product and Feed Crop Trade Flows

Bilateral trade shares are calculated using data from the Commodity Flow Survey (CFS) for dairy products and the Census of Agriculture and NASS Crop Production reports for feed crops. The procedure for interpolating trade flows relies on available data on state-level values of production and consumption. We then use the interpolated values to calculate the a_{ij}^n and ρ_{ij}^l parameters.

[15]The conversion factors used by ERS can be found in the documentation for their dairy data: https://www.ers.usda.gov/data-products/dairy-data/documentation/

Table B.2: Share of feed crops used as animal feed

Commodity	Share
Grains	
Corn	0.368
Other Grains	0.268
Oilseeds	
Soybeans	0.303
Other Oilseeds	0.615
Hay	1.000
Silage	1.000

Source: Authors' calculations based on USDA ERS *Feed Grains Yearbook* and *Oil Crops Yearbook* data.

For dairy product shipments, calculating bilateral trade shares is straightforward since we assume that the products are consumed at the destination. However, for feed crops it is not true that the entire shipment will be used by the dairy industry. For example, a shipment of soybeans from Iowa to Arizona may be used as dairy feed, used as feed in another livestock industry, or used in separate industry entirely. Since we define $W_j^l F_j^l$ as the quantity of crop l used in the dairy industry in region j, rather than the entirety of crop l used in region j, the numerator of ρ_{ij}^l, $(\tau_{ij}^l w_i^l)F_{ij}^l$, must represent the value of the shipment of crop l from region i to region j actually used in the dairy industry. Therefore, we need to first determine the share of each crop that is used as feed, then determine the share of livestock feed used by the dairy industry.

B.4.1 Feed Crop Use by the Dairy Sector

ERS reports uses of feed grains and oilseeds in the *Feed Grains Yearbook* and the *Oil Crops Yearbook*. Uses of feed grains include food, alcohol, industrial, and seed, with feed calculated as the residual use case. Note that by using the "feed and residual" category to calculate the share of grain crops used for animal feed, we may overstate the actual quantity of grains used for feed.

Oilseed domestic use is categorized into biofuel use, edible uses, crush, or seed, feed, and residual. The *Oil Crops Yearbook* data include the quantities of oil and meal produced from oilseeds used for crush, therefore we include oilseed meals in the quantity used for animal feeds. For oilseed meals we assume that the quantity that is not exported is used as animal feed, while oilseed oils are not used as feed.

The calculated feed use shares are reported in Table B.2. Note that both hay and silage are assumed to be used entirely for animal feed. We multiply these shares by the interpolated crop trade flows to calculate the value of feed crops shipped between regions.

This gives an overall estimate of the share of feed crops used as animal feed, but the question of the share used in the dairy industry remains. We can again utilize the feed-consuming animal units calculated by ERS for the *Feed Grains Yearbook* to determine the share of feed used in the

dairy industry in each state. We calculate the number of FCAUs in each state following Conley, Nagesh, and Salame (2012). Summing across the six livestock categories yields a total FCAU value, from which one can calculate the share of FCAUs in the dairy sector. This share is used as an approximation to calculate the quantity of feed crop shipments actually consumed by the dairy industry in each state.

Returning to the example of California in 2017, we previously calculated that California had 1.9 million dairy cattle grain-consuming animal units (GCAUs) and a total of 3.8 million GCAUs. Therefore, about 49% of GCAUs in California were dairy cattle, so we assume that 49% of grain crops used as feed in California were used in the dairy industry. Combining this share with the share of feed crops used as animal feed from Table B.2, we assume 37% of the corn shipped to California is used as animal feed, of which 49% is used in the dairy industry. In other words, we assume that 18% of corn shipments to California are used as dairy feed.

With corresponding dairy GCAU shares for each state, along with high-protein-consuming animal unit (PCAU) and roughage-consuming animal unit (RCAU) shares, we calculate $(\tau_{ij}^l w_i^l)F_{ij}^l$ for each destination region. The remainder of each shipment, i.e., the share not consumed as animal feed or used in other livestock industries, is assumed to be part of the "other uses" sector and is included in the $(\tau_{i0}^l w_i^l)F_{i0}^l$ values.

B.4.2 Dairy Product Imports and Exports

Interpolated trade flow values provide the data to calculate the bilateral trade flows between domestic regions, but the CFS data do not identify shipments that are traded with the rest of the world. The Census Bureau reports state-level import and export data that we use to supplement the CFS data.

State-level exports can be difficult to work with because they reflect the origin of movement of a shipment, which in the case of shipments that have been consolidated may not match the origin of the commodity. The Census Bureau notes that this is especially common in unprocessed agricultural commodities since they may be exported by intermediaries and consolidation may occur prior to export. Exports of dairy products may face similar issues, especially for the bulk commodity-type products that tend to be exported, but it is also common for large dairy manufacturing firms to be directly involved in exports.

Imports include a reported state of destination code which is used to construct the state-level import data. However, as with the export data, the state of destination may reflect an intermediary storage point rather than the location of final consumption. Since the value of imported dairy products is small relative to domestic production, even if our shares misrepresent the location of final consumption it will be a small discrepancy.

Note that crop exports are included in the calculation of the feed use shares in Table B.2. Since we include exports, crops used in other industries, and feed used by other livestock industries in the share shipped to "other uses," it is not necessary to include separate sources of export data in these calculations.