Mapping Milk: Investigating the Effects of Federal Milk Marketing Orders on the Geography of Milk Production and Inter-Regional Trade in Milk and Dairy Products

By

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Abstract

Since the passage of the Agricultural Marketing Agreement Act of 1937, the Federal Milk Marketing Orders (FMMOs) have overseen sales of milk within regions comprising the majority of milk production and processing in the United States. The stated objective of the FMMOs is to support milk producers by establishing minimum prices for farm milk across four end-use product classes and by ensuring farmers are paid a weighted average of the minimum class prices. To the extent that prices paid for farm milk are higher due to FMMO pricing rules than they otherwise would be, milk production is also higher than it would be in the absence of the FMMOs.

This dissertation investigates the impact of FMMO pricing rules on the geographic distribution of milk production, inter-regional shipments of farm milk, and the value of manufactured dairy products and dairy product exports. Chapter 1 provides an introduction and Chapter 2 outlines the history of U.S. dairy policy and introduces the regulatory structure of the FMMOs. Chapter 2 also explores regional milk supply and demand through a graphical model based on the foundational literature that describes the incentives to ship raw milk created by FMMO regulations. Chapter 3 introduces methods for calculating inter-regional trade flows in dairy products and feed crops from available data. Finally, Chapter 4 expands on the analysis in Chapter 2 and the data developed in Chapter 3 by developing and calibrating a simulation model of the dairy supply chain in the United States.

Milk marketing orders use a system of classified pricing to define minimum prices that buyers must pay based on the intended end use of the milk purchased. This system uses a price differential intended to set the minimum price paid by beverage milk processors above the prices paid for milk used in more heavily processed dairy products. High transportation costs lead to local markets for beverage products with relatively inelastic demand, which allows for this price discrimination to

generate additional revenue for dairy farmers. This additional revenue is redistributed through a blend price, a weighted average of the classified prices that ensures all participating dairy farmers in a marketing order region receive a uniform minimum price.

These two mechanisms, classified pricing and revenue pooling, were explored in a series of papers in the 1960s and 1970s to show the impact of FMMO regulations on milk production and social welfare. In Chapter 2 I extend these models by incorporating the bilateral trade relationship between two regions, with and without marketing order pricing rules in place, to demonstrate the incentives that lead to farm milk shipments between regions. The model shows that FMMO regulations lead to increased milk production in both regions, greater shipments of farm milk between regions, and more milk used in more heavily processed dairy products rather than beverage products. To the extent that manufactured dairy products are more easily traded internationally, increased production of these products leads to an increase in exports.

While some of the data I use in more intensive modeling of regional dairy markets are readily available, detailed information on bilateral trade within the United States is not. Chapter 3 details a method used to interpolate the value of inter-regional trade in dairy products and feed crops using a gravity approach and available data on regional production and consumption. Survey data provides some information on inter-regional shipments but is often unavailable. Gravity models are commonly used in the international trade literature to model bilateral trade between countries, and they have been extended to develop regional trade flow matrices and input-output tables at a sub-national level. Chapter 3 develops and explains substantial data on dairy product and feed crop production, consumption, and inter-regional trade.

Chapter 4 develops, calibrates, and presents simulation results from a multi-market equilibrium trade model that shows empirically the extent to which FMMO pricing rules affect the quantity of milk produced in each region, shipments of farm milk between regions, the value of regional production of dairy products, and the value of dairy product exports from each region. The model allows for calculation of welfare impacts after removal of the FMMO pricing rules, from which I determine the impact on buyers of dairy products in the U.S., buyers of U.S. dairy products in the rest of the world, and crop producers. Due to the longstanding nature of the milk marketing order policies, the simulation approach reflects the impacts of removing FMMO pricing rules rather than adding regulation to a previously unregulated system. The model is calibrated to a baseline

scenario with FMMO pricing rules in place, then used to explore a counterfactual scenario where the FMMO pricing rules are eliminated, removing classified pricing in each FMMO region.

Chapter 4 has four main results addressing the primary research questions investigated in this dissertation. First, milk production declines in each region and falls by 1.3 percent nationally. Second, the total quantity of farm milk shipped between regions declines by 3.1 percent, but with a range of impacts regionally. Third, the value of U.S. dairy products falls by 0.2 percent and the value of dairy product exports falls by 0.3 percent. Finally, buyers of dairy products in the U.S. gain $323 million due to the decline in dairy product prices.

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I also want to acknowledge the role that my high school FFA advisors played in kickstarting my interest in agriculture and agricultural policy. Greg Pile and Rusty Finch were, and continue to be, incredible mentors to young people who are excited about agriculture. In many ways, Mr. Finch encouraging me to participate in Dairy Foods Evaluation and Prepared Public Speaking led directly, if not immediately, to the writing of this dissertation.

I found that the crucible of graduate school can lead to the formation of many deep and enduring friendships. The friends I made at Davis, and all of the board games, bonspiels, and other gatherings along the way, kept me grounded through prelims, orals, dissertation research, as well as a global pandemic. Despite what they think, I will not be forgetting them anytime soon.

My immediate family are the primary influences on where I am today. My parents, Greg and Cassa, made sure that from a young age I developed an appreciation for education and thinking deeply about the way the world works. My father gave me an interest in government and policy and taught me how to argue my case. My mother is the most understanding person I know, and always encourages me to look at the world from different perspectives. My sister, Delaney, is always willing to offer support when I need it, but is not afraid to call me out if that is more important. Delaney is one of my best friends, and I hope she knows just how wonderful I think she is.

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And to anyone who I heard me say "I'm just about to finish," or "I only have a bit more work to finish up," or "it's pretty much just editing at this point," or any other claim about my progress over the years: I cannot thank you enough for being patient with me and helping me see this through to the end.

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Chapter 1

Introduction

Since the passage of the Agricultural Marketing Agreement Act of 1937, the Federal Milk Marketing Orders (FMMOs) have overseen sales of milk within regions comprising the majority of milk production and processing in the United States. The stated objective of the FMMOs is to support milk producers by establishing minimum prices for farm milk across four end-use product classes and by ensuring farmers are paid a weighted average of the minimum class prices. To the extent that marginal prices paid for farm milk are higher due to FMMO pricing rules than they otherwise would be, milk production is also higher than it would be in the absence of the FMMOs.

Marketing order pricing rules use a system of classified pricing, defining classes based on end-use products and establishing minimum prices for milk used in those products, and revenue pooling within marketing areas. The classified pricing system allows for price discrimination of milk used in beverage milk products due to relatively inelastic regional demand for beverage products due to the relatively high cost to transport beverage milk, establishing natural limits on competition from beverage milk products from 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 FMMO 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 if milk producers can receive a higher price in another region, despite relatively high transportation costs for farm milk relative to manufactured dairy products.

On the supply side, feed is the most important input to milk products when measured as a share of input costs. The dairy sector therefore represents an important source of demand for U.S. feed crops, especially forage crops necessary in the diet of ruminants. If FMMO price regulations increase the quantity of milk produced in the United States, then the derived demand from the dairy industry for feed crops would correspondingly increase. Cropland availability may be a limiting factor in feed crop supply that causes regional dairy industries to face an upward-sloping supply function for feed, therefore generating an upward-sloping marginal cost function for milk production in each region.

Crop producers face opportunity costs of producing crops for feed used by dairy farms and other cropland uses, including feed for other livestock or for export. Feed crop production competes for resources with non-feed crops, which represent a large share of land use in some regions. Forage crops are an essential portion of dairy feed rations, which used to include substantial grazing on pasture but, in the United States, is now derived mainly from harvested forages such as hay and silage. Relative to grains and oilseeds used for feed, harvested forage crops tend to be produced near the places where they are used due to their bulkiness and higher transportation costs. These relationships lead to the upward-sloping marginal cost of feed facing milk producers, and a close relationship between the geography of milk production and the geography of dairy feed crop production.

Using data collected by each FMMO, the USDA Agricultural Marketing Service (AMS) reports the quantity of milk pooled in each marketing order by the state of origin. One stated objective of the FMMOs is to ensure a regular supply of farm milk for use in beverage products. This objective could be consistent with the shipments of farm milk between marketing order regions observed in these data. If farm milk is shipped from a region with a large share of milk production to a region with higher population and a greater demand for dairy products, then such shipments could meet a demand for beverage milk products that would not otherwise be met. In contrast, if the same farm milk was used to manufacture dairy products in the region it was originally produced, those dairy products could be shipped more cheaply than the farm milk used to produce them. In this analysis, I investigate whether the observed shipments of farm milk are more costly than shipments of consumer-ready dairy products, and the extent to which FMMO pricing rules encourage such shipments of farm milk.

The price discrimination and blend pricing mechanisms utilized by the FMMOs incentivize milk producers to increase milk production. If this occurs in all regions with a marketing order, then it is likely that some of the increase in milk production occurs in regions with relatively high costs of production. Which regions see an increase in milk production under FMMO pricing rules? Are some regions affected more than others? If so, what are the impacts of these regional differences? These questions about the geography of milk production are addressed through simulations in the following chapters.

The United States has experienced a steady increase in exports of U.S. dairy products over the last two decades. Since FMMO pricing rules rely on price discrimination in the market for milk used in beverage products, consumers face a higher price for such products. Lower domestic beverage milk consumption and increased milk production overall would tend to lead to an increase in manufacturing of tradable dairy products. Products such as cheese, butter, and dry milk products are more easily stored and transported than beverage products, potentially leading to an increase in exports. This analysis also investigates the extent to which the recent increases in dairy product exports are due to classified pricing under the FMMO pricing rules.

In Chapter 2, I provide an overview of FMMO regulations, the history of Federal intervention in dairy markets, and the current regulatory environment. I discuss two entries from the rich literature analyzing milk marketing orders, focusing on models of the FMMO pricing rules and the market for farm milk. These models provide an opportunity to introduce the effects of FMMO regulations on milk production, manufactured products, and the incentives to ship milk between regions. I then extend these models to a case with two milk producing regions and examine the interactions between them across several scenarios.

Understanding how FMMO regulations affect regional interactions requires detailed data on inter-regional trade flows. Unfortunately, these data are not widely available or are unreliable due to missing observations. Chapter 3 introduces and discusses procedures for interpolating the values of inter-regional dairy product and crop trade flows using available data on regional production and consumption. I evaluate the accuracy of these procedures against the trade flow observations that are available.

Chapter 4 develops and calibrates a multi-market regional trade model of the dairy supply chain: crop production, milk production, dairy product manufacturing, and consumer demand for dairy products. The modeling technique draws from the recent international trade literature to model U.S. inter-regional trade in crops, farm milk, and manufactured dairy products (Costinot, Donaldson, and Smith, 2016; Gouel and Laborde, 2021). The model is calibrated using a set of behavioral parameters drawn from the literature and data that represent a baseline scenario. Once the model is calibrated, a counterfactual scenario is simulated that removes the FMMO pricing rules. These simulations calculate the impact of classified pricing and revenue pooling under the FMMOs on milk production, shipments of farm milk between regions, the value of U.S. dairy products, and dairy product exports.

Chapter 2

Understanding Milk Pricing Regulations and their Impact on Milk Movements

2.1 Introduction

In this chapter I outline the history of Federal Milk Marketing Orders, their regulatory structure, and their impact of movements of milk between regions. The first part of the chapter provides a historical perspective on the development of milk marketing order policy. The economics literature surrounding milk marketing orders is well established, and I discuss some of the foundational analyses of marketing order policies. Due to significant changes to milk marketing orders, both in terms of their number and specific regulations, following the 1996 Farm Bill, I also survey some of the more recent economics literature on milk marketing orders.

To begin answering the research questions posed in Chapter 1, the second half of this chapter expands upon prior models used in the marketing order literature by including inter-regional trade. This model is developed for the case of two regions that differ in milk production costs and demand for beverage milk products, first in a state of autarky and then with trade between regions. I then incorporate the major milk marketing order pricing rules, classified pricing and revenue pooling, and observe changes in the equilibrium. I examine two scenarios, one in which the high-cost region implements a marketing order and trades with an unregulated region and one in which both regions adopt FMMO-style regulations. This approach shows that FMMO pricing rules can lead to increased milk production in each region and create incentives for farm milk to be shipped between regions.

2.2 Background on Federal Milk Marketing Order Policies

> The phrase "orderly marketing conditions" is the most frequently employed phrase in all of the federal milk order literature. Its frequent use likely springs from its origin in the legislation as well as from its ambiguity.
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>
> *Milk Marketing: A Report of the U.S. Department of Justice to the Task Group on Antitrust Immunities*
>
> Roger W. Fones, Janet C. Hall, Robert T. Masson

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 due to the lack of refrigeration technology, which limited the distance that fresh milk could travel before it spoiled. 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 regulation and producer cooperatives formed in the dairy industry to counter the buyer power among 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.

2.2.1 Federal Intervention in Milk Marketing

The Agricultural Adjustment Act of 1933 (AAA) included language laying the groundwork for milk marketing orders by authorizing marketing agreements between agricultural producers and product handlers to be enforced by the Secretary of Agriculture. Marketing agreements were generally intended to outline guidelines for wholesale and retail price setting, fair trade practices, and production controls (Duane, 1933). Once agreed to by a group of processors and producers, and approved by the Secretary of Agriculture, a marketing agreement was supported by licenses that were issued to processors in a region defined as the "marketing area." Even if a processor did not voluntarily participate in the marketing agreement, a license was required to participate in the market for the relevant commodity within the designated marketing area.

The first marketing agreement governed fluid milk marketing in Chicago and became effective August 1, 1933 (Rasmussen, Baker, and Ward, 1976). Many of the initial marketing agreements approved by the Secretary of Agriculture governed marketing of milk and dairy products, including setting minimum prices for farm milk that must be paid by processors as well as wholesale and retail prices for dairy products (Duane, 1933).

Participation in marketing agreements was voluntary for milk handlers, and violations were common even when handlers chose to participate (Erba and Novakovic, 1995). The system of marketing agreements and processing licenses was supplemented by the introduction of marketing orders in an amendment to the AAA passed in 1935. The legislation included special provisions for milk and dairy products that defined the processes of classified pricing and revenue pooling. Marketing orders differ from marketing agreements in that handlers are required to be regulated under certain conditions, alleviating the issues encountered with the initial marketing agreements under the AAA of 1933. Milk markets that were regulated under marketing agreements were often replaced by milk marketing orders to implement these new pricing policies and enforce handler participation.[1]

The AAA was declared unconstitutional in 1936 by the U.S. Supreme Court after numerous legal challenges to its authority. While the case in which the law was declared unconstitutional, *United*

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[1] Marketing orders and agreements are also commonly used to regulate marketing of specialty crops, but do not include the specialized provisions allowing classified pricing and revenue pooling that are authorized for milk marketing orders.

States v. Butler, focused on the levying of taxes on processors to pay producers to reduce production, the marketing agreement provisions were also challenged on the basis of their regulation of interstate commerce. Violations of marketing agreement regulations by processors could result in governing boards withdrawing a processor's license, effectively cutting them out of the market. In California, local marketing agreement boards prevented violators from participating in the fluid milk market, leading to injunctions by the Ninth Circuit Court of Appeals on the basis that the Federal government could not regulate intrastate commerce (Sumner and Wilson, 2000).

Due to these challenges to the authority of the AAA, the California Farm Bureau Federation and other producer groups sought state-level legislation to institute locally-administered milk marketing agreements (Sumner and Wilson, 2000). Even prior to the Supreme Court decision in 1936, challenges raised in 1934 and 1935 in the Ninth Circuit made it clear that Federal authority was being challenged. This led to the Young Act of 1935 which essentially replicated the milk marketing provisions of the AAA in California law. California milk production remained governed by state-level milk marketing regulations for more than 80 years until 2018, when the California Federal Milk Marketing Order was formed.

After the AAA of 1933 was declared unconstitutional, the Agricultural Marketing Agreement Act of 1937 (AMAA) was passed to reimplement the marketing agreement and order provisions of the AAA. The AMAA is the permanent legislation that governs milk marketing orders to this day. Echoing language in the AAA, the AMAA declares 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 AMAA outlines the process by which marketing agreements and orders may be established for applicable commodities, including certain fruits, vegetables, grains, livestock, and milk. However, the Act establishes that marketing orders related to milk and dairy products shall operate differently than marketing agreements and orders for other agricultural commodities, requiring that milk marketing orders outline procedures to classify milk according to its end use and establish minimum prices based on that classification to be paid by handlers. Producers may request the creation of an FMMO in a specified marketing area. Handlers are then presented with a specific marketing order proposal, but even if the proposal is rejected by the handlers the Order may be created by the Secretary of Agriculture if the Secretary determines that a sufficient number of producers vote to move forward. Therefore, since producers request and provide final authorization for the marketing order even if the handlers do not accept the proposal, the FMMOs provide a method for producers to impose governments regulation on milk handlers (Kessel, 1967).

The legislative and regulatory texts establishing marketing orders state that they are intended to ensure a regular supply of commodities to market and avoid "unreasonable fluctuations in supplies and prices," (7 U.S.C. §602(4)). With respect to milk, this leads to language that focuses on ensuring a regular supply of fluid milk for use in beverage milk products, even through seasons of lower milk production or lower beverage demand.

The early implementation of FMMO policy involved government oversight of a two-price system, with a higher minimum price established for milk used in beverage products and a lower price for milk used in more heavily processed dairy products, also known as manufactured products. The FMMOs only regulate minimum prices for farm milk meeting Grade A standards, which is the quality standard required for use in beverage milk products. When a handler purchases Grade A milk they are required to pay one of the two minimum prices depending on what the milk is used to produce. By establishing a higher price for milk used in beverage products, the system was intended to ensure that demand for beverage milk products was met first, with remaining milk supplied to the market being used in manufactured products. Additionally, the FMMOs create an incentive for producers to meet Grade A standards, since producers selling Grade A milk received the higher blend price under the FMMOs than producers selling Grade B milk, and the share of milk meeting Grade A standards rose steadily as a result (Balagtas, Smith, and Sumner, 2007).

In other words, FMMO regulations were designed to ensure that beverage milk bottling plants received a regular supply of farm milk, generally encouraging shipments of milk from production regions into cities where bottling plants were located. When there were numerous FMMOs and marketing areas were relatively small, the corresponding distances traveled between producers and bottling plants was relatively short compared to current practices. But as marketing orders consolidated, the regulated marketing areas became much larger.

Eventually, the regional price differentials between the minimum price for milk used in beverage products and the price for milk used in manufacturing products was set to partially reflect the cost to deliver farm milk to beverage product plants across regions. The price differentials were set such that lower price differentials were paid in regions with higher milk production and higher price differentials were paid in regions with larger populations and more demand for dairy products. This structure incentivizes movement of farm milk from regions with lower production costs to regions with less milk production, and observed data suggest that more shipments of farm milk between marketing order regions occur than might be expected without marketing orders.

2.2.2 Modeling Marketing Order Regulations

Kessel (1967) models a two-price system that reflects the regulatory structure of an individual milk marketing order. The demand for milk used in manufactured products is assumed to be infinitely elastic, due to the small share of manufacturing milk produced in an individual FMMO and the national, or even international, scope of the market for manufactured milk products. The market for beverage milk products was assumed to be local and fairly inelastic, allowing for effective price discrimination through the two-price system. Kessel's empirical foundations are based on the findings of a report to the Secretary of Agriculture by the U.S. Federal Milk Order Study Committee published in 1962 (Nourse, 1962).

The number of FMMOs, and the share of total milk production pooled under federal orders, grew steadily through the 1940s and 1950s. The number of FMMOs peaked in 1962 at 83, at which point 47 percent of all U.S. milk production and 70 percent of Grade A milk was marketed under an FMMO.[2] The expectation that each order would face infinitely-elastic demand for manufacturing milk is consistent with the observation that each individual order would supply small share of manufactured milk products in the relevant market. Further, government purchase programs created a support price for milk used in manufactured products, suggesting that the manufacturing milk demand function was flat at the government support price.

Figure 2.1 depicts Kessel's model for a single order. In this model Kessel defines two equilibrium conditions: at the equilibrium quantity the blend price must equal marginal cost, and at the equilibrium quantity of milk used for beverages the marginal revenue in the fluid milk and manufacturing milk markets must be equal. Based on the first condition, in Figure 2.1 the quantity of milk supplied to the market is Q^s, with producers receiving a blend price equal to P^b. The AR curve defines the blend price for any level of output, with the curve approaching the flat

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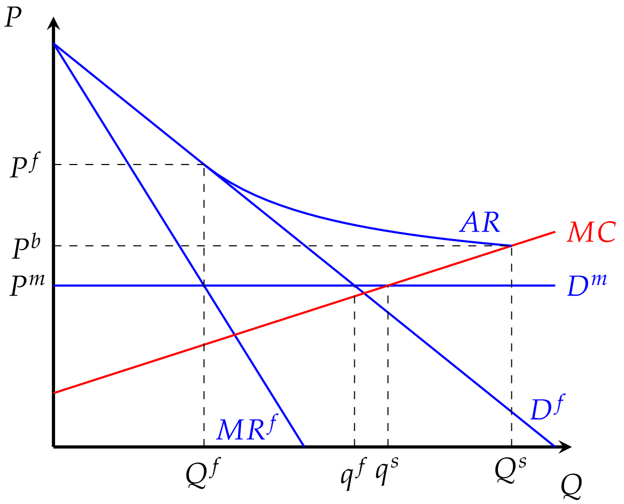
[2] Agricultural Marketing Service, Measures of Growth in Federal Milk Orders

Figure 2.1: Model of a Single Federal Milk Marketing Order from Kessel (1967)



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

manufacturing demand asymptotically. The second condition determines the quantity of milk demanded by the fluid market, Q^f, and the wedge between the fluid and manufacturing milk prices, setting the price paid by fluid milk handlers at P^f. The difference between Q^s and Q^f is supplied to the manufacturing milk market, with processors paying the fixed manufacturing milk price. The counterfactual quantities q^f and q^s depict the quantity of milk that would be demanded by the fluid sector and the total quantity of milk that would be supplied if the marketing order did not exist.

Kessel argues that the milk marketing order framework allows producers to impose a set of rules that govern terms of trade on handlers, and investigates the economic effects of such pricing rules. He finds that a two-price system for identical products leads to an increase in milk production, due to a blend price above the price that would result in the absence of regulation. The quantity of beverage milk demanded is lower due to the higher minimum price under classified pricing, while the quantity supplied to the manufacturing market is higher.

Additionally, Kessel considers whether this set of regulations affects the economic efficiency of the quantity of milk produced. In the 1960s, producers that interacted with FMMOs were those that could cheaply supply a beverage milk market, while producers that exclusively focused on the manufactured product market would not participate in an FMMO. In a region where the market for beverage milk was sufficiently small, such as the Upper Midwest, the benefit of revenue pooling was not large enough to justify the additional cost to produce milk at Grade A sanitary standards. Therefore, regions with a predominant share of Grade B milk would not participate in an FMMO, instead only receiving the price for manufacturing milk. However, due to the increased output among producers who participated in an FMMO, more milk would enter the manufacturing market and depress the price for Grade B milk, lowering the returns for non-order producers. Kessel argues that the non-order producers tend to have a comparative advantage in milk production, so the FMMO regulations would increase output by producers who are less efficient while decreasing production among the non-order producers that hold a comparative advantage.

Note that Kessel does not consider interactions between marketing order regions or the sale of milk between markets. With a flat demand function for manufacturing milk, an excess supply function could not be defined using the model depicted in Figure 2.1. I consider extensions to this model to allow for evaluation of how marketing order regulations affect inter-regional trade in farm milk.

2.2.3 Increases in Interrelated Markets

Starting in the latter half of the 1960s the number of marketing orders declined as they were consolidated and designated marketing areas merged, but the share of U.S. milk production that was regulated under the FMMO system continued to grow. Between 1962 and 1999, the number of marketing orders fell from 83 to 33 while the share of milk marketed through an FMMO increased from 47 percent to 71 percent.[3] Over the same time most operations adopted the increased sanitary standards to produce Grade A milk, so the share of Grade A marketed through the FMMO system stayed between 70 and 80 percent over the same period.

Initially, individual marketing orders were organized as separate systems, created under the same set of guidelines but focused primarily on their local milk market. Each order established their own set of classified pricing rules without considering a national market for milk. Given

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[3] Note that this is only the share of milk marketed through the Federal system, not including state milk marketing orders. In particular, California produced about 16 percent of U.S. milk production in 1999, and participation in the marketing order was mandatory in California. Therefore, the share of milk covered by any marketing order system was much higher.

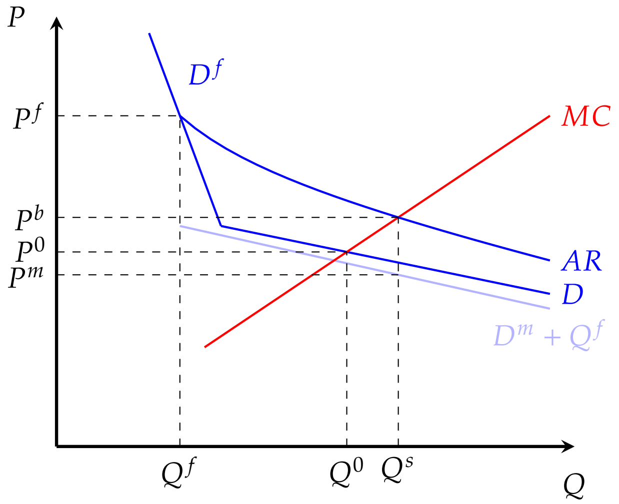
that the majority of milk was not marketed through a marketing order until the late 1960s, FMMO pricing regulations were not the main drivers of national milk prices (Novakovic and Pratt, 1991). As marketing orders began to consolidate and merge marketing areas in the 1960s this view changed, with more focus on connections between markets and transportation between regions (Erba and Novakovic, 1995).

Class prices became more linked across orders throughout the 1960s with the adoption of the Minnesota-Wisconsin Grade B milk price series as a basic input to class price formulas. Since Grade B milk is not regulated by the FMMOs, individual orders gradually adopted the price received for Grade B milk as a representation of the manufacturing milk price under competition (Erba and Novakovic, 1995). When handlers purchase Grade A milk it may be used in beverage products, or it may be used in manufactured products if the demand for milk in beverage products is already met. Therefore, under the two-price classified system the FMMOs established a minimum price for Grade A milk used in manufactured products that accounted for the additional cost of meeting Grade A standards and set the minimum price for milk used in beverage products using an additional price differential. The Minnesota-Wisconsin Grade B price series was introduced in the 1960s and eventually adopted across all FMMOs within the decade (Erba and Novakovic, 1995). With every order adopting the same underlying price series to measure the price of manufacturing milk, minimum class prices became inherently linked across orders as they began utilizing the same formulas.

In 1955, the USDA studied the relationship between milk prices across the U.S., in both regulated and unregulated markets (Trelogan and Herrmann, 1955). Trelogan and Herrmann evaluated barriers to inter-regional shipments of milk and found that milk prices east of the Rocky Mountains could largely be explained by transportation costs and the distance from a base region (Novakovic and Pratt, 1991). Trelogan and Herrmann used Eau Claire, Wisconsin as a base point and estimated how milk prices changed with distance from the region with the greatest surplus of milk production.

Ippolito and Masson (1978) take advantage of the Eau Claire plus transportation cost pricing rule to model the market for milk in the United States as an aggregate of the existing marketing orders. In other words, by considering milk prices that are net of transportation costs, the authors aggregate demand for milk used in beverage products and in manufactured products across the

Figure 2.2: Model of Aggregate Milk Market from Ippolito and Masson (1978)



Source: Author reproduction of "Aggregate Milk Market" panel of Figure 3 from Ippolito and Masson (1978).

U.S. and evaluate the market as if it is one nationwide FMMO. Their model is depicted in Figure 2.2. Note that the model differs from Kessel in that the price of milk used in beverage products, also commonly referred to as "fluid milk," is fixed at P^f and the quantities demanded and supplied are determined from that fixed price. In 2.2 D^f is the demand for fluid milk and the upper portion of the aggregate demand function labeled D, $D^m + Q^f$ is the demand for manufacturing milk assuming that the fluid milk market is satisfied first, MC is the marginal cost, and AR is the average revenue or blend price function. Since the authors consider an aggregate U.S. milk market, the demand for manufacturing milk is downward sloping, and therefore the manufacturing milk price, P^m, is determined endogenously. The equilibrium price and quantity in the absence of regulation are depicted by P^0 and Q^0.

Ippolito and Masson use this model to calculate Harberger-like distortions from competitive welfare results due to the FMMO pricing rules relative to the equilibrium without regulation (Harberger, 1971). They discuss a misallocation distortion from the reduction in fluid milk consumption due to the higher regulated price and the corresponding shift in milk to supply the manufacturing market, causing a decline in the price of manufacturing milk. Ippolito and Masson also consider some regional differences in the cost of milk production in evaluating the increase in milk production due to the increase in price received by milk producers. As output increases in regulated regions the price for manufacturing milk will further decline, leading to decreased milk production in unregulated regions.

This aggregate model obscures the effects of regulation on inter-regional milk movements. Ippolito and Masson acknowledge the increased social cost due to increased shipments of farm milk. They argue that since manufactured milk products are cheaper to transport than farm milk, the efficient social outcome is for shipments of farm milk to only serve the fluid milk market while manufacturing takes place where the cost of milk production is lowest. However, Ippolito and Masson state, "the USDA does appear to determine the general level of price in relation to a goal of ensuring that 'adequate supplies' of bottled milk are available throughout the year in all its market orders." They argue that if the "adequate supplies" are defined in such a way as to meet demand for beverage milk products in parts of the year with the lowest milk production, then in months with higher milk production the quantity produced in excess of beverage milk demand is used in manufactured products. In cases where these "adequate supplies" are met by increased shipments from regions with high milk production to regions with lower milk production, regulatory costs are increased when shipments of farm milk are used in manufactured products in the destination region rather than shipping only the quantity of farm milk needed to meet beverage product demand.

2.2.4 Federal Milk Marketing Order Reform and Consolidation Following the 1996 Farm Bill

The 1996 Farm Bill, officially known as the Federal Agriculture Improvement and Reform Act, or FAIR Act, directed the USDA to consolidate the number of FMMOs and reform the milk marketing order regulatory system. As cooperatives with national reach increased in prominence and larger dairy farms served multiple marketing areas, it became common for marketing regions to implicitly overlap multiple FMMOs. The FAIR Act required USDA to consolidate the existing 32 marketing orders in 1996 to between 10 and 14 merged FMMOs. A separate provision was included to allow for approval of a California FMMO, if desired by California producers, in addition to the consolidated orders if desired by California producers (7 U.S.C. §7253).

In addition to the directive to consolidate marketing orders, the FAIR Act authorized the USDA to restructure the classified pricing system and minimum price formulas. As the share of milk production meeting Grade A standards had increased, the Minnesota-Wisconsin Grade B price series became a poor representation of the price of milk used in manufacturing cheese, butter, and powder products. The replacement for the Minnesota-Wisconsin series was a system of price formulas that used market prices for a specific set of manufactured dairy commodities to establish the minimum prices of milk used to manufacture those and other dairy products. The price formulas set minimum prices for four end-use product categories, detailed in Table 2.1.

Table 2.1: FMMO Milk Utilization Classes and Examples of End-Use Products

Class	Products
I	Beverage milk, flavored milk, eggnog
II	Soft products, cream, ice cream, cottage cheese
III	Hard cheeses, cream cheese
IV	Butter and dry milk products

Source: 7 C.F.R. §1000.15, §1000.40 (2023).

The USDA also evaluated the differential between the price for milk used in manufactured products and the Class I price, the price for milk used in beverage products.[4] A set of Class I differentials was adopted that established differentials across counties using a series of "range bands" that generally reflected the distance from the Upper Midwest. This set of differentials, which have remained constant over time, leads to the current different regional prices for Class I milk.

These changes to order regulations and consolidations of orders geographically were implemented at the beginning of 2000. In general, they resulted in larger marketing areas for each FMMO, a common system of price formulas used by all FMMOs, and a more interconnected system overall.

2.3 Federal Milk Marketing Order Regulations in 2022

Once a Federal Milk Marketing Order is established in a region, the order administers a system of classified pricing and revenue pooling. Classified pricing acts as a form of price discrimination

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[4] Milk in the New England and Other Marketing Areas, 64 Fed. Reg. 16,026, 16,108 (April 2, 1999).

and revenue pooling allows for the redistribution of revenues from discriminatory pricing across milk producers. While FMMOs offer some additional benefits to milk producers, such as research and promotional efforts, these policies are the most important from the perspective of their effect on inter-regional trade.

2.3.1 Classified Pricing

The AMAA of 1937 specifies that milk marketing orders shall provide a structure for classifying milk according to its end use and setting minimum prices to be paid by handlers for each use case (7 U.S.C. §608c(5)(a)). Under the current regulations, each milk handler participating in an FMMO faces the same set of minimum class prices which are only allowed to be adjusted for specific purposes, including the county where the plant receiving milk is located. At the end of each month a regulated handler must account for the use cases of all milk received, and is then responsible for the value associated with each use.

For example, a handler operating a cheese plant who wanted to participate in the FMMO revenue pool would utilize most purchased milk for cheese manufacturing, but would also be required to send some of the farm milk received to a beverage milk bottling plant for the cheese plant to qualify as an FMMO pool plant. If the handler sent 20 percent of milk received to a bottling plant, then they would be responsible for paying the minimum Class I price into the regional revenue pool for the quantity of farm milk utilized in beverage products. The handler would also pay the minimum Class III price into the revenue pool for the remaining 80 percent of milk received that was used for cheese manufacturing. The total payment is referred to as the "classified value" of milk utilization.

2.3.2 Revenue Pooling and Uniform Prices

In addition to providing for milk classification and minimum prices by end-use class, the AMAA of 1937 requires milk marketing orders to ensure all milk producers that deliver milk to a regulated plant receive a uniform minimum price for that milk regardless of how their specific milk is utilized (7 U.S.C. §608c(5)(b)). In other words, a producer that delivers milk to two different manufacturing plants regulated under the same FMMO would receive the same minimum price from both, even though the handlers of the two plants may be responsible for paying different minimum class prices into the revenue pool based on the end uses of the milk that they purchased.

The price received by milk producers is a weighted average of the minimum class prices known as a "blend price." Rather than paying the class minimum price directly to producers, handlers pay producers the blend price so that a uniform price is received. Then, handlers interact with a "producer settlement fund," paying into the fund if the classified value of their milk utilization is higher than the blend price paid to farmers or receiving a payment if the classified value is lower. Once again, handlers are obligated to make these minimum payments as regulated entities under the FMMOs, but plants often pay premiums based on milk quality and market pressures.

In the previous example of the cheese plant handler, if we assume the Class I price is higher than the Class III price, then the handler would be responsible for the difference between the Class I price and the blend price as a payment to the producer settlement fund and would be owed a payment from the fund equal to the difference between the blend price and the Class III price. If the Class I price is the highest price, then handlers with predominantly Class I utilization are responsible for paying into the producer settlement fund. Since the Class III handler in this example uses a greater share of milk that it purchased in cheese manufacturing, they would receive a net payment from the producer settlement fund, drawn from the payments from Class I handlers.

In this case it is beneficial for the cheese-producing handler to participate in the FMMO since they receive a payment that lowers their price paid for milk. It is also beneficial for the dairy farmers delivering milk to this handler, given that they receive a blend price that is higher than the Class III minimum price.

Handlers that utilize milk in Class I products are required to participate in the FMMO based on the assumption that the Class I price is likely to be the highest minimum class price. This is meant to ensure that the producer settlement fund receives positive payments from the handlers associated with the higher-priced use cases. However, the Class I price is not always the highest class price. Situations where the Class III or Class IV minimum prices are higher than the minimum Class I price have occurred during periods when the market prices of butter, nonfat dry milk powder, cheese, or dry whey are particularly high. In such situations, handlers of milk used to produce a manufactured product may be required to pay into the producer settlement fund if they participate in the order.

Since handlers producing manufactured products are not required to participate in the FMMO, this has led to a situation known as "depooling," where handlers choose not to be regulated in a given month if they would be required to pay into the producer settlement fund. In cases of depooling the fund is left with a negative value, reducing the amount received by dairy farmers who deliver to regulated plants. Each FMMO has different rules governing the quantity of milk that may enter the revenue pool in a given month, which may impose restrictions on "repooling" and delay or reduce the frequency of handlers choosing to depool from a marketing order.

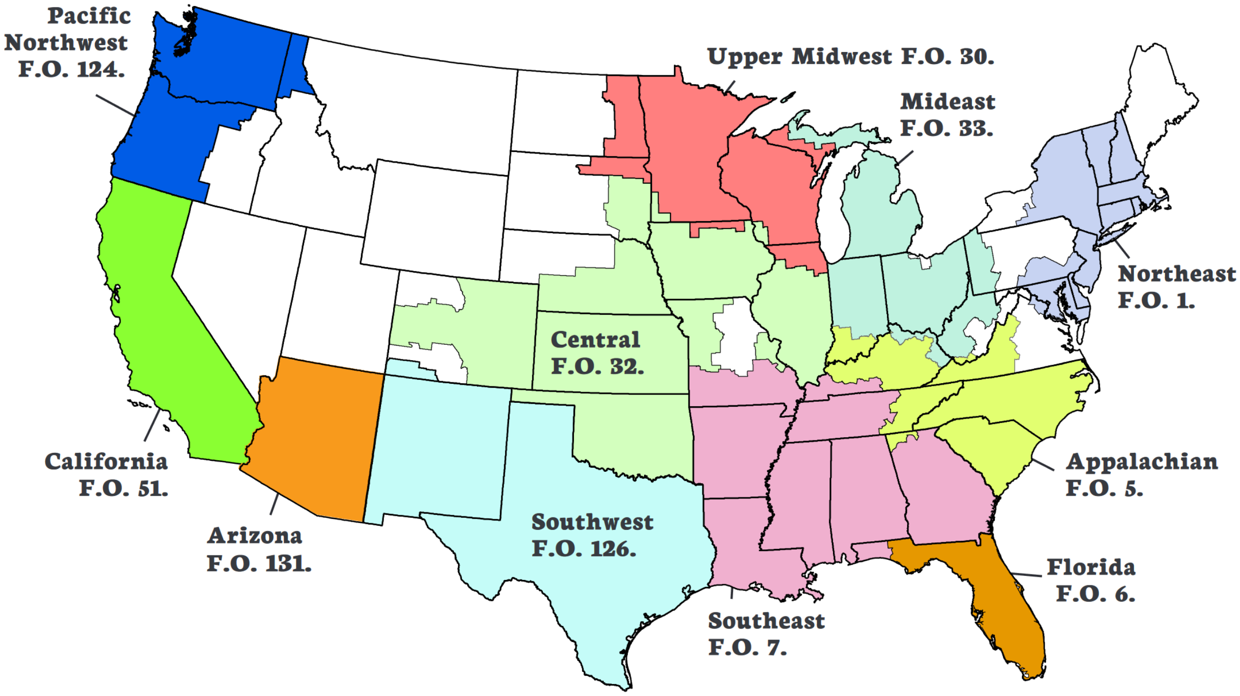
2.3.3 Regional Aspects of FMMO Regulations

Since the marketing order consolidation in 2000, 10 or 11 FMMOs cover a large share of U.S. milk production. Figure 2.3 shows the 11 current marketing areas defined by each FMMO. Since handlers and plants are the regulated entities under an FMMO, the location of a plant primarily determines the marketing area that a handler is associated with. A producer who delivers milk to a handler regulated under a specific marketing order will be associated with that order, regardless of the location of the producer's operation.

For example, a beverage milk bottling plant located in California would be associated with Federal Order 51 if the bottled milk they produce is primarily delivered within California. A dairy farmer in Nevada could deliver milk to the bottling plant in California and qualify as a producer under order 51, even though the producer is located outside of California. The producer would receive the blend price established for California, and if the blend price is higher than what they could receive locally, even subject to transportation costs, then it would be profitable to ship milk between states and pool in the California order to receive the regulated price.

The price received by farmers delivering to a regulated plant depends on the specific location of the plant within a marketing order due to the Class I price differential. The minimum prices for classes II, III, and IV are set nationally, but the minimum Class I price paid by a handler depends on the location of their plant. As a result, the blend price is also adjusted by plant location. When the class minimum prices are established for a given month, the Class I price is set at a base level which can then be adjusted for plant location. Continuing with the previous example of the California bottling plant, a plant located in Los Angeles county would face a Class I minimum price that is \$2.10 above the base price, while a plant located in Sacramento county would pay \$1.70 more than

Figure 2.3: Map of Current Federal Milk Marketing Orders



Source: USDA Agricultural Marketing Service

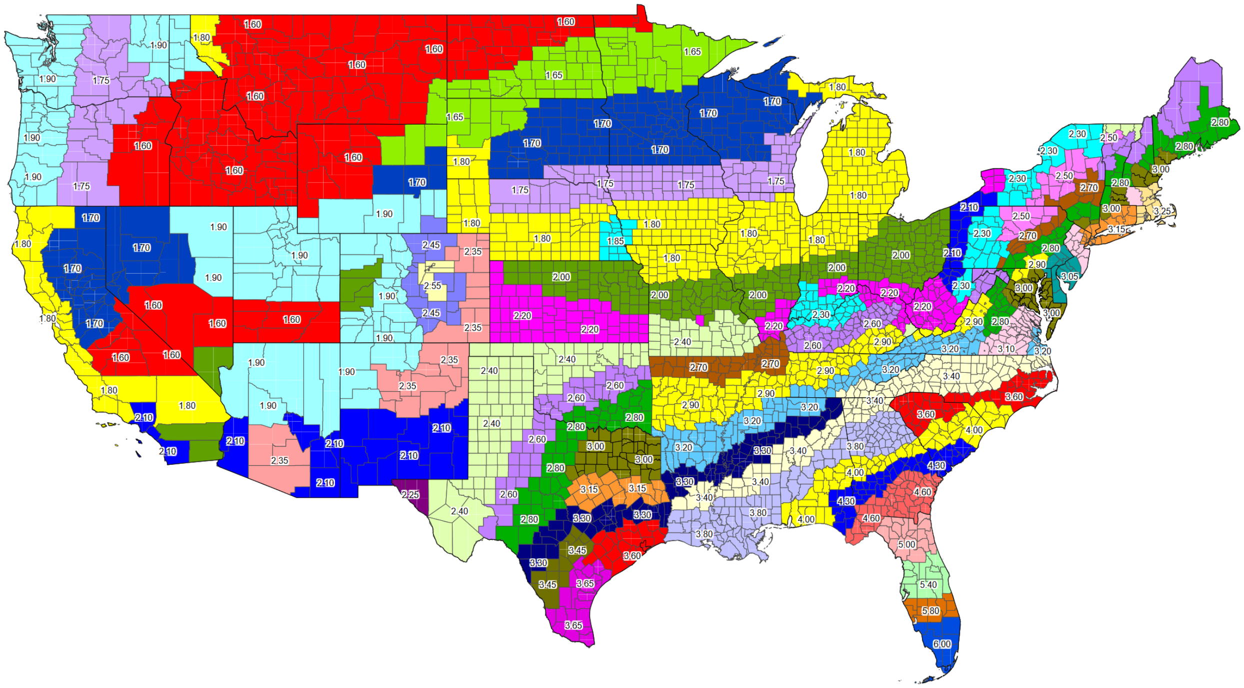
the base price. Figure 2.4 shows the Class I price differentials for each county across the U.S.

The Class I differentials are fixed values that drive the difference in prices across regions. Additionally, due to the revenue pooling mechanism, orders with a higher share of beverage milk utilization relative to other uses of producer milk will generate a higher blend price when the Class I price is high. The blend price redistributes the additional revenue generated from the Class I differential across dairy farmers, regardless of what their milk is used to produce.

Table 2.2 lists the Class I price, Class I milk utilization, and blend prices for each order in August 2022. While the Class I price varies by \$3.60/cwt across regions, the blend price ranges from a low of \$20.60/cwt in the Upper Midwest to \$29.74 in Florida due to the difference in Class I utilization. Since about 84 percent of the milk regulated in the Florida order was used for beverage milk product, the resulting blend price was more strongly influenced by the Class I price, which was already higher than any other order due to the high Class I differential in Florida counties.

The blend prices in Table 2.2 show that, for example, a producer in Ohio could choose to deliver milk to a plant in New York regulated by the Northeast order and receive a FMMO-regulated blend

Figure 2.4: Class I Price Differential by County



Source: USDA Agricultural Marketing Service

price that was about 9 percent higher than if they delivered to a plant regulated under the Mideast order. Unsurprisingly, we observe shipments of farm milk between FMMO regions, despite the relatively high cost of transporting farm milk compared to shipping finished dairy products other than beverage milk.

2.3.4 Shipments of Farm Milk Between Regions

Table 2.3 outlines the origins of the farm milk shipped to and regulated under each marketing order in 2017 (the last year for which the full array of data required to calibrate the model described in Chapter 4 is available). Note that some regions have bi-directional shipments, which would not make sense as point-to-point shipments on the same date for an almost homogeneous product like farm milk. However, since these data are on an annual basis and milk production is highly seasonal, these shipments likely indicate seasonal surpluses and deficits in different regions. They may also reflect that the FMMO areas are large, so transport costs differ substantially within an FMMO region. Consistent with the example given previously, about 130 million pounds of farm milk was shipped from the Mideast region and pooled under the Northeast Federal Order.

Table 2.2: August 2022 Class I Prices, Utilization, and Blend Prices by Order

Order	No.	Class I Price ($/cwt)	Class I Utilization (%)	Blend Price ($/cwt)
Northeast (Boston)	1	28.38	28.72	25.42
Appalachian (Charlotte)	5	28.53	72.98	27.49
Florida (Tampa)	6	30.53	83.57	29.74
Southeast (Atlanta)	7	28.93	77.59	28.17
Upper Midwest (Chicago)	30	26.93	5.77	20.60
Central (Kansas City)	32	27.13	28.05	22.82
Mideast (Cleveland)	33	27.13	38.86	23.33
California (Los Angeles)	51	27.23	21.83	22.38
Pacific Northwest (Seattle)	124	27.03	21.71	23.08
Southwest (Dallas)	126	28.13	28.61	23.16
Arizona (Phoenix)	131	27.48	31.20	23.68

Source: USDA Agricultural Marketing Service.
Note: The cities listed for each marketing order are the principal pricing points for the corresponding Class I prices.

2.4 Extending the Models of FMMO Regulation

The models developed by Kessel (1967) and Ippolito and Masson (1978) provide important insight into the impact of FMMO regulations within a marketing region or with the United States treated as a single market. Extending these models to an inter-regional context creates a simplified framework for discussion of the incentives to ship milk between regions that are introduced by FMMO regulations. The following examples continue with linear supply and demand functions for illustrative purposes and to fix ideas regarding inter-regional milk shipments.

These extensions serve to update the models of Kessel and Ippolito and Masson to reflect current FMMO policy and better represent inter-regional trade and current milk marketing conditions. As discussed previously, Kessel's formulation of the model of milk marketing orders uses an infinitely-elastic demand for manufacturing milk. This was justified by the small share of all manufacturing milk produced by a single order and government price supports through purchases of manufactured dairy products at a fixed price level. Both of these arguments no longer apply. Only 11 FMMOs exist now compared to the large number of small marketing areas at the time of Kessel's article. Likewise, the federal government no longer purchases dairy products through support programs.

Table 2.3: Share of Eligible Milk Production Utilized in Each FMMO Region, 2017

Order	No.	1	5	6	7	30	32	33	51	124	126	131	Not Pooled	Production (Bil. lbs)
Northeast	1	87.52	1.69	0.00	0.04	0	0	7.14	0	0	0	0	3.62	31.1
Appalachian	5	0.50	77.95	0.06	18.52	0.00	0.21	0.32	0	0	0	0	2.48	4.64
Florida	6	0	0.07	92.72	6.76	0	0	0	0	0	0	0	0.46	2.49
Southeast	7	0	6.60	12.20	80.11	0.06	0.35	0	0	0	0	0	0.69	2.29
Upper Midwest	30	0.02	0.00	0	0.01	73.49	1.70	0.35	0	0	0	0	24.44	40.2
Central	32	0	0.54	0	6.89	12.35	59.53	0.26	0.00	0	1.11	0	19.32	20.7
Mideast	33	0.62	6.20	0	2.59	0.79	0.04	84.22	0	0	0	0	5.53	21.1
California	51	0	0	0	0	0	0	0	97.32	0	0	0.41	2.27	40.0
Pacific Northwest	124	0	0	0	0	0	0.00	0	0.23	84.89	0	0	14.88	9.02
Southwest	126	0	0.43	0.06	2.98	0.05	13.40	0.08	0.01	0	62.25	0.39	20.34	20.2
Arizona	131	0	0	0	0	0	0	0	0	0	2.06	96.54	1.39	5.00
Unregulated	–	0	0	0	0	0.06	0.75	0.03	3.32	0.04	1.04	0	94.76	17.9
Total Received (Bil. lbs)		27.4	5.80	2.60	5.45	32.3	15.9	20.2	39.3	7.66	13.1	5.06	39.7	214

Source: USDA Agricultural Marketing Service, Producer Milk Pooled by State of Origin and author calculations.

Note: Eligible milk means Grade A milk, which is eligible for participation in the FMMO system.

Table 2.4: Share of Regional Milk Production that was Exported and Share of Milk Received that was Imported, 2017

Order	No.	Share Exported	Share Imported
Northeast	1	0.089	0.006
Appalachian	5	0.196	0.377
Florida	6	0.068	0.113
Southeast	7	0.192	0.663
Upper Midwest	30	0.021	0.085
Central	32	0.211	0.224
Mideast	33	0.102	0.121
California	51	0.004	0.016
Pacific Northwest	124	0.002	0.001
Southwest	126	0.174	0.040
Arizona	131	0.021	0.048
Unregulated	–	0.052	0.000

Source: Agricultural Marketing Service, Producer Milk Pooled by State of Origin and author calculations.
Note: The share of regional milk production that was exported is the quantity of milk that was shipped from each region to all regions other than the origin region divided by the quantity of milk produced in the origin region. The share of milk received that was imported is the quantity of milk received in the destination region that was not produced in the destination region divided by the total quantity of milk received.

In addition to better reflecting the modern policy environment, as in Ippolito and Masson, downward-sloping demand for manufacturing milk is necessary to model inter-regional trade. In moving from an autarky scenario to one in which trade occurs between regions, the difference between the quantity of milk supplied and quantity of derived demand generates either excess supply or excess demand for a production region. Downward-sloping demand for manufacturing milk ensures total demand is also downward sloping, allowing for calculation of the excess supply and excess demand functions.

Both Kessel and Ippolito and Masson fix either the beverage milk price or manufacturing milk price exogenously, determining the other price and the quantities demanded and supplied from this starting point. This also follows from the government support prices for manufactured dairy products, or an attempt to focus on the regular supply of beverage milk to the market. I allow for both beverage milk and manufacturing milk prices to be endogenous in the model, solving for an equilibrium in which both prices can react to inter-regional trade.

Finally, I model two regions of milk production to show the effects of FMMO regulations on inter-regional trade. This allows for an interpretation of the U.S. milk market as several interconnected regions rather than a single large market or many isolated markets.

2.5 Milk Movement without FMMO Regulation

To outline the model, we start by considering two regions without marketing order regulations. Milk is produced in both regions and the two regions are differentiated by their cost of milk production. The "high-cost" region, denoted by an h subscript, produces milk at a higher marginal cost at all quantities than the "low-cost" region, denoted with an ℓ subscript.

Milk producers face derived demand for milk from beverage milk bottling plants and manufactured dairy product plants. In other words, the demand functions defined below are not representative of consumer demand for dairy products, but rather the demand for farm milk as an input to the manufacturing process. While the market for dairy products is worth discussion, and will be modeled further in Chapter 4, dairy product manufacturers are the regulated entities under FMMO regulations. Therefore, we set aside the indirect effects on consumer demand for direct products to focus on the direct impacts of FMMO regulations on quantities of farm milk demanded by dairy product manufacturers.

Due to the relatively high cost to transport beverage milk products, markets for beverage milk products tend to be local, and therefore we model the derived demand functions for milk used in beverage products differently across the two regions. We assume that the high-cost region also faces higher demand for beverage milk products. As an example, the high-cost region could represent the Northeast or the Southeast, where a higher share of milk goes to fluid consumption and milk production costs are generally higher. The low-cost region has fewer beverage milk consumers, similar to the Upper Midwest or the West where costs are lower and most milk is used in manufactured products.

We assume both regions face identical derived demand for manufacturing milk, both for simplicity and to reflect the more national scope of the market for manufactured dairy products. While the derived demand function is still downward sloping to reflect demand from local manufacturing plants, manufactured products are more readily trade due to lower transportation costs and potential for storage.

2.5.1 Autarky Equilibrium without FMMO Regulation

We first consider an autarky case where no milk is traded between the two regions. This does not mean that no trade occurs between these regions, simply that the cost to transport farm milk is sufficiently high that milk is not shipped. It may be the case that manufactured dairy products are traded to satisfy consumer demand, but that is outside the scope of this model.

Let the quantities of milk demanded for use in beverage products and manufactured products be represented by the following linear demand functions:

$$Q_h^f = a_h^f - b^f P_h \qquad Q_\ell^f = a_\ell^f - b^f P_\ell, \tag{2.1}$$

$$Q_h^m = a^m - b^m P_h \qquad Q_\ell^m = a^m - b^m P_\ell, \tag{2.2}$$

$$Q_h^d = (a_h^f + a^m) - (b^f + b^m) P_h \qquad Q_\ell^d = (a_\ell^f + a^m) - (b^f + b^m) P_\ell, \tag{2.3}$$

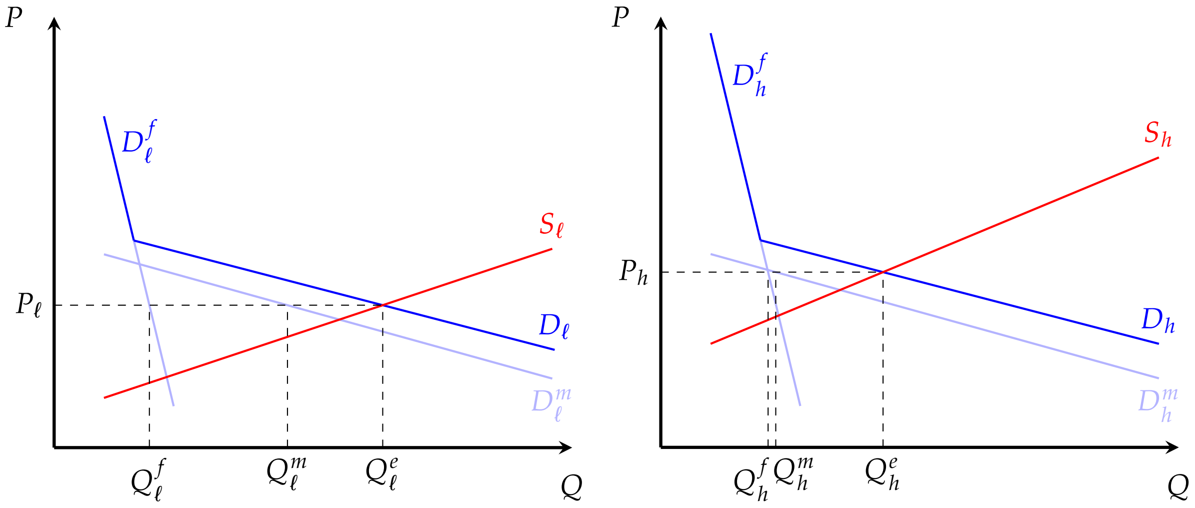
where Q_h^f and Q_ℓ^f are the quantities of milk demanded for use in beverage products, Q_h^m and Q_ℓ^m are the quantities demanded for use in manufactured products, and Q_h^d and Q_ℓ^d are the total quantities of milk demanded. Lower demand for milk used in beverage products in the low-cost region is modeled as a shift in the demand function towards the vertical axis relative to demand in the high-cost region, i.e., $a_\ell^f < a_h^f$. However, note that the slope parameters in equation (2.1) are identical, as are the slope and intercept parameters in equation (2.2).

The supply functions for the low-cost and high-cost regions reflect the differences in marginal costs:

$$Q_h^s = u_h P_h - v_h \qquad Q_h^s = u_h P_h - v_h. \tag{2.4}$$

The low-cost region supply is modeled with a lower intercept, $v_\ell < v_h$, and a flatter slope, $u_\ell > u_h$, relative to the high-cost region. These assumptions are reflected in the supply and demand functions plotted in Figure 2.5.

Figure 2.5: Autarky Equilibria for Regions h and ℓ



In the autarky case with no pricing regulations each region achieves a separate equilibrium. The equilibrium milk price is determined where quantity supplied equals the total quantity of milk demanded:

$$(a_h^f + a^m) - (b^f + b^m)P_h = u_h P_h - v_h \qquad (a_\ell^f + a^m) - (b^f + b^m)P_\ell = u_\ell P_\ell - v_\ell,$$

$$P_h = \frac{a_h^f + a^m + v_h}{b^f + b^m + u_h} \qquad P_\ell = \frac{a_\ell^f + a^m + v_\ell}{b^f + b^m + u_\ell}, \tag{2.5}$$

where P_h P_ℓ are the equilibrium prices in region ℓ in the autarky case. The equilibrium quantities supplied to the market are depicted as Q_h^e and Q_ℓ^e in in Figure 2.5.

In this example, we see that the low-cost region uses a higher share of total farm milk in manufactured products. Again, it may be that the low-cost region ships manufactured products to the high-cost region, an outcome which would not require farm milk to be shipped between regions. This scenario may in fact reflect the most realistic outcome in the absence of FMMO regulation, since both regions are able to supply their local markets for beverage products and could trade in finished manufactured products. However, we will now explore a case where the cost to transport milk is sufficiently low for the low-cost region to ship farm milk to the high-cost region.

2.5.2 Trade Equilibrium without FMMO Regulation

We now model trade in farm milk between the two regions subject to an additive transportation cost. The low-cost region will become a net exporter of milk to the high-cost region if the transportation cost is sufficiently low.

For a given price P that is above the autarky equilibrium price in the low-cost region, P_ℓ, the low-cost region will have excess supply determined by subtracting equation (2.4) from equation (2.3).

$$\begin{aligned} XS_\ell(P) &= u_\ell P - v_\ell - (a_\ell^f + a^m) + (b^f + b^m)P, \\ &= (b^f + b^m + u_\ell)P - (a_\ell^f + a^m + v_\ell). \end{aligned} \tag{2.6}$$

Let τ represent the per-unit transportation cost between the low-cost region and the high-cost region. Given the prevailing price in the high-cost region, P_h, producers in region ℓ will face a price $P_h - \tau$ to deliver to region h:

$$XS_\ell(P_h, \tau) = (b^f + b^m + u_\ell)(P_h - \tau) - (a_\ell^f + a^m + v_\ell). \tag{2.7}$$

From this equation we can also determine a threshold for the transportation cost above which the low-cost region will not ship to the high-cost market. Setting $XS_\ell(P_h, \tau) = 0$ and solving for τ, we find that trade occurs only if:

$$\tau \leq P_h - \frac{a_\ell^f + a^m + v_\ell}{b_\ell^f + b^m + u_\ell}, \tag{2.8}$$

where the latter fraction is the value of P_ℓ under autarky. In other words, the transportation cost must be less than the difference between the price in the high-cost region under trade and the price in the low-cost region under autarky, otherwise producers in the low-cost region would be better off only supplying the local market.

The high-cost region will have excess demand at price P_h found by subtracting equation (2.3) from equation (2.4):

$$\begin{aligned} XD_h(P_h) &= (a_h^f + a^m) - (b^f + b^m)P_h - u_h P_h + v_h, \\ &= (a_h^f + a^m + v_h) - (b^f + b^m + u_h)P_h. \end{aligned} \tag{2.9}$$

Equating equations (2.7) and (2.9) will determine the equilibrium price in the high-cost region subject to the transportation cost, τ:

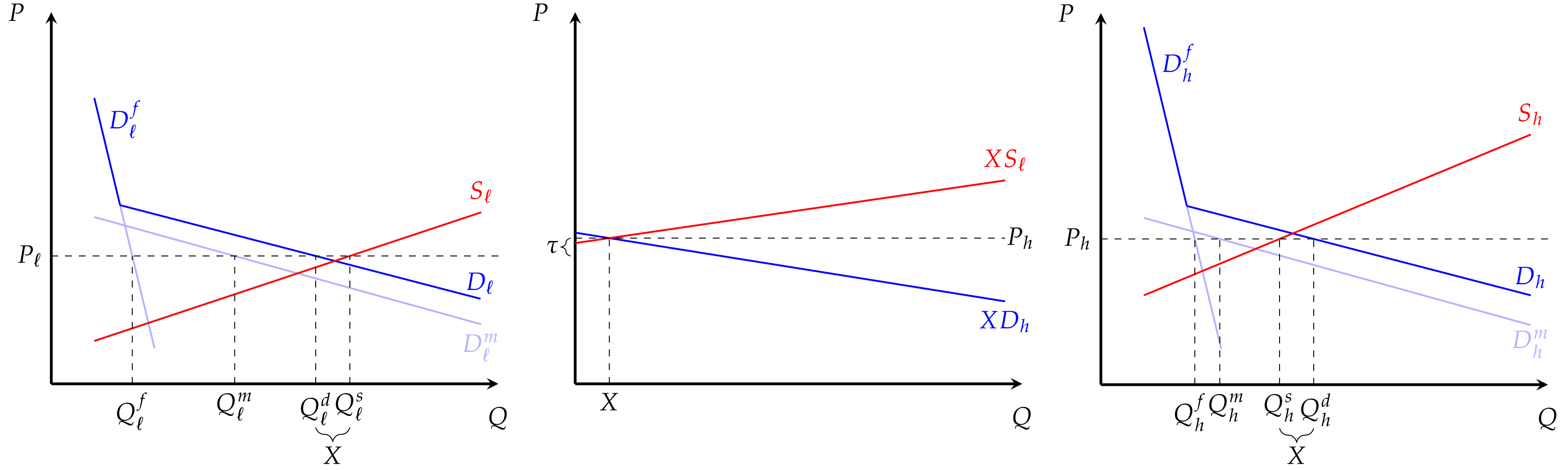
$$\begin{aligned} (b_\ell^f + b^m + u_\ell)(P_h - \tau) - (a_\ell^f + a^m + v_\ell) &= (a_h^f + a^m + v_h) - (b_h^f + b^m + u_h)P_h, \\ P_h &= \frac{(a_h^f + a^m + v_h) + (a_\ell^f + a^m + v_\ell) + (b^f + b^m + u_\ell)\tau}{(b^f + b^m + u_\ell) + (b^f + b^m + u_h)}. \end{aligned} \tag{2.10}$$

Equation (2.10) shows that a higher transportation cost will increase the equilibrium price in the high-cost region up to the autarky level. The transportation cost forms a wedge between the prices received by dairy farmers in region ℓ and region h. The trade equilibrium is depicted in figure 2.6, which assumes the transportation cost is below the threshold defined in Equation (2.8).

The trade equilibrium between the low-cost and high-cost regions is depicted in Figure 2.6. We can see that, relative to the autarky equilibria depicted in Figure 2.5, the milk price in the high-cost region has fallen while the price in the low-cost region has increased, with τ shown as a wedge between the prices in the center panel. At the new prevailing prices in each region, the low-cost region exports a quantity of milk represented as X. In the high-cost region the imported milk is primarily used in manufactured dairy products, while less milk is used in manufactured products in the low-cost region.

This case, with a sufficiently low transportation cost for farm milk, would generate gains from trade due to an increase in milk production in the region with a comparative advantage. In reality this could occur between two regions that are close geographically, such that transportation costs are at a minimum, or with sufficiently different costs of milk production. However, it is likely that the most efficient outcome would be for the low-cost region to continue supplying manufactured products to the high-cost region without shipping farm milk, as seen in the autarky case. Without considering trade in dairy products in these examples this is difficult to represent, but it is fully considered in the model in Chapter 4.

Figure 2.6: Trade Equilibrium in Each Region with Low Transportation Costs



2.6 Milk Trade with FMMO Regulations

Each FMMO introduces a set of regulations in their respective marketing regions, but the primary policies we represent in these examples are classified pricing and revenue pooling. In this section we emulate these policies in the high-cost region and demonstrate how FMMO regulations act to increase the quantity of milk produced, the quantity shipped from the low-cost region to the high-cost region, and the quantity of milk available for manufactured dairy products.

In both the autarky case and the trade example examined previously bottling plants and manufacturing plants paid the same price for farm milk. Classified pricing sets separate minimum prices depending on milk utilization, so milk buyers in an FMMO region will pay different prices depending on the end-use products that are manufactured. This is emulated in the high-cost region by introducing a wedge, w_h, between the price paid for milk used in manufactured products, P_h^m, and the price paid for milk used in beverage products, P_h^f.

Milk producers receive a weighted average of the beverage and manufacturing minimum prices, denoted P_h^b, regardless of how their milk is utilized. If producers in the low-cost region ship milk to the high-cost region and "pool" under the FMMO, then they also receive the blend price. Under these policies the milk price received by farmers will increase, the price paid by buyers for beverage milk plants will increase, and the price paid by manufacturers will decrease, leading to distortions relative to the equilibrium in Figure 2.6.

2.6.1 Introducing a Milk Marketing Order in the High-Cost Region

Returning to the autarky case, we can consider the effects of the FMMO-style price regulations in the high-cost region in isolation. Since the wedge between the beverage milk price and manufacturing milk price is a fixed value, we can set $P_h^f = P_h^m + w_h$ and reduce the number of endogenous prices. The derived demand functions are then functions of the price paid for milk used in manufactured products, P_h^m, and the price wedge, w_h:

$$Q_h^f \left(P_h^m, w_h\right) = a_h^f - b^f \left(P_h^m + w_h\right), \tag{2.11}$$

$$Q_h^m \left(P_h^m, w_h\right) = a^m - b^m P_h^m, \tag{2.12}$$

$$Q_h^d \left(P_h^m, w_h\right) = \left(a_h^f + a^m\right) - \left(b^f + b^m\right) P_h^m - b^f w_h. \tag{2.13}$$

With the price wedge serving as a policy parameter, both the manufacturing milk and beverage milk prices are set endogenously. As stated previously, Ippolito and Masson treat the beverage milk price as an exogenous policy parameter, fixing the quantity of milk demanded for use in beverage products before determining the market equilibrium. Both approaches reflect some aspects of the FMMO regulations, but lead to largely similar conclusions regarding the impact of those policies.

The blend price is calculated as a quantity-weighted average of the manufacturing and beverage milk prices:

$$\begin{aligned} P_h^b &= \frac{P_h^m Q_h^m + P_h^f Q_h^f}{Q_h^d}, \\ &= P_h^m + w_h \frac{Q_h^f}{Q_h^d}. \end{aligned} \tag{2.14}$$

From equation (2.14) we can see that the blend price redistributes the additional revenue generated from the price wedge, $w_h Q_h^f$, across all milk produced by dairy farmers in region h.

The autarky equilibrium with pricing regulations is determined by equations (2.4) and (2.11)-(2.14), with P_h^m, P_h^m, and the quantities endogenous. Quantity supplied is determined where marginal cost is equal to the blend price, equivalent to the average revenue. To find an equilibrium by equating equation (2.4) and equation (2.14), the latter must be in terms of total quantity demanded instead of multiple endogenous variables. Rearranging equation (2.13) gives an inverse demand function:

$$P_h^m = \frac{a_h^f + a^m - b_h^f w_h - Q_h^d}{b_h^f + b^m}. \tag{2.15}$$

Substituting this expression into equation (2.11) defines the quantity of beverage milk demanded in terms of the total quantity of milk demand, which can then be used in equation (2.14) to yield an expression for the blend price that is solely in terms of total quantity demanded:

$$\begin{aligned} P_h^b\left(Q_h^d\right) &= \frac{a_h^f + a^m - b_h^f w_h - Q_h^d}{b_h^f + b^m} + \frac{w_h}{Q_h^d}\left(a_h^f - b_h^f w_h - b_h^f \frac{a_h^f + a^m - b_h^f w_h - Q_h^d}{b_h^f + b^m}\right), \\ &= \frac{a_h^f + a^m - Q_h^d}{b^f + b^m} + \frac{w_h}{Q_h^d}\left(\frac{a_h^f b^m - b^f a^m - b^f b^m w_h}{b^f + b^m}\right). \end{aligned} \tag{2.16}$$

Equation (2.16) is an average revenue function, which can now be set equal to the marginal cost defined as the inverse of equation (2.4):

$$\frac{Q_h^e + v_h}{u_h} = \frac{a_h^f + a^m - Q_h^e}{b^f + b^m} + \frac{w_h}{Q_h^e}\left(\frac{a_h^f b^m - b^f a^m - b^f b^m w_h}{b^f + b^m}\right), \tag{2.17}$$

where Q_h^e is the equilibrium quantity of milk supplied in the autarky case. While Q_h^e is fully determined by equation (2.17), an explicit expression is only defined using the quadratic equation. Since the expression is complex and does not help understanding, I have excluded it for the sake of brevity.

The model depicted in Figure 2.7 is not too dissimilar from the Ippolito and Masson model in Figure 2.2, though with some small differences due to the beverage milk price being determine endogenously. Relative to the autarky equilibrium in the high-cost region without FMMO regulations, less milk is used in beverage milk products due to the higher minimum price while overall milk production has increased since the blend price is greater than the equilibrium price without regulation. The combination of these effects leads to more milk utilization in manufactured products. Ippolito and Masson argue that this result leads to an increase in social cost as fewer manufactured products are produced in regions with a comparative advantage. With the changes to U.S. trade policy since the mid-1990s, it is also likely that more manufactured products are exported as a result of these pricing rules.

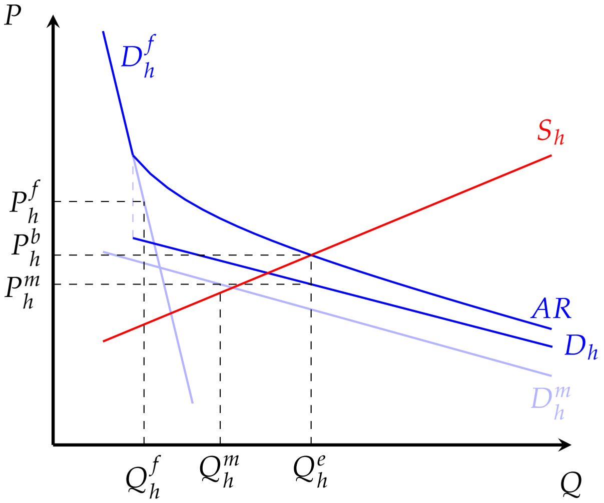
Note that the value used for w_h in Figure 2.7 is larger than the average Class I price wedge in reality. Using a larger value in the figure allows for clarity but is not intended to reflect actual prices. The Class I price differentials are shown in Figure 2.4 and vary across regions.

2.6.2 Trade Equilibrium with the High-Cost Region Marketing Order

If transportation costs are high, then introducing FMMO-style pricing regulations in the high-cost region would have no effect on the low-cost region, if it continues to be unregulated. In that case, the low-cost region would be comparable to the unregulated portions of the Western U.S., with Idaho as a prime example.

However, the transportation cost threshold defined in equation (2.8), below which inter-regional trade in milk would occur, is higher under the FMMO regulations since the blend price in the high-

Figure 2.7: Autarky Equilibrium with FMMO Regulations in High-Cost Region



cost region is higher than the price received by farmers in the unregulated case. Therefore, it is possible that an autarky case of separate regional equilibria, as depicted in Figure 2.5, becomes an inter-regional equilibrium with trade in farm milk due to the introduction of the FMMO regulations.

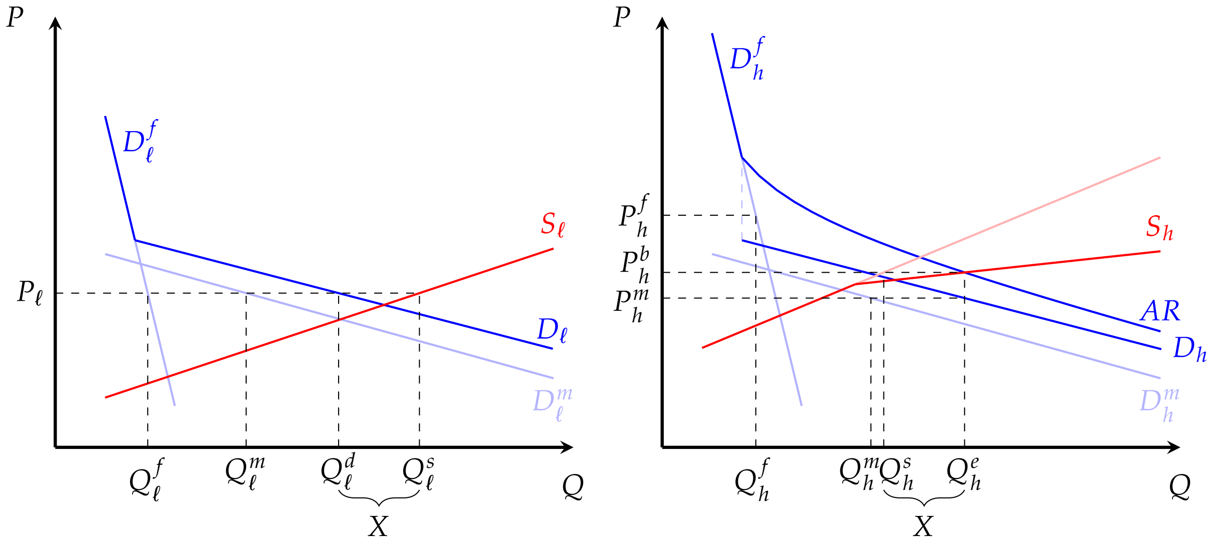
Unlike in the trade equilibrium without regulation, excess demand from the high-cost region can no longer be defined as the difference between the quantity demanded and the quantity supplied for a given price. As seen in Figure 2.7, the quantity supplied is determined where the supply function is equal to the average revenue curve, with the price for manufacturing milk determined where the inverse demand function is equal to the quantity supplied. In other words, all milk supplied to the high-cost region will find a use, given that the manufacturing price is set to clear the market. However, excess supply from the low-cost region can be added to the supply function for the high-cost region to define the total supply of milk to the high-cost region. As before, the excess supply from the low-cost region, subject to transportation costs, is defined by equation (2.7). Adding equation (2.7) to equation (2.4) for the high-cost region defines total supply:

$$S_h\left(P_h^b, \tau\right) = u_h P_h^b - v_h + \left(b_\ell^f + b^m + u_\ell\right)\left(P_h^b - \tau\right) - \left(a_\ell^f + a^m + v_\ell\right) \tag{2.18}$$

$$= \left(b_\ell^f + b^m + u_\ell + u_h\right) P_h^b - \left(b_\ell^f + b^m + u_\ell\right)\tau - \left(a_\ell^f + a^m + v_\ell + v_h\right) \tag{2.19}$$

The inverse of equation (2.19) defines the marginal cost of milk delivered to the high-cost region.

Figure 2.8: Trade Equilibrium with FMMO Regulations in the High-Cost Region



Setting this expression equal to the average revenue defined by equation (2.16) determines the equilibrium quantity supplied to the high-cost region and the corresponding blend price. The resulting quadratic equation is similar to equation (2.17) but with the addition of parameters from the low-cost region entering through the total supply function:

$$\frac{Q_h^e + (b^f + b^m + u_\ell)\tau + (a_\ell^f + a^m + v_\ell + v_h)}{(b^f + b^m + u_\ell + u_h)} = \frac{a_h^f + a^m - Q_h^e}{b^f + b^m} + \frac{w_h}{Q_h^e}\left(\frac{a_h^f b^m - b^f a^m - b^f b^m w_h}{b^f + b^m}\right) \tag{2.20}$$

The inter-regional trade equilibrium is depicted in Figure 2.8. Notice that the total supply curve for the high-cost region is now kinked at the low-cost region autarky price plus the transportation cost. If the prevailing price in the high-cost region were to fall below this level, then inter-regional trade would cease and the region would only be supplied by local producers.

With the additional quantity supplied from the low-cost producers the blend price under the trade equilibrium is lower than in the autarky case. Therefore, milk production in the high-cost region is lower, represented by Q_h^s in Figure 2.8, even though more milk is supplied to the market overall. As a result, a share of the additional revenue from beverage milk price discrimination is distributed to low-cost region producers. To the extent that this additional revenue covers transportation costs between the regions, trade in farm milk will increase under FMMO regulations.

Consider the excess supply function for the low-cost region defined by equation (2.7). Let P_h^0 be the price in the high-cost region in the trade equilibrium without regulation. Then, $XS_\ell(P_h^0, \tau)$ is the quantity of milk shipped to the high-cost region by producers in the low-cost region in the scenario without FMMO regulations. We can determine the increase in milk shipments by calculating the difference between the excess supply in the scenario with regulation, $XS_\ell(P_h^b, \tau)$, and $XS_\ell(P_h^0, \tau)$:

$$\begin{aligned} XS_\ell(P_h^b, \tau) - XS_\ell(P_h^0, \tau) &= (b^f + b^m + u_\ell)(P_h^b - \tau) - (b^f + b^m + u_\ell)(P_h^0 - \tau), \\ &= (b^f + b^m + u_\ell)(P_h^b - P_h^0). \end{aligned} \tag{2.21}$$

Therefore, since the blend price under FMMO-style regulation will always be higher than the equilibrium farm milk price in the absence of regulation, the quantity of milk shipped between regions will be higher when one region implements a marketing order.

2.6.3 Trade Equilibrium with a Marketing Order in Both Regions

The final scenario to consider is one in which both regions implement FMMO-style regulations. We have already detailed what this looks like for the high-cost region, and the policies are emulated in a similar fashion for the low-cost region.

Let w_ℓ denote the price wedge between the manufacturing and beverage milk prices, with $w_\ell < w_h$ to reflect the higher level of milk production in the low-cost region. In general, the Class I price differentials are set such that regions with higher milk production have lower differentials. As in the high-cost region, the price wedge enters into the set of demand functions as follows:

$$Q_\ell^f\left(P_\ell^m, w_\ell\right) = a_\ell^f - b^f\left(P_\ell^m + w_\ell\right), \tag{2.22}$$

$$Q_\ell^m\left(P_\ell^m, w_\ell\right) = a^m - b^m P_\ell^m, \tag{2.23}$$

$$Q_\ell^d\left(P_\ell^m, w_\ell\right) = \left(a_\ell^f + a^m\right) - \left(b^f + b^m\right) P_\ell^m - b^f w_\ell. \tag{2.24}$$

From these demand functions we can then derive an expression for the low-cost region blend price:

$$P_\ell^b\left(Q_\ell^d\right) = \frac{a_\ell^f + a^m - Q_\ell^d}{b^f + b^m} + \frac{w_\ell}{Q_\ell^d}\left(\frac{a_\ell^f b^m - b^f a^m - b^f b^m w_\ell}{b^f + b^m}\right). \tag{2.25}$$

Given the conditions in the high-cost region, the blend price in region h will be above the blend price in region ℓ, therefore leading to net exports from the low-cost region. The blend price in a region is determined by the quantity of milk utilized by milk buyers in that region, and as producers in the low-cost region ship milk to the high-cost region less milk will be "pooled" in region ℓ, in turn increasing the local blend price. Similarly, as milk from the low-cost region is received and utilized in the high-cost region, the region h blend price will fall until the two prices reach the same level (subject to the transportation cost).

To define the excess supply function for the low cost region, we first need to determine the quantity utilized at a given blend price level. This quantity is found by setting equation (2.25) equal to an arbitrary price level and solving for Q_ℓ^d:

$$Q_\ell^d(P) = \frac{1}{2}\left((a_\ell^f + a^m) - (b^f + b^m)P\right) + \left(\frac{1}{4}\left((a_\ell^f + a^m) - (b^f + b^m)P\right)^2 + w_\ell\left(b^m(a_\ell^f - b^f w_\ell) - b^f a^m\right)\right)^{\frac{1}{2}} \tag{2.26}$$

Then, given the blend price from region h, P_h^b, and the transportation cost, τ, the excess supply from the low-cost region is the difference between the quantity supplied and the quantity utilized at price $P_h^b - \tau$:

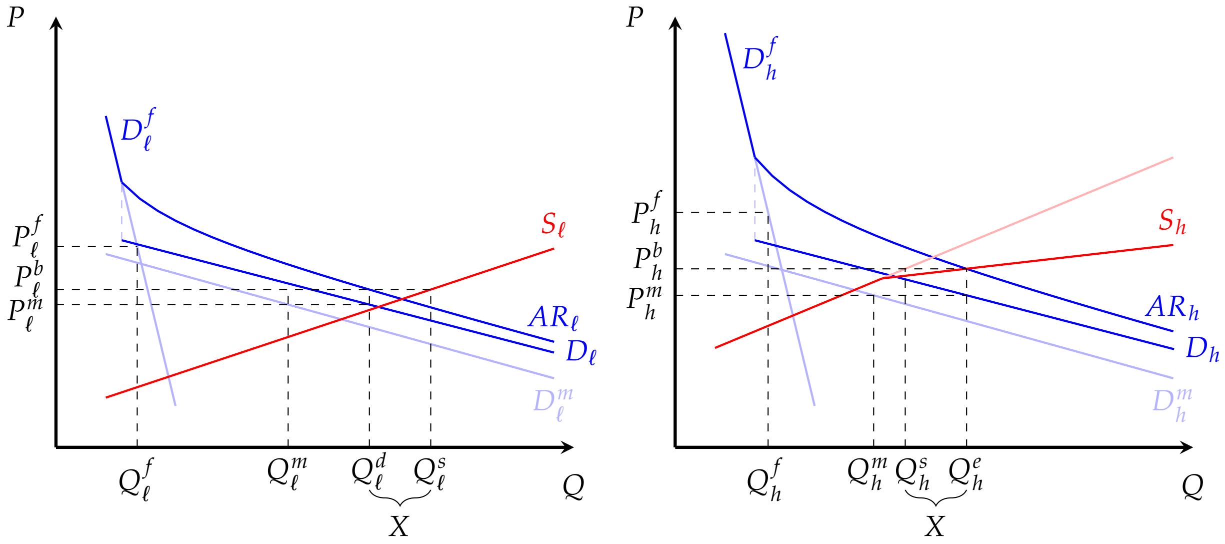
$$XS_\ell(P_h^b, \tau) = u_\ell(P_h^b - \tau) - v_\ell - Q_\ell^d(P_h^b - \tau). \tag{2.27}$$

As before, the total milk supplied to the high-cost region is found by adding the excess supply from region ℓ to the local supply function for region h:

$$S_h(P_h^b, \tau) = (u_h + u_\ell)P_h^b - (v_h + v_\ell) - u_\ell\tau - Q_\ell^d(P_h^b - \tau). \tag{2.28}$$

This function is then set equal to the average revenue curve, or the inverse of the average revenue to ensure both functions are on a quantity basis, to determine the blend price and equilibrium

Figure 2.9: Trade Equilibrium with FMMO Regulations in Both Regions



quantity in the high-cost region. Once P_h^b is determined, we can work backwards to find the equilibrium blend price, quantity of milk utilized locally, and overall quantity of milk supplied in the low-cost region.

The trade equilibrium with FMMO-style regulations in both regions is depicted in Figure 2.9. Compared to Figure 2.8 the equilibrium in the high-cost region is fairly similar, with a slightly higher blend price compared to the trade equilibrium with only the high-cost region regulated. With marketing order regulations now in place in the low-cost region, the price that milk producers would receive in the absence of trade is higher due to revenue pooling, leading to lower exports of farm milk relative to the cases where region ℓ is unregulated. Therefore, we should expect less trade in farm milk between two regions with marketing orders than from an unregulated region to a regulated region. This also suggests that when two regulated regions are similar in terms of Class I milk utilization and price differentials, and thus are more likely to have blend prices at similar levels, the incentive to trade in farm milk will be lower.

2.7 Conclusion

The models of FMMO regulations and the market for farm milk developed by Kessel and Ippolito and Masson demonstrate that FMMO pricing rules lead to greater milk production and more farm milk utilized in manufactured products than would be the case otherwise. By extending these models to a case with two regions, I demonstrate that when FMMO pricing rules are introduced in one or both regions more farm milk is shipped between regions than in the scenario without regulation. Additionally, I show that FMMO regulations may increase the price received by farmers enough to shift from an autarky case, where no farm milk is shipped between regions, to a case with trade in farm milk.

These models are useful for discussing FMMO regulations and their impacts on milk markets, but, given that they are specified in general terms, they do not allow for explicit calculation of the magnitude of those effects. Data and parameters that represent shipments of dairy products between regions are developed and explained in Chapter 3. The model developed in Chapter 4 takes the concepts introduced in this chapter and develops them further within the structure of an inter-regional trade model that is calibrated to recent data and imposes explicit quantitative parameters drawn from the literature. I use this framework to simulate the quantitative impacts of FMMO regulations.

Chapter 3

Interpolating Inter-Regional Trade Flows in Dairy Products and Feed Crops

A detailed analysis of the impact of the Federal Milk Marketing Orders (FMMOs) on inter-regional trade requires measures of shipments of all processed dairy products and feed crops between regions. Chapter 4 develops a model that is calibrated, in part, using bilateral trade shares calculated from available data on inter-regional trade flows. While data on international trade are widely available, measures of sub-national trade are often difficult to find, especially disaggregated across commodities. Some sources of data on U.S. inter-regional shipments are available, but are limited in their usefulness due to missing or suppressed observations. Therefore, by interpolating the missing observations and using the available data to improve the interpolation process, I produce a data set capable of calibrating the Chapter 4 model.

In the inter-regional trade literature, it is common to utilize some form of interpolation to generate an inter-regional trade flow matrix for use in analysis. A typical approach is to rely on the gravity-style representation of trade flows that is widely-used in international trade research. By using a gravity-style model as a foundation, the interpolation approaches ensure that regions that are closer together are more likely to trade with one another. Additionally, origin regions that are "large," using an appropriate definition of size, are more likely to be the source of a given trade flow, while "large" destination regions are more likely to receive trade flows. Even with a lack of available data on inter-regional trade, these basic elements of the interpolation approaches that are derived from a gravity-style model ensure that the resulting interpolated trade flows are consistent with observed data on regional production, consumption, and distance.

This chapter outlines a procedure to use available data on the value of regional production and consumption of dairy products and feed crops to interpolate missing data on inter-regional trade flows. First, I introduce the data utilized in this procedure and discuss the missing observations. Then, the interpolation procedure is outlined generally and compared to the standard gravity model utilized in the international trade literature. Finally, two specific procedures are discussed in detail, applied to the available data, and evaluated for accuracy against the known observations of inter-regional trade.

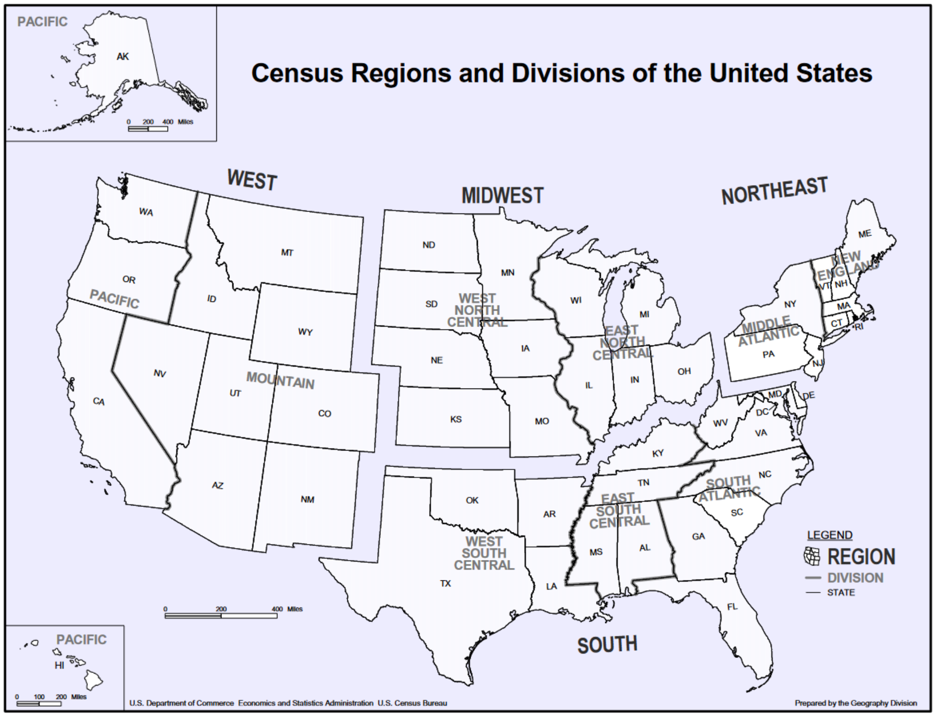
3.1 Description of Data

Two sources of data underlie the calculations of inter-regional trade flows in dairy products and crops. The Commodity Flow Survey (CFS) is conducted every five years by the U.S. Census Bureau and the Bureau of Transportation Statistics, with the most recent survey measuring shipments of raw materials and finished goods by shipping companies in 2017. Shipments are measured in value and weight by origin, destination, and commodity. Ideally, this would provide state-level observations of inter-regional trade that could be used to calculate bilateral trade shares for dairy products and feed crops.

However, some observations are suppressed by the Census Bureau and Bureau of Transportation Statistics before the CFS is released. This may be due to insufficient data or a risk of revealing individual operations and results in missing values. However, it is likely that these suppressed observations are non-zero, and I must use the available data to interpolate the missing values.

In addition to the CFS, the National Agricultural Statistics Service (NASS) provides data on crop sales through the Census of Agriculture and other surveys of crop production. I use these data to represent the value of crop production in each state as one input to the interpolation procedure for inter-regional trade. The CFS also reports shipments of feed crops between regions, but for reasons described in detail below it is preferable to use NASS data.

Figure 3.1: Census Bureau Geographic Levels Used in Commodity Flow Survey Data



Source: U.S. Census Bureau

3.1.1 Commodity Flow Survey Data on Dairy Product Shipments

The CFS data used in this study were provided by the Census Bureau as a special tabulation of publicly-available CFS data. Observations consist of the dollar value and weight of commodity shipments between origins and destinations at multiple geographic levels, including states, Census divisions and regions, and the United States as a whole (Figure 3.1).

The interpolation procedures used in this chapter require inputs of state-level values of production and consumption for each commodity. Since shipment observations are are also reported for higher-level origins and destinations, I use the aggregate measures of shipment value to and from all other U.S. destinations to represent the state-level values of production and consumption.

For example, consider cheese shipments from California. CFS observations include the value and weight of cheese shipped from California to all other states, including to destinations within California. If every observation was available, then these data could be used to calculate bilateral trade shares for California. However, since some observations are suppressed, I use the available data to calculate the total value of cheese shipments originating California as an input to the interpolation procedure. The data include aggregate shipments to higher-level geographic regions, so observations include cheese shipments from California to each of the Census divisions, regions, and the U.S. Since the reported value of shipments of cheese from California to the U.S. aggregates observed values of all shipments to U.S. destinations (including observations that may have been suppressed), I use this observation to represent the value of California cheese production. Mirroring this process, the aggregate value of shipments from all U.S. destinations to California is used as the value of California cheese consumption.

In some cases these aggregate shipments may also have suppressed observations. When U.S.-aggregate shipment values are not available for a state I use shipments between Census divisions and regions to back out the values for each state in a specific geographic level. For example, the West South Central Census division consists of Texas, Oklahoma, Arkansas, and Louisiana. For ice cream and other frozen products, Texas, Oklahoma, and Louisiana all had observations of shipments values to U.S. destinations while the observation for Arkansas was missing. The value of all shipments from the West South Central division to U.S. destinations was also known, so the imputed value for supply from Arkansas was equal to the difference between the West South Central value and the sum of the Texas, Oklahoma, and Louisiana shipments.

If multiple states within a higher-level geographic region had missing values, then it was necessary to calculate each state's share of the remaining value of production or consumption at the regional or divisional level. Among the states in a division or region with missing values, a state's share of milk production was used as the production value share and their share of population was used as the consumption value share. After determining the value of production and consumption for each state and commodity, these values are used to interpolate intra- and inter-regional trade flows.

The CFS groups shipments by commodity codes from the Standard Classification of Transported Goods (SCTG). The codes I use are outlined in Table 3.1 and grouped into categories that correspond to the four end-use product classes defined by the FMMOs. Note that the categories are not equivalent to the FMMO product classes due to some commodity groups including products that would be split between different FMMO classes. For example, SCTG code 07199 includes yogurt, buttermilk, sour cream, whey, and casein. This commodity group is assigned to the soft products category even though only yogurt, buttermilk, and sour cream are Class II products

Table 3.1: Matching Commodity Flow Survey Standard Classification of Transported Goods Commodity Codes to FMMO Product Classes

Category	Description	SCTG Code
Beverage Milk Products	Milk and Cream	07111
	Other beverage products (includes chocolate and other milk drinks, soya, almond, and coconut beverages, and fortified, non-concentrated juices)	07899
Soft Products	Ice cream, etc.	07130
	Yogurt, buttermilk, sour cream, whey, and casein	07199
	Other food preparations (includes malt extract, ice cream and milk shake mixes, pudding powders, and infant formula)	06399
Cheese	Cheese and curds	07120
Butter and Dry Milk	Milk and cream, in powder, granules, or other solid forms	07112
	Other dairy products, not elsewhere classified (includes evaporated or condensed whole milk)	07119
	Butter and other fats and oils derived from milk	07191

Source: Standard Classification of Transported Goods and Agricultural Marketing Service.

under the FMMOs, while whey and casein would be included in Class III.

The beverage milk products category is difficult to identify from SCTG codes. First, commodity code 07111 is described as “milk and cream, unconcentrated and unsweetened,” which could describe shipments of farm milk or shipments of packaged beverage milk products. The CFS reports a total value of shipments between all U.S. destinations of $30 billion in 2017 and total shipment weight of 66 billion pounds in 2017. Comparing these numbers to milk production reported by NASS, which totaled 216 billion pounds and $38 billion in 2017, suggests that the CFS data are shipments of packaged beverage milk products rather than farm milk.

The second commodity code included in the beverage milk products category, 07899, is more complicated given that it includes non-dairy products. While the description says that it includes chocolate and other milk drinks, it also includes plant-based milk products and fortified non-concentrated juices. It is not clear what share of this category is dairy products, but it is included in the beverage milk products category for this analysis.[1]

3.1.2 Census of Agriculture Data

The Census of Agriculture is completed every five years and attempts to collect data from all U.S. agricultural operations with sales of crops or animal products greater than $1,000. The most recent data are available from the 2017 Census, and include the value of sales across a wide range of crops for each state. Sales are not directly comparable to value of production, but provide a useful representation of the state-level production value for each food crop.

While the CFS also includes observations of shipment values for crops, the implied production values are quite different from those reported by the Census of Agriculture. For example, the total value of corn shipments between U.S. states in the CFS data is $67.4 billion, while Census of Agriculture data reports $51.2 billion in corn sales. Because the CFS simply reports the value of shipments between states, this suggests that shipments of corn may be counted multiple times as they travel between their origin and final destination. For example, shipments along the Mississippi river may be consolidated at multiple points, each potentially being recorded by the CFS. In contrast, the value of hay shipments in the CFS total $9.7 billion, while the value of hay production NASS reported in 2017 was $16.1 billion.[2] Since hay may be produced on the same farm operation where it is used as feed it may never be handled by a shipping company surveyed by the CFS while still being included in NASS production reports. Therefore, the Census of Agriculture and other NASS data appear to better represent crop production values.

State-level feed crop consumption values are calculated using a metric called "feed-consuming animal units" (FCAUs) reported by the Economic Research Service (ERS) as part of the Feed Grains Yearbook. ERS uses weights to convert livestock inventories to an indexed value, the FCAUs, that can be used to directly compare feed consumption. For a given category of feed crops, which include grains, high-protein feeds, and roughage, an animal unit is based on the dry-weight

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[1] An alternative approach may be to utilize data on beverage milk product sales published by the FMMOs. However, these data only covers sales within the FMMO areas and are in terms of quantities rather than sales values. The Economic Research Service publishes national estimates of per capita beverage milk consumption, which could be used to calculate consumption in regions that are not part of an FMMO marketing area.

[2] Since the Census of Agriculture does not report the value of hay sales, NASS survey data on value of production are used to represent hay supply.

Table 3.2: Feed-Consuming Animal Units, Million Head, 2017

Feed Type	Dairy	Cattle on Feed	Other Cattle	Hogs	Poultry	Other Livestock	Total
Grains	10.67	20.62	3.62	29.32	31.97	0.62	96.82
High-Protein	10.93	11.96	6.24	37.24	83.31	0.50	150.18
Roughage	13.60	2.13	48.74	3.77	0.57	2.11	70.93

Source: USDA Economic Research Service, Feed Grains Yearbook.
Note: 2017 FCAUs are calculated from 2016/17 and 2017/18 marketing years, which run from September through August.

quantity of such crops consumed by an average milk cow (Capehart, 2013).[3]

Table 3.2 reports the quantities of feed-consuming animal units across livestock categories in 2017. Utilizing these values allows for comparison of feed use on a common basis, rather than comparing livestock inventories directly. For example, the U.S. inventory of poultry was about 2 billion head, which cannot be easily compared in terms of feed use to the 14 million head of milk cows and heifers. However, comparing the 10.67 million head of grain-consuming animal units in dairy to the 31.97 million head of grain-consuming animal units in poultry shows that the poultry industry consumes roughly three times the amount of grain that the dairy industry uses.

Following a method utilized by Conley, Nagesh, and Salame (2012) in a report on the supply and utilization of corn across states, I use state livestock inventories and the national FCAUs to construct a measure of state-level feed consumption across livestock categories. As shown in Table 3.2, FCAU calculations are available for dairy cattle, cattle on feed, other beef cattle, hogs, poultry, and other livestock. Using NASS data on livestock inventories, I calculate each state's share of livestock from a given category. Then, I multiply this share by the FCAUs for the same livestock category to calculate the corresponding FCAUs for each state. Summing across the six livestock categories yields the total FCAUs for each state, from which I calculate the share of total FCAUs in each state. The FCAU share is then used to calculate each state's implied consumption of feed crops by multiplying the relevant FCAU share by the total value of each feed crop produced in the U.S.

As an example, in 2017 California had about 2.5 million head of dairy cattle, including both

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[3] The weights used to construct the index values were initially calculated for a base period of 1969-71. For more information, see Capehart (2013)

milk cows and replacement heifers. This was about 18 percent of the 14.3 million head of dairy cattle across the U.S. The total number of grain-consuming animal units (GCAUs) in 2017 was 96.8 million head, of which about 10.7 million were dairy cattle. Although the GCAU factor for milk cows is just over 1, the number of dairy GCAUs is less than the dairy cattle inventory because the conversion factor for replacement heifers is about 0.18 (Capehart, 2013). Therefore, when converted to a common basis the replacement heifers count for less than the milk cows in terms of feed use. I assume that California also accounts for about 18 percent of the dairy GCAUs, meaning about 1.9 million dairy GCAUs were in California. Applying this same method across the other livestock categories, California had a total of 3.8 million GCAUs, or about 4 percent of U.S. total GCAUs. Therefore, I calculate the value of grain crops consumed in California as 4 percent of the total value of grains produced in the U.S.

3.2 Methods for Interpolating Inter-Regional Trade Flows

Interpolation of inter-regional trade flows begins with a measure of each region's production and consumption values for a given commodity. I use values of production and consumption rather than quantities to allow for aggregation across commodity groups. Regional production value is equal to the sum of all outgoing trade flows, including intra-regional shipments, while product consumption value is equal to the sum of all incoming shipments. Since this process is intended to calculate internal trade only, the sum of regional production value should be equal to the sum of regional consumption value at the national level.

A common approach is to assume that inter-regional trade follows a gravity-type framework, i.e., proportional to the sizes of the origin and destination regions and inversely proportional to the distance between them. Note that I use the terms "size" and "distance" generically since each can be defined with different variables or measures depending on the relevant context (Sargento, Ramos, and Hewings, 2012). Letting x_{ij}^{n} be the value of a shipment of commodity n between region i and region j, a simple gravity-type equation could be expressed as follows:

$$x_{ij}^{n} = G\frac{(M_i)^{\alpha_1}(M_j)^{\alpha_2}}{(d_{ij})^{\alpha_3}}, \tag{3.1}$$

where M_i and M_j are measures of the sizes of regions i and j, d_{ij} is a measure of the distance between the regions, α_1, α_2, and α_3 are parameters that represent the weight of each factor in the equation, and G is a constant that will be defined further momentarily. In an international trade context, it is common to use observed bilateral trade flows between countries as a dependent variable in a double-log expression of equation (3.1) to estimate the α parameters. However, in cases where the trade flows are unknown, as is typical in an inter-regional trade context, x_{ij}^n can be calculated using equation (3.1) and relevant data for M_i, M_j, and d_{ij}.

Starting from known values of production and consumption for each region also sets constraints on the procedure. That is, if X_i^n represents the value of commodity n production in region i, then $\sum_j x_{ij}^n = X_i^n$ should hold once the calculations are complete. The factor G in equation (3.1) is called a "constant of proportionality," and is defined such that the constraint on the value of production in the origin region holds. Similarly, if C_j^n is the value of consumption of commodity n in region j, then $\sum_i x_{ij}^n = C_j^n$ is a second constraint. However, once the x_{ij}^n values are calculated they may not sum to the value of consumption.

The solution is to utilize biproportional adjustment, otherwise known as the RAS technique, which adjusts the values of a matrix such that row and column sums are equal to a set of known values. In other words, starting with a matrix of the x_{ij}^n values interpolated from equation (3.1), the RAS technique iteratively adjusts the matrix entries until the $\sum_j x_{ij}^n = X_i$ and $\sum_i x_{ij} = C_j^n$ constraints are met. The RAS technique was developed by Richard Stone, and is described in further detail in Lahr and de Mesnard (2004). The technique is useful in this application due to its simplicity and a tendency to preserve the structure of the initial matrix.

Given this overview, the general procedure for interpolating inter-regional trade flows starts with gathering data or calculating the values of production and consumption for each region and each commodity. These values form the known row and column sums of the inter-regional flow matrix and set the constraints on the calculations. Then, a version of equation 3.1 is used to compute the x_{ij}^n values that form the body of the inter-regional flow matrix. Finally, the RAS technique is applied using the known values of production and consumption to update the interpolated values.

With the data from the CFS for dairy products and from NASS for feed crops, The first step in this procedure is complete. The next step is to identify a gravity-type equation that performs best in interpolating inter-regional trade flows for these commodities. Gabela (2020) evaluates two gravity-type approaches to inter-regional trade flow calculation that could be used in this study. One approach has an advantage in its simplicity, but requires knowledge of intra-regional trade flows in addition to the regional values of production and consumption. The second approach provides an option to interpolate intra-regional flows, but is less accurate in Gabela's assessment.

3.2.1 Standard Gravity Approach

The method defined by Gabela as the "standard" approach is a direct extension of equation (3.1) with an additional term representing the origin region's "degree of specialization" with respect to a given commodity. The degree of specialization shows the extent to which commodity n is more or less important to region i's overall value of production when compared to the relative importance of commodity n in U.S. production. This formulation is based on Sargento, Ramos, and Hewings, who also determine that including the degree of specialization improves the performance of a gravity-type equation. Continuing with the notation used in equation (3.1):

$$x_{ij}^{n} = \left\{ \frac{M_i M_j}{d_{ij}} \right\} \cdot \left\{ \frac{X_i^n / \sum_n X_i^n}{\sum_i X_i^n / \sum_i \sum_n X_i^n} \right\} \cdot G_i^n \ , \tag{3.2}$$

where the term in the second set of brackets is the degree of specialization. In words, the numerator is the share of region i's total value of production contributed by commodity n, while the denominator is the total value of commodity n produced in the U.S. as a share of total U.S. production value. In this study, the set of commodities in the summation is either dairy products or feed crops. Naturally, if region i produces a small share of the total value of commodity n produced in the U.S., then the estimated flow of product n from i to j will be lower.

The constant of proportionality, G_i^n, is defined to ensure the first constraint on the origin region value of production is met:

$$G_i^n = X_i^n \cdot \left[\sum_j \left\{ \frac{M_i M_j}{d_{ij}} \right\} \cdot \left\{ \frac{X_i^n / \sum_n X_i^n}{\sum_i X_i^n / \sum_i \sum_n X_i^n} \right\} \right]^{-1} . \tag{3.3}$$

Notice that the terms inside the summation are the same as the bracketed terms in equation (3.2). To better understand the contribution of G_i^n to the equation, consider a version of equation (3.2) that did not include G_i^n. If I were to use this adjusted equation to interpolate values of x_{ij}^n, then the calculated values may not sum to the total value of production, X_i^n. To ensure that my interpolated values sum to the production constraint I could divide total production by the sum of my first set of interpolated values. If my first guess was greater than total production, then this ratio could be multiplied by each x_{ij}^n to scale down the second set of interpolated values. This ratio is identical to G_i^n, and by including G_i^n in equation (3.2) I can ensure the production value constraint is met with the first set of interpolated values. Since G_i^n ensures that $\sum_j x_{ij}^n = X_i^n$, the final step is to apply the RAS technique to balance the trade flow matrix and ensure $\sum_i x_{ij}^n = C_j^n$.

Sargento, Ramos, and Hewings use per capita GDP to measure regional sizes through M_i and M_j since they apply equation (3.2) to aggregate industry trade flows. In the context of disaggregated commodities such as dairy products and feed crops different measures of regional size are more appropriate. For dairy product trade flows I use quantity of milk produced as the origin region weight and population as the destination region weight. This assumes that more dairy product trade flows originate in regions that produce more milk and more dairy products are consumed in regions with higher populations, both of which seem like reasonable assumptions. Crop trade flows are calculated using acres harvested as the origin weight and the corresponding FCAU total as the destination region weight for feed crop flows and population as the destination weight for other crop flows. Again, it seems reasonable to assume that more crops will originate in regions with more acres of that crops, and the FCAU values are a useful measure to calculate an aggregate measure of livestock feed demands.

Note also that the α parameters from equation (3.1) are each set to one in equation (3.2). Sargento, Ramos, and Hewings acknowledges that this choice is arbitrary, but additionally suggests an approach for choosing α_3, the parameter on d_{ij} also known as the distance decay parameter. Since the initial values computed using equation (3.2) may not meet the constraint on the destination value of consumption, $\sum_i x_{ij}^n = X_j^n$, the authors suggest calculating a measure of error between the initial $\sum_i x_{ij}^n$ and X_j^n which can be minimized to choose an optimal value for the distance decay parameter. However, Gabela (2020) points out that these parameters cannot be estimated without the inter-regional trade flow data the equation is being used to calculate. In this analysis I leave the α parameters equal to one, but further research could implement a procedure to choose parameter values to minimize error.

The procedure using equation (3.2) is simple in its approach, but requires knowledge of intra-regional shipments in addition to the regional production and consumption values. If the intra-regional shipments are known, or can be confidently estimated as a first step of the estimation procedure, then the standard gravity-type approach can be employed. However, alternative approaches allow for intra-regional shipments to be estimated alongside inter-regional values.

3.2.2 Extended Gravity Approach

The second approach evaluated in Gabela (2020) was introduced in Horridge, Madden, and Wittwer (2005) for use in regional CGE models and outlined in detail in Dixon and Rimmer (2004). While this approach is also based on a gravity-type foundation, it includes a first step that interpolates intra-regional shipments. This approach interpolates the full set of shipment values in an iterative process, first calculating trade shares, then calculating the value of the shipment by multiplying the trade share by the known regional consumption values, and finally correcting shipment values using the RAS technique. The approach calculates the share of region j value of consumption for product n that originated in region i, which I define as b_{ij}^{n}.

The intra-regional shipment values are first interpolated using the own-region value of production and consumption and a measure of product tradability. Product tradability is defined using the average difference between regional production and consumption values. The production-consumption gap for each region is calculated as a proportion of the average of production and consumption:

$$GAP_i^n \equiv \left| \frac{C_i^n - X_i^n}{\left(C_i^n + X_i^n\right)/2} \right|. \tag{3.4}$$

A value close to zero for the production-consumption gap is assumed to correspond to a less tradable product, since this would suggest that most of the region's production is consumed locally. If GAP_i^n is close to its upper limit of 2, then region i has either large excess production or excess consumption, suggesting that there must be a trade outlet to clear the market. By taking the average across all regions, I determine whether the product tends to be more or less tradable on average. The average production-consumption gap is then bound between 0.5 and 1 using the following functional form:

$$T^n \equiv \frac{1 + 0.5 \cdot \exp\left\{5 \cdot \left(\frac{1}{I}\sum_{i\geq 1} GAP_i^n - 1\right)\right\}}{1 + \exp\left\{5 \cdot \left(\frac{1}{I}\sum_{i\geq 1} GAP_i^n - 1\right)\right\}}. \tag{3.5}$$

Using the known values of X_i^n and C_i^n, plus the calculated tradability factor for commodity n, the initial intra-regional trade share for product n, $\hat{b_{ii}^n}$, is computed as follows:

$$\hat{b_{ii}^n} = \min\left\{\frac{X_i^n}{C_i^n}, 1\right\} \cdot T^n. \tag{3.6}$$

If T^n is close to 1, then product n is more difficult to trade and intra-regional trade is likely to be higher as a result. In other words, if product n consumption in region i exceeds local production, then intra-regional trade will fill the gap depending on the degree of tradability.

Bounding the tradability factor between 0.5 and 1 is a decision by the modelers based on the functional form of equation (3.5). Since equation (3.6) calculated the share of region i's consumption that is met by intra-regional shipments, it is natural that the upper bound for T^n is one. However, consider a case where a product is as tradable as possible, thus $T^n = 0.5$, and region i is a large producer of product n relative to local consumption, such that $X_i^n / C_i^n > 1$. From equation (3.6), this would produce a calculated intra-regional trade share equal to 0.5, and would therefore suggest that 50 percent of region i consumption of product n is supplied by local producers while the remaining 50 percent is shipped in from producers in other regions. It is possible that by adjusting the lower bound of T^n a more accurate interpolation of intra-regional trade could be produced.

Once the own-region trade shares have been calculated the bilateral trade shares are interpolated using a gravity-type equation. Horridge, Madden, and Wittwer and Dixon and Rimmer do not use GDP or a similar metric as measures of regional size, instead directly using the known values of production and consumption. Let $a_i^n \equiv \frac{X_i^n}{\sum_j X_j^n}$ be the share of product n produced in region i, which represents the origin region's size. The size of the destination region is measured by the share of consumption in region j that was not met by local production, $\left(1 - \hat{b_{jj}^n}\right)$. Combined with a similar proportionality adjustment as used in equation (3.2), the inter-regional trade share is calculated as follows:

$$\hat{b}^n_{ij} = \left(\frac{a^n_i}{d_{ij}}\right) \cdot \left(\frac{1 - \hat{b}^n_{jj}}{\sum_{i' \neq j} \frac{a^n_{i'}}{d_{i'j}}}\right), \tag{3.7}$$

where d_{ij} is the distance between region i and region j. Region i and j are more likely to trade in product n if region i is a large producer of product n, if local consumption in region j is not met with local production, or if the regions are close geographically (Dixon and Rimmer, 2004).

With interpolated shares for all $\hat{b}^n_{ij}$, the values of each bilateral shipment are calculated using the observed regional consumption:

$$\hat{x}^n_{ij} = \hat{b}^n_{ij} \cdot C^n_j. \tag{3.8}$$

As before, the RAS balancing technique is applied to ensure the observed regional production and consumption contraints are met. In this case the procedure ensures that the sum of interpolated bilateral trade flows is equal to observed regional consumption, $\sum_i \hat{x}^n_{ij} = C^n_j$, but it is not guaranteed that summing across destinations will equal observed regional production. Applying the RAS balancing technique to the trade flow matrix adjusts the inter-regional trade flows such that $\sum_{j \geq 1} x^n_{ij} = X^n_i$, where x^n_{ij} are the adjusted trade flow values.

The Horridge approach provides an option to calculate intra-regional trade if needed, and the tradability factor is a reasonable explanation on which to base the calculation. However, Gabela (2020) finds that when evaluated against a known inter-regional trade matrix, the standard gravity-type approach performs better than the Horridge approach in terms of accuracy. Gabela suggests this is because the standard approach utilizes additional information for each region in the form of the M_i and M_j size measures, improving the accuracy of the resulting interpolated values.

3.3 Interpolation of Inter-Regional Trade Flows

In this section, I apply both procedures to interpolate dairy product trade flows using CFS data and calculate accuracy measures using available observations from the CFS. Using these accuracy measures I select a set of interpolated trade flows to use in calibrating the model in Chapter 4 as well as selecting which method to apply to the crop production data derived from the Census of Agriculture data.

Since the CFS data also has suppressed observations for intra-regional trade, the first step of the Horridge approach is used in both cases. Ideally the standard gravity approach would start with a full set of intra-regional flows, but in this case the use of the Horridge approach serves as a first stage of the interpolation process. Nevertheless, the intra-regional observations that are available present an opportunity to incorporate some additional information into the interpolation procedures. Therefore, I first calculate all intra-regional trade flows using the Horridge approach, then use these values to proceed with the standard and extended gravity approaches. Then I compute a second round of interpolated values by replacing the interpolated intra-regional trade flows with known observations where available, creating a hybrid of known and interpolated data. This results in four sets of interpolated trade flows that I test for accuracy against the known observations in the CFS data.

After calculating the accuracy of each approach used with the CFS data on dairy product shipments, I determine which approach is best utilized to interpolate feed crop trade flows. Since no data are available on intra-regional crop shipments I compare the performance of the standard approach and extended approach when all intra-regional flows are interpolated. Once the best approach is determined I apply it to the Census of Agriculture data on feed crops.

3.3.1 Calculating Commodity Tradability Factors

The Horridge approach requires calculation of tradability factors for each of the dairy product categories to interpolate intra-regional trade flows. Using equation (3.5), the calculated T^n values for each dairy product category are reported in Table 3.3. I find that the tradability factor for milk and cream is close to one, which is consistent with the expectation that most beverage milk production serves the local market. Since the other beverage products category contains flavored milk drinks it is consistent that these products would be somewhat more tradable. The less perishable products, cheese, butter, dry milk products, and other food preparations containing dairy, are the most tradable.

As an example, the tradability factor for milk and cream suggests that in a region where beverage production exceeds consumption, 94 percent of local consumption would be met by

Table 3.3: Calculated Tradability Factor for Dairy ProductCategories

Category	**Description**	T^n
Beverage Milk Products	Milk and Cream	0.943
	Other beverages	0.795
Soft Products	Ice cream, etc.	0.847
	Yogurt, sour cream, etc.	0.743
	Other food preps.	0.663
Cheese	Cheese and curds	0.774
Butter and Dry Milk	Powdered milk	0.613
	Evaporated, condensed	0.727
	Butter and other fats	0.585

Source: Author calculations using Equation (3.5) and data from U.S. Census Bureau and Bureau of Transportation Statistics, Commodity Flow Survey.

intra-regional shipments. If a region's value of consumption is greater than local production, then 94 percent of local production would be shipped intra-regionally with the remaining consumption value coming from other regions.

3.3.2 Interpolating Dairy Product Trade Flows from CFS Data

For each entry in the CFS data, which represents a shipment of a given commodity between an origin and destination region, the shipment may have a nonzero reported value or be reported as zero with a flag. The flag indicates whether the entry rounds to zero, in which case the shipment value is less than one million dollars, or if it is a suppressed observation. If no entry exists for a specific origin-destination pair, I assume no shipments were reported and do not calculate a trade flow for that pair.

Table 3.4 indicates the number of missing observations for intra-regional shipments and inter-regional pairs. Each CFS commodity has a potential of 50 intra-regional shipments and 2,450 inter-regional shipments.[4] Since not every state trades in every dairy product, a large share of

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[4] Alaska and Hawaii are included in the CFS data and the interpolation of missing values since they are part of the West Census region and Pacific Census division. Since some data are interpolated using the Census region and division data, it is important to ensure that any reported shipments from or to Alaska and Hawaii are considered as part of the region and division totals. However, they are then excluded from the regional totals calculated for the FMMO regions

Table 3.4: CFS Missing Values and Share of Missing Observations by SCTG Commodity

Category	Description	Intra-Regional Missing	Intra-Regional Share	Inter-Regional Missing	Inter-Regional Share
Beverage Milk	Milk and Cream	13	0.277	200	0.543
	Other beverages	22	0.449	316	0.620
Soft Products	Ice cream, etc.	25	0.641	252	0.733
	Yogurt, sour cream, etc.	18	0.474	307	0.652
	Other food preps.	24	0.615	343	0.710
Cheese	Cheese and curds	17	0.395	343	0.529
Butter and Dry Milk	Powdered milk	17	0.586	142	0.714
	Evaporated, condensed	27	0.675	257	0.687
	Butter and other fats	19	0.594	113	0.582

Source: Author calculations using data from U.S. Census Bureau and Bureau of Transportation Statistics, Commodity Flow Survey.

the potential origin-destination pairs are not reported by the CFS, so Table 3.4 reports the share of observed trade flows that are missing rather than the share of potential trade flows. Table 3.4 shows that the missing value problem is extensive for both intra-regional and inter-regional shipments.

Once missing observations are interpolated using either the standard gravity approach or the extended gravity approach, I compare the interpolated trade flow values to the non-missing shipment values from the CFS. I calculate accuracy using two measures. The first is a symmetric mean absolute percentage error (sMAPE):

$$sMAPE^n = \frac{1}{IJ}\sum_{i\in I}\sum_{j\in J}\frac{|x_{ij}^n - \hat{x_{ij}^n}|}{|x_{ij}^n| + |\hat{x_{ij}^n}|}, \tag{3.9}$$

where I and J are the set of origins and destinations with actual values, x_{ij}^n, present in the CFS data. Gabela (2020) uses a weighted mean absolute percentage error (wMAPE) which weights the absolute error by the total value of product n:

$$wMAPE^n = \frac{\sum_{i\in I}\sum_{j\in J}|x_{ij}^n - \hat{x_{ij}^n}|}{\sum_{i\in I}\sum_{j\in J} x_{ij}^n}. \tag{3.10}$$

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used in the simulation in Chapter 4.

Table 3.5: Accuracy of Interpolated Dairy Product Trade Flows with Fully Interpolated Intra-Regional Flows

		sMAPE		*wMAPE*	
Category	**Description**	**Standard**	**Extended**	**Standard**	**Extended**
Beverage Milk	Milk and Cream	0.411	0.532	0.366	0.410
	Other beverages	0.424	0.443	0.426	0.491
Soft Products	Ice cream, etc.	0.590	0.628	0.429	0.411
	Yogurt, sour cream, etc.	0.437	0.451	0.388	0.456
	Other food preps.	0.526	0.494	0.489	0.480
Cheese	Cheese and curds	0.448	0.448	0.491	0.528
Butter and Dry Milk	Powdered milk	0.425	0.437	0.478	0.533
	Evaporated, condensed	0.448	0.498	0.493	0.534
	Butter and other fats	0.398	0.415	0.425	0.489

Source: Author calculations using data from U.S. Census Bureau and Bureau of Transportation Statistics, Commodity Flow Survey.

Table 3.5 reports the accuracy of the standard and extended approach when used with intra-regional trade flows that were fully interpolated using the Horridge approach. When starting from the fully interpolated intra-regional trade flows, the standard approach generally outperforms the extended approach for most dairy product categories.

This is consistent with the findings in Gabela (2020). Gabela applies both the standard and extended approach to calculate an inter-regional input-output table for Japan, which is then compared to actual data to determine accuracy. When applied to the agricultural sector, the weighted MAPE for the standard approach was 0.215 and 0.246 for the extended approach. Compared to an overall accuracy across all sectors of 0.201 for the standard approach and 0.299 for the extended approach, both approaches perform relatively well when applied to the agricultural sector.

Sargento, Ramos, and Hewings (2012) use data from the OECD Bilateral Trade Database to conduct a similar analysis as Gabela. However, the OECD Bilateral Trade Database measure trade flows between 14 countries in the European Union, meaning the analysis is somewhat analogous to inter-regional trade but still draws from international trade data. Sargento, Ramos, and Hewings apply the standard approach to four sectors in the OECD Bilateral Trade Database. For agricultural trade flows, the weighted MAPE was 0.319 compared to an accuracy of 0.284 across all sectors.

Table 3.6: Accuracy of Interpolated Dairy Product Trade Flows Using Known Intra-Regional Flows

		sMAPE		*wMAPE*	
Category	**Description**	**Standard**	**Extended**	**Standard**	**Extended**
Beverage Milk	Milk and Cream	0.409	0.412	0.361	0.240
	Other beverages	0.406	0.396	0.410	0.239
Soft Products	Ice cream, etc.	0.547	0.575	0.420	0.358
	Yogurt, sour cream, etc.	0.423	0.410	0.367	0.360
	Other food preps.	0.505	0.466	0.472	0.429
Cheese	Cheese and curds	0.429	0.416	0.418	0.320
Butter and Dry Milk	Powdered milk	0.403	0.380	0.437	0.397
	Evaporated, condensed	0.430	0.448	0.483	0.469
	Butter and other fats	0.384	0.367	0.388	0.348

Source: Author calculations using U.S. Census Bureau and Bureau of Transportation Statistics Commodity Flow Survey.

Compared to the results in Sargento, Ramos, and Hewings (2012) and Gabela (2020), both the standard and gravity approaches do not appear to perform as well when applied to the CFS data on dairy product trade flows. However, when I use the available intra-regional observations from the CFS, both methods improve in accuracy. These accuracy results are presented in Table 3.6.

When known intra-regional flow data is provided, interpolation of the inter-regional flows using the extended approach performs better than the standard approach. This suggests that the inter-regional values from the extended approach are highly affected by the calculation of intra-regional flows in the first step. Additionally, the accuracy of the extended approach is now more in line with the results from Sargento, Ramos, and Hewings and Gabela.

In both Sargento, Ramos, and Hewings (2012) and Gabela (2020), the authors conclude that the accuracy of the standard approach is reasonable. Sargento, Ramos, and Hewings further analyze the value of these gravity-based approaches by using the interpolated trade matrix in an input-output analysis and comparing the results to the same analysis performed using known data. As a result of this comparison, Sargento, Ramos, and Hewings determine that using the interpolated trade matrix does not significantly affect the results of the input-output analysis, and across the approaches tested a gravity-based approach proved the most accurate. This suggests that utilizing the interpolated dairy product trade flows in the analysis in Chapter 4 is a reasonable alternative given the prevalence of missing data.

3.3.3 Interpolating Crop Trade Flows using Census of Agriculture Data

As discussed previously,

As with the CFS data on dairy product trade flows, I start by applying the Horridge approach to estimate intra-regional trade flows. This first step uses the values of feed crop production in each state from the Census of Agriculture and feed crop consumption calculated using the FCAUs for each state.

Since the standard approach was more accurate when starting from a fully interpolated set of intra-regional flows, I apply the standard approach to estimate the inter-regional crop flows. This requires selecting measures of the "sizes" of the origin and destination region. As discussed previously, the origin region size is defined by acres harvested of each crop and the destination size is defined by the total FCAUs.

Along with the interpolated dairy product trade flows, the interpolated feed crop flows from this two step approach are used to calibrate the simulation model defined in Chapter 4.

3.4 Conclusion

Due to a lack of detailed data on inter-regional shipments, the inter-regional trade and input-output analysis literature utilizes many approaches to interpolate inter-regional trade flows from available data. This chapter details two approaches for interpolating inter-regional trade flows and the data used to define regional production and consumption values. After comparing the two approaches, I apply these methods to data on dairy products and feed crops to generate data for use in Chapter 4.

The Commodity Flow Survey provides data on inter-regional shipments of dairy products, but due to a high number of suppressed or missing values the data are not complete. However, the available observations provide an opportunity to test the accuracy of different interpolation approaches and select the approach that leads to the most accurate interpolated values. When starting from only the total production and consumption values for each state the standard gravity approach is more accurate than the extended approach. If the known intra-regional shipments from the CFS are used as a starting point, with the remaining missing intra-regional flows filled in via interpolation, the extended approach performs better than the standard approach. Therefore, I use the interpolated values generated by the extended approach and the available intra-regional observations in Chapter 4.

The accuracy measures calculated while interpolating the inter-regional dairy product trade flows provide guidance on the interpolation of inter-regional crop flows. Since the CFS data on feed crop trade flows appear unreliable, I instead use a combination of NASS data from the Census of Agriculture and other surveys to represent regional crop production and consumption. Using the regional production and consumption values I interpolate intra-regional trade flows. Given that the standard approach was more accurate when starting from fully-interpolated intra-regional trade flows, I apply the standard approach to interpolate inter-regional trade flows in feed crops.

I demonstrate that the interpolation approaches produce reasonably accurate inter-regional trade flows for dairy products. In Chapter 4, the dairy product trade flows are used to calculate the share of production of each dairy product in a given origin region that is shipped to each other destination region. In discussing the simulation results, I focus on the impacts of removing FMMO pricing rules on the value of processed dairy products at the regional and national aggregate levels. It is likely that the simulated changes in individual dairy product trade flows between a specific set of regions is more impacted by the accuracy of the interpolated trade flows. Provided that the interpolated trade flows are sufficiently close to the unobserved dairy product trade flows, the aggregate impacts on the value of processed dairy products are likely unaffected by using an interpolated trade flow matrix as a substitute for the missing CFS data.

For feed crop trade flows, measuring the accuracy of the interpolated trade flow matrix is not possible given that I use NASS data rather than CFS data as a starting point for interpolation. Therefore, it is harder to conclude whether the interpolated feed crop trade flows may impact the simulation results. However, in the simulation model the marginal cost of milk production is largely driven by the cost of forage crops, in particular silage. Since I assume that silage is not traded between regions, the feed crop category with the largest impact on the farm milk supply is unaffected by the interpolation results.

The performance of both interpolation approaches could likely be improved by optimally adjusting the interpolation equations to maximize accuracy. I use a specification of the standard gravity approach that uses a value of one for the parameter that affects the impact of distance on trade flows. If this parameter was instead chosen to maximize accuracy the overall performance of the interpolation could be improved. Similarly, intra-regional flows are interpolated using a tradability factor calculated from the data. The tradability factor is bounded between 0.5 and one, and it is possible that adjusting the lower bound of the tradability factor could improve the accuracy of the extended approach. The tradability factor bound could also be adjusted separately for each product category, allowing further flexibility to adjust to the conditions that affect a given set of products. Further research could determine the potential improvements in accuracy available by adjusting these parameters.

Sargento, Ramos, and Hewings (2012) and Gabela (2020) conclude that these interpolations approaches provide reasonably accurate trade flow matrices when the actual data are not available. Compared to the accuracy results in these studies, my interpolated dairy product trade flows are similarly accurate when measured against the subset of available CFS observations. Additionally, Sargento, Ramos, and Hewings (2012) argues that the interpolated trade flow matrices provide sufficiently accurate results when utilized in input-output analysis. Given the lack of quality, detailed data on inter-regional shipments of dairy products and feed crops, the results in this chapter and previous research suggest that the interpolation approaches provide a reasonable alternative to a full set of known observations.

Chapter 4

Simulating Effects of Federal Milk Marketing Orders on Inter-Regional Trade and the Dairy Supply Chain

4.1 Introduction

In this chapter I develop a multi-market equilibrium trade model of the dairy industry supply chain to examine the extent to which FMMO pricing rules increase shipments of farm milk between regions, increase milk production, and increase the value of U.S. dairy products and exports of manufactured dairy products. The supply chain model includes crop production and dairy product manufacturing stages allowing simulations to account for induced upstream and downstream effects in the crop and dairy product markets.

The effects of FMMO pricing rules on milk production, shipments of milk between regions, and the value of dairy products would ideally be assessed by evaluating the change in each of these factors when changes to FMMO policy were implemented, controlling for the impacts of other factors that also may have changed. However, since FMMO policies change infrequently the effectiveness of this approach is limited. While policy reforms and consolidations of marketing order regions have occurred throughout the existence of FMMOs, with the most recent changes implemented in 2000, 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. Therefore, I adopt a simulation approach to evaluated the changes in variables of interest in a scenario where FMMO pricing rules are removed.

The model outlined in this chapter facilitates this simulation approach by representing regional milk production and the details of the dairy industry supply chain. Milk is produced using feed crops as an input, and by modeling regional crop production I relate the cost of milk production in each region to land use and crop yields. Once milk is produced the components, fat, protein, and other solids, are used to produce consumer-oriented dairy products. At each stage of the supply chain, production of crops, farm milk, and dairy products, output may be traded between regions.

I establish the structure of the model by explicitly modeling each stage of the dairy supply chain. For example, the supply of milk is derived from the supply of feed crops rather than relying on a specific functional form or an econometrically estimated supply function. The geography of crop production allows the model to endogenously account for the regional distribution of milk production. That is not to say that milk is produced only where feed crops are produced, but that the marginal cost of milk production is related to the cost of feed inputs and those costs are impacted by regional crop production.

Classified pricing is implemented in this model by including a policy parameter that increases the price paid by dairy product manufacturers for milk components depending on their end use. The policy parameter represents the wedge between the minimum prices set by the FMMOs and the prices for milk components that would prevail in the absence of FMMO pricing rules.

I pull from the recent international trade literature to develop this multi-market equilibrium trade model (Costinot, Donaldson, and Smith, 2016; Gouel and Laborde, 2021). In addition to interregional shipments at each stage of the supply chain, I include exports of crops and both imports and exports of dairy products. The equilibrium concept is partial in the following respects: quasi-linearity of consumer preferences with respect to all goods other than dairy products, a fixed price for non-crop and non-milk processing inputs, fixed prices for dairy products originating from abroad, and fixed prices for feed crops that are traded internationally. This depiction of the intra-national and international trade flows affected by regulations in the dairy industry allows me to explore a variety of impacts from eliminating regulatory price distortions, shedding new light on the social costs of these longstanding policies.

The model is calibrated using data on costs, expenditures, and regional shares from a variety of sources and 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 an acreage elasticity that is governed by the heterogeneity of crop yields within regions, elasticities of substitution between feed crops and their origins for use in dairy feed, and elasticities of substitution between milk components in dairy product manufacturing.

Following Gouel and Laborde (2021), I describe the equilibrium in relative changes. That is, I compare the equilibrium in the baseline scenario, where the FMMO pricing rules are in place, to a counterfactual equilibrium where the pricing distortions are eliminated. This set of equations is calibrated transparently using a series of share parameters, such as the share of total U.S. milk production that is produced in each region or the share of dairy product consumption that is imported. The share parameters are either calculated from available data or deduced from physical relationships between share parameters. From the equations that specify the equilibrium in relative changes, one can directly calculate changes to the counterfactual equilibrium due to the reduction in regulatory distortions, such as: changes to the quantity and price of milk produced in each region, that is, the geography of milk production; changes to milk shipments between regions; induced changes in regional cropping patterns and land rents; changes to the value of dairy products produced in the U.S. and exported to the rest of the world; and changes in welfare for buyers of dairy products and crop producers.

4.1.1 Milk Components

I explicitly model the market 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, they are utilized in different ratios in dairy products.

For example, since butter is between 80 and 82 percent fat it requires the fat contained in about 20 pounds of milk to produce one pound of butter. Additionally, nonfat dry milk is often produced alongside butter to utilize the nonfat milk solids that are not used in butter production. If butter production increases, and therefore increases the derived demand for milk fat, then the component market could clear with an increase in production and a decline in the price of nonfat dry milk.

The model I develop in this chapter is built around the markets for milk components and the relationship between consumer demand for dairy products, derived demand for milk components, and milk production. Milk component prices are also the point where FMMO pricing rules are implemented. Since dairy product manufacturers buy milk to use the milk components, FMMO pricing rules set minimum prices for milk components rather than for milk as a whole. Therefore, understanding the effect of FMMO regulations on milk production requires understanding the direct impacts on the market for milk components.

4.1.2 Land Use as a Basis for Milk Supply

Following the modeling framework utilized by Costinot, Donaldson, and Smith and Gouel and Laborde, I use crop production and the share of land used for dairy feed crops to determine regional milk supplies. Feed costs are a large portion of input costs in milk production, and feed ration composition is an important part of modern dairy production. The extent to which feed crops are available in a given region, and the cost at which they can be acquired, affects the marginal cost of milk production.

Cropland supply limitations and characteristics generate upward-sloping marginal cost functions for feed crops facing the dairy industry. If production of a given crop increases, then the increase in acreage will likely come from cropland that is less suited to producing that crop. Additionally, as feed crop production increases it competes for acreage with other crops, the marginal value product of which rises due to downward-sloping demand for competing crops and increases in marginal yields as acreage contracts. Therefore, the supply of feed crops is upward sloping due to yield effects and the opportunity cost of producing other crops.

The dairy industry relies on forage crops as an essential component of feed rations. Both alfalfa hay and corn silage tend to be produced near dairies or on dairy farms given their high cost of transportation relative to other feed crops. In fact, many dairy farms produce their own feed crops, especially forage crops. While alfalfa hay is increasingly traded, both to international buyers and within the U.S., it is still likely that regions with high milk production will have more cropland devoted to forage production. If a region has a comparative advantage in forage production, then this advantage should also translate to the cost of milk production in the region.

4.1.3 Abstraction from Details of Marketing Order Policy and Milk Production

Although I model the stages of the dairy supply chain and inter-regional trade at each of these stages, I choose to abstract from some details of marketing order policy and milk production. This simplifies the analysis and the interpretation of results, but it is important to provide an overview of certain policies.

Each milk marketing order specifies a set of rules for milk delivered to handlers in the marketing area to qualify as “producer milk,” or milk that can be included in revenue pooling and receive the marketing order blend price. These rules are primarily concerned with the share of milk delivered to beverage milk plants and the share of milk transferred to plants that are not regulated by the FMMO. Regions with a higher share of milk used in beverage products enforce higher standards on these delivery requirements. It is common for milk that is being shipped to a beverage milk plant to be redirected or “diverted” to a manufacturing plant if demand from original beverage milk plant is met. To ensure that demand for beverage milk is met, these diversions are limited in regions with a high share of milk used in beverage products.

For example, the Florida FMMO requires that an individual producer must deliver at least 10 days’ milk production to plants regulated by the FMMO to receive the blend price, and regulated handlers may not divert more than 20-40 percent of total milk received to plants that are not regulated by the marketing order, where the exact limit depends on the month. In contrast, the Upper Midwest FMMO, which uses a large share of milk in manufactured products rather than beverage products, producers are only required to deliver one day’s milk production to a regulated plant in the first month they are affiliated with the order, and handlers may divert up to 90 percent of milk received to plants that are not regulated by the FMMO.

While the limitations on diversions and producer milk delivery requirements are not represented in the model, I believe their absence does not change the interpretation of the results. The calibration data used to define the baseline scenario reflects milk production, shipment, and classification by end-use class with these rules in place. By excluding the diversion limits and other similar rules from the model, the counterfactual scenario not only reflects the removal of classified pricing and revenue pooling, but also the removal of FMMO regulations in general. Additionally, these rules generally govern the behavior of individual firms within a marketing order region, while the model is developed to reflect regional impacts in aggregate.

The Appalachian and Southeast FMMOs additionally operate a transportation credit fund that facilitates shipments of farm milk from outside of the marketing areas. The transportation credit fund is funded through an assessment on Class I handlers, buyers of milk for use in beverage products, and payments for shipments of farm milk are based on a mileage rate factor and the distance traveled. Farm milk shipments only qualify for a transportation credit if the origination point is outside of the Appalachian and Southeast marketing areas and deliveries are received at a beverage milk plant.

Naturally, the transportation credits used by the Appalachian and Southeast FMMOs must impact shipments of farm milk between regions. However, the transportation credit fund is operated separately from the system of classified pricing and revenue pooling. Therefore, in a counterfactual scenario where the classified pricing and revenue pooling rules are removed, the transportation credits in the Appalachian and Southeast orders would be unaffected. The simulations results can be interpreted to include the impacts of the transportation credits on milk shipments, and therefore isolate the effects of classified pricing and revenue pooling on incentives to ship farm milk between regions.

By using an annual model, I am inherently abstracting from the seasonality of milk production. Milk production peaks in the spring before declining through the summer and reaching a low point in the fall. While dairy product consumption is generally less seasonal, some patterns also exist such as an increase in beverage milk consumption in the fall at the start of the school year. When milk production is high in the spring, dairy product manufacturing shifts towards storable products, such as butter and cheese, leading to an increase in stocks or exports during this time. In contrast, a higher share of milk production is used in beverage products in the fall as consumption increases and milk production is at a low point.

Ippolito and Masson (1978) consider the seasonality of milk production in the context of the stated FMMO objective of ensuring an "adequate supply" of milk for beverage products. They argue that FMMO pricing rules may help to reduce the impact of seasonal fluctuations in milk production on prices and consumption by increasing the overall price received by farmers such that more farm milk is produced throughout the year.

I consider annual milk production and an aggregate of dairy product manufacturing across seasons. Shipments between regions may shift during different seasons, but I observe total shipments across the year. To account for this, I use net shipments of farm milk between regions rather than bilateral shipments. Calculating the annual impact provides one interpretation of the long-run effect of removing FMMO pricing rules, with any seasonal adjustments aggregated annually.

This model also does not explicitly incorporate the role of marketing cooperatives, which are common in the dairy industry. Within the FMMO framework cooperatives often act as handlers who may sell milk from members to dairy product manufacturing plants or use member milk to produce dairy products at cooperative-owned plants. Some cooperatives operate on a national scale, such as Dairy Farmers of America, or interact with multiple marketing order regions. Therefore, it is possible that some cooperatives operate with a degree of market power, whether in their capacity as sellers of farm milk or as marketers of dairy products. I do not include cooperatives or market power in this model, and as a result the counterfactual scenario reflects perfect competition in the markets for farm milk and dairy products.

4.2 A Model of the Dairy Supply Chain

My model consists of four stages and the links between them: crop production, milk production, dairy product manufacturing, and consumption of dairy products. Crop production and milk production are linked through the supply and demand for feed crops used to feed dairy cows. Milk production is linked to dairy product processing through the supply and demand of milk components. Finally, the supply and demand of dairy products links dairy product processing and dairy consumption. An important feature of this model is that it is spatial, like the policy it represents, in that production and consumption activities are explicitly regional and linked spatially through trade in crops, farm milk, and dairy products.

In a review of modeling techniques used in spatial economics, Donaldson (2022) states that an empirical model "provides a clear mapping of assumptions to answers—but it does so conditional on the extra information provided by features that can be observed in the data." The model I develop in this section leverages the spatial structure of the milk marketing orders to map available data on the dairy supply chain to my primary research questions investigating the impact of FMMO pricing rules on farm milk production and prices, shipments of farm milk between regions, and the value of U.S. dairy products and dairy product exports.

Regions are indexed from 0 (for rest of the world, hereafter ROW) to I using either i or j. I consider inter-regional trade in crops, farm milk, and dairy products, including exports of feed crops and both imports and exports of dairy products. Farm milk is only traded between U.S. regions. Due to the high cost to transport farm milk, international 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 sufficiently small to ignore in this analysis.

4.2.1 Market for Dairy Products

Demand for dairy products and equilibrium in the dairy product market

Categories of dairy products are indexed from 1 to N using 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 region of origin and j the destination region. Iceberg-style trade costs represent the cost of shipping goods between regions as a loss of some portion of the good which "melts" in transit. In other words, in order for one unit of dairy product n to arrive in region j, region i would ship τ_{ij}^{n} units since τ_{ij}^{n} units "melt" to one in transit. This assumption also defines the relationship between prices in each region, since the price of product n in region j that was shipped from region i would be equal to the cost of acquiring τ_{ij}^{n} units in region i. That is, $p_{ij}^{n} = \tau_{ij}^{n} p_{i}^{n}$ where p_{i}^{n} is the price of product n in region i and p_{ij}^{n} is the price of product n in region j originating in region i. Iceberg trade costs are mathematically convenient and commonly used in the trade literature, but since they are proportional rather than additive they may not be the best representation of trade costs facing the dairy industry.

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

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

where $\beta_j > 0$, $0 < \epsilon < 1$ is the (absolute) elasticity of total demand for dairy products, and C_j^0

is consumption of non-dairy products. The utility function is quasi-linear with respect to goods other than dairy products, C_j^0, with the non-linear portion utilizing a nested constant elasticity of substitution (CES) form. The first "nest" is an aggregate dairy product consumption bundle, C_j, representing dairy products $n = 1, \ldots, N$ and defined 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 $\kappa \in (0, 1) \cup (1, \infty)$ is the elasticity of substitution between dairy products from different categories. The second consumption bundle, C_j^n, is a product aggregate representing the regional origins of product n and defined as:

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

where $\beta_{ij}^n \geq 0$, $\sum_{i \geq 0} \beta_{ij}^n = 1$ and $\sigma^n \in (0, 1) \cup (1, \infty)$ is the elasticity of substitution between dairy products from category n from different origin regions. Thus, C_{ij}^n represents the physical quantity of a given dairy product, n, from a given origin, i, consumed in a given region, j, while C_j^n and C_j are conceptual aggregates of these quantities. The elasticity of substitution between dairy products from different origin regions, σ^n, is allowed to vary across dairy products because for some products, e.g., cheese, the region of origin may be a true differentiating attribute while for others, e.g., butter, products are likely more homogeneous across regions. However, I assume that the elasticities of substitution are identical across regions, as σ^n and κ, the elasticity of substitution across dairy products categories, are both independent of the consumption region j.

Demand for U.S. dairy products by the ROW is represented using a similar structure, with the exception that demand for dairy products originating from outside the U.S. 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.[1] I also allow for differing substitution and demand elasticities, denoted σ_0^n,

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[1] The rationale for this modeling choice is that if one were to introduce foreign consumption of foreign dairy products into the model, one would need to also 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, this choice, which does not negate trade in dairy products but abstracts from world-level market-clearing mechanisms, seems appropriate.

κ_0, and ϵ_0.

Standard utility maximization implies that the demand in region $j \geq 1$ for dairy product n coming from region $i \geq 0$ is:

$$C_{ij}^n = \beta_j \beta_j^n \beta_{ij}^n \left(P_j\right)^{\kappa - \epsilon} \left(P_j^n\right)^{\sigma^n - \kappa} \left(\tau_{ij}^n p_i^n\right)^{-\sigma^n}, \tag{4.1}$$

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

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

P_j^n and P_j are price indices for dairy product n in region j and for all dairy products in region j.

Similarly, demand in the ROW for U.S. dairy products exported by region $i \geq 1$ is

$$C_{i0}^n = \beta_0 \beta_0^n \beta_{i0}^n \left(P_0\right)^{\kappa_0 - \epsilon_0} \left(P_0^n\right)^{\sigma_0^n - \kappa_0} \left(\tau_{i0}^n p_i^n\right)^{-\sigma_0^n} \tag{4.2}$$

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

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

Denoting the quantity of dairy product n produced in region $i \geq 1$ as Q_i^n produces the following market-clearing condition:

$$Q_i^n = \sum_{j \geq 0} \tau_{ij}^n C_{ij}^n. \tag{4.3}$$

I assume that the price of each dairy product sourced from international markets, p_0^n, is fixed, but the prices of dairy products sourced from U.S. regions are endogenous.

Dairy Product Manufacturing and Derived Demand for Milk Components

Milk components are indexed from 1 to K using k. Dairy products are produced using a combination of milk components along with other inputs including labor, capital, and energy. I 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 an aggregate of milk components, N_i^n is other inputs, and ν_i^n represents the amount of other inputs used per unit of output. The milk component aggregate is also defined as a CES aggregate and is written as:

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

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 dairy product n. This specification allows for component k to not be used in the manufacturing of product n by setting $\gamma_i^{nk} = 0$.

Note that while milk provides components in relatively fixed proportions, for specific products within dairy product categories manufacturing allows for substitution between components. For instance, fat content may vary in yogurt through a change in the product mix or a recipe change. I allow for differing substitution among components across products as the elasticity ς^n depends on n.

In regions regulated by an FMMO, component prices are set according to the 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 in region i. As a normalization I assume that there is at least one product category for which $\delta_i^{nk} = 1$ (thereby determining the baseline price of the component), and $\delta_i^{nk} > 1$ for products in which the component price is set above the baseline price. In other words, if a handler in an FMMO region purchases butterfat for use in a beverage product, then they are required to pay the Class I minimum price for butterfat, here represented as $\delta_i^{nk} v_i^k$. The baseline component prices, v_i^k, are defined as the prices of components used in butter and dry milk products, i.e., the Class IV component prices.

The output-conditional demand for milk component k used in product n in region i is then:

$$Z_i^{nk} = Q_i^n \gamma_i^{nk} \left(V_i^n\right)^{\varsigma^n} \left(\delta_i^{nk} v_i^k\right)^{-\varsigma^n} , \tag{4.4}$$

where V_i^n is a price index representing the overall price of milk components used in production of product n in region i. This price index is defined as:

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

I denote the price of other inputs as w, assumed to be fixed. The fixed-proportions dairy product production technology implies that the market price of dairy products must exhaust their production cost, that is,

$$p_i^n = V_i^n + w\nu_i^n. \tag{4.5}$$

4.2.2 Equilibrium in the Farm Milk and Component Markets

I denote by M_j the quantity of farm milk produced in region $j \geq 1$. Farm milk may be traded across regions (but not internationally), with iceberg trade cost $\tau_{ji} \geq 1$. Denoting by M_{ji} the quantity of milk from region j used in region i, this assumption requires that:

$$M_j = \sum_{i\geq 1} \tau_{ji} M_{ji} . \tag{4.6}$$

In other words, the total quantity of farm milk produced in region j must be equal to the quantities of farm milk shipped from region j to all other regions subject to iceberg trade costs.

Unlike dairy products, farm milk is assumed to be homogeneous with respect to its origin region, which implies that milk only travels in one direction between two regions and that prices between regions that trade milk must be related through trade costs. That is, denoting m_j the price of milk in region j:

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

The first equality requires that if trade in farm occurs between two regions (in which case one of M_{ji} or M_{ij} is positive), then shipments of farm milk are not traveling in both directions (since one of M_{ji} or M_{ij} must be equal to zero). The second condition states that when trade in farm milk occurs between regions, the prices received for farm milk in both regions are related through trade costs. In terms of calibration, I handle observations of bilateral trade in farm milk by computing net exports from one region to the other. I argue that any observed cases of bilateral trade in farm milk arise from within-year variability in local demand and supply conditions due to the seasonality of milk production and demand for dairy products.

The total quantity of milk used in region i determines the availability of milk components in that region, which are then used to produce local dairy products. I assume that farm milk contains each component in fixed proportions. Denoting by ζ^k the amount of component k in one unit of milk, equilibrium in the milk component markets implies that

$$\sum_{n\geq 1} Z_i^{nk} = \zeta^k \sum_{j\geq 1} M_{ji} \qquad\qquad k \geq 1 \, . \tag{4.7}$$

Note that this set of equalities imply that no components are leftover: the product mix in each region is such that all farm milk available in the region is exhausted, and all components from that milk are exhausted as well. In this annual model, the further implication is that components are not carried over year to year (or carryover is sufficiently small to be ignored). For long run implications, ignoring carryovers seems to be an acceptable simplification. If not, this would imply a price of zero for the component, and Equation (4.4) implies that the demand for that component across all products would increase. In that sense, the substitutability of components in dairy processing, the demand side of the component markets, is key to the equilibrium concept.

The value of component k used in region i is equal to the sum across dairy product categories of the quantity of component k used in each category multiplied by the price of component k when used in category n:

$$\sum_{n\geq 1} v_i^{nk} Z_i^{nk} = v_i^k \sum_{n\geq 1} \delta_i^{nk} Z_i^{nk} .$$

Dividing the value of component k by the total quantity of component k used in region i, $\sum_{n\geq 1} Z_i^{nk}$, defines a weighted-average price for component k. This process represents system of revenue pooling under the FMMOs, with the weighted-average price for component k analogous to the FMMO blend price. Notice that if component prices were not differentiated by class, i.e., classified pricing was removed, then $\delta_i^{nk} = 1$ for all n and the weighted-average price would reduce to v_i^k.

Since the price of milk in a region i must exhaust the value of its components, the milk price is determined by:

$$m_i = \sum_{k\geq 1} \zeta^k v_i^k \left(\frac{\sum_{n\geq 1} \delta_i^{nk} Z_i^{nk}}{\sum_{n\geq 1} Z_i^{nk}} \right) . \tag{4.8}$$

Using equation (4.7), Equation (4.8) can also be expressed as:

$$m_i = \frac{\sum_{k\geq 1} v_i^k \sum_{n\geq 1} \delta_i^{nk} Z_i^{nk}}{\sum_{j\geq 1} M_{ji}} , \tag{4.9}$$

where the denominator is the total quantity of milk used in dairy products in region i. Equation (4.9) makes clear the comparison to 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 region i.

4.2.3 Milk Production and Derived Demand for Crops

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

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

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. Crops may be traded between regions with iceberg trade cost τ_{ji}^l for a shipment from j to i.[2] The quantity of feed crop l used in the dairy industry in region i is also assumed to

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[2] 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

be an aggregate of physical quantities of feed crop l from different origins. This aggregate, F_i^l, is defined as:

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

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 between feed crops from different origins. I assume substitution across feed crops from different origin regions is identical for each feed crop category. For the feed crop categories I define in this study, including grains, oilseeds, hay, and silage, it is likely that feed crops have a similar degree of homogeneity across regions.

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

$$F_{ji}^l = M_i \omega_i^l \omega_{ji}^l (W_i)^{\rho} \left(W_i^l \right)^{\lambda-\rho} \left(\tau_{ji}^l w_j^l \right)^{-\lambda} , \tag{4.10}$$

where W_i and W_i^l are price indices. W_i is the overall price index for feed crops used in the dairy industry in region i, and is defined as:

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

The price index for feed crop l used in the dairy industry 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 require that the milk price in region i is equal to the production cost of farm milk:

$$m_i = W_i + w v_i . \tag{4.11}$$

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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.

Equilibrium in the Crop Market

I assume that no feed crop is imported from outside the United States, but feed crops may be exported from each region i to the world market with iceberg trade cost τ_{i0}^{l}. Therefore, the price of crop l from U.S. region i that reaches the international market is equal to $\tau_{i0}^{l} w_{i}^{l}$. Feed crops may also be used in other animal sectors (cattle, poultry, etc.), or in the energy sector. In such cases, I assume that crops used in sectors other than the dairy industry receive the same price as feed crops exported to the international market. For simplicity, the total quantity of feed crop l produced in region i that either reaches the international market or is used in another sector within the U.S. are aggregated together.

In addition to feed crops, crop producers may produce an alternative crop representing an aggregate of food and other energy crops competing for land in each region. The aggregate of other crops is notated with $l = 0$, and I assume that the price of the alternative crop in region i, 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 shipments by:

$$Y_{i}^{l} = \sum_{j \geq 0} \tau_{ij}^{l} F_{ij}^{l}, \tag{4.12}$$

where F_{i0}^{l} is the quantity of crop l from region i that either reaches international markets or is used in sectors other than dairy.

The price of crop l from U.S. region i on international markets, $\tau_{i0}^{l} w_{i}^{l}$, is assumed to be fixed. This implies that regions that trade feed crops internationally or use feed crops in sectors other than dairy face fixed crop prices, even if these may differ from the world price due to trade costs. Since grains and oilseeds are widely used in other livestock sectors, the prices of grains and oilseeds in each market are fixed in the model. Given that a shock to the dairy industry such as removal of the FMMO pricing rules is unlikely to have a large impact on the prices of grains and oilseeds due to the relatively small share of these feed crops used in the dairy industry, this assumption is reasonable. A larger share of forage crops are consumed in the dairy industry and are less likely to be exported internationally, so the regional prices of forage crops may be endogenous. This is especially true for silage, which I assume is used only in the dairy industry and is not traded inter-regionally or internationally.

Crop Production and Land Allocation

Crops are produced using fixed-proportions technologies combining land and other inputs. Each region i has a continuum of parcels ω with heterogeneous yields for crop l, $A_i^l(\omega)$. Crop yields follow a Fréchet distribution with shape parameter $\theta > 1$ and A_i^l as the central (unconditional) crop yield. The output from parcel ω when grown in crop l is:

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

where $N_i^l(\omega)$ is the quantity of other inputs used 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, assumed 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 also cannot exceed the natural yield of the land when planted to crop l.

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

$$r_i^l \equiv w_i^l - w\nu_i^l\,. \tag{4.13}$$

Standard computation utilizing the Fréchet distribution of crop yields implies that the share of region i's cropland dedicated to crop l is expressed as:

$$\pi_i^l = \frac{\left(r_i^l A_i^l\right)^\theta}{\sum_{l'\geq 0}\left(r_i^{l'} A_i^{l'}\right)^\theta}, \tag{4.14}$$

where the summation at the denominator is over all crops, including other crops, grown in region i. Note that the supply of other crops is not important to the model results. Demand for other crops is not explicitly modeled and their price is fixed. However, it is important to represent the share of cropland planted to non-feed crops because of the wide variation in non-feed crop acreage across regions.

Denoting by L_i the fixed cropland area in region i, the supply of crop l is derived as:

$$Y_i^l = L_i A_i^l \left(\pi_i^l\right)^{1-\frac{1}{\theta}} . \tag{4.15}$$

The conditional yield of crop l is $A_i^l \left(\pi_i^l\right)^{-\frac{1}{\theta}}$, and it is higher than the unconditional yield A_i^l whenever $\pi_i^l < 1$.

4.2.4 Notational Summary

The notation used to describe the model is summarized in Table 4.1. Without counting price indices, which are just transformations of the underlying prices, and assuming that all crops, milk, and dairy products are manufactured in all regions, the number of true endogenous prices is $I \times N$ (regional prices of dairy products), plus I (regional milk prices), plus $I \times K$ (regional component prices), plus $I \times L$ (regional crop prices), plus $I \times L$ (regional land rents). That is, $I \times (N + K + 2L + 1)$ total endogenous prices.

The number of true endogenous quantities (not counting quantity indices or the land shares π_i^l) is $I \times (I + 1) \times N$ (consumption of dairy products from all sources by all U.S. regions), plus $I \times N$ (consumption of dairy products from U.S. regions by ROW), plus $I \times N$ (quantities of dairy products produced in U.S. regions), plus $I \times N \times K$ (quantities of components used in production of dairy products regionally), plus $I \times I$ (milk shipments), plus I (milk production), plus $I \times I \times L$ (feed crop shipments to U.S. regions), plus $I \times L$ (exports of feed crops), plus $I \times L$ (regional feed crop supply). Therefore, the total number of endogenous quantities is $I \times [N \times (I + 3 + K) + I \times (L + 1) + 1 + 2L]$.

Regarding crop prices and crop exports, note that if a crop produced in a region is exported, then its regional price is determined by the (fixed) world price, and therefore the number of endogenous prices is reduced by one. If the crop is not exported, then the variable F_{i0}^l is zero and does not need to be determined. That is, given the assumption of fixed world prices for exported crops, the variables w_i^l and F_{i0}^l are such that either one is always determined exogenously. That means that the actual number of endogenous variables is reduced by $I \times L$.

Similarly, if two regions i and j are not exchanging milk, then $M_{ij} = M_{ji} = 0$. If the same two regions are trading in farm milk, then one of the milk prices is determined by the other subject to transport costs. Thus, there is redundancy in counting the entire set of bilateral milk shipments

Table 4.1: Summary of Model Notation

Category	Notation
Shape Parameters	ϵ, ϵ_0, $(\sigma^n)_{n\geq 1}$, $\left(\sigma_0^n\right)_{n\geq 1}$, κ, κ_0, $(\varsigma^n)_{n\geq 1}$, ρ, λ, θ
Share Parameters	$\left(\beta_j, \beta_j^n, \beta_{ij}^n\right)_{\substack{i\geq 0, j\geq 1\\ n\geq 1}}$, $\left(\beta_0, \beta_0^n, \beta_{i0}^n\right)_{\substack{i\geq 0\\ n\geq 1}}$, $\left(\gamma_i^{nk}\right)_{\substack{i\geq 1\\ n\geq 1\\ k\geq 1}}$, $\left(\omega_i^l, \omega_{ij}^l\right)_{\substack{i,j\geq 1\\ l\geq 1}}$
Other Technology Parameters	$\left(\nu_i^n\right)_{\substack{i\geq 1\\ n\geq 1}}$, $(\nu_i)_{i\geq 1}$, $\left(\nu_i^l\right)_{\substack{i\geq 1\\ l\geq 0}}$, $\left(\zeta^k\right)_{k\geq 1}$, $\left(A_i^l\right)_{\substack{i\geq 1\\ l\geq 0}}$
Trade Costs	$\left(\tau_{ij}^n\right)_{\substack{i,j\geq 0\\ n\geq 1}}$, $\left(\tau_{ij}\right)_{i,j\geq 1}$, $\left(\tau_{ij}^l\right)_{\substack{i\geq 1, j\geq 0\\ l\geq 1}}$
Exogenous Prices	w, $\left(p_0^n\right)_{n\geq 1}$, $\left(w_i^0, r_i^0\right)_{i\geq 1}$, $\left(w_i^l, r_i^l\right)_{\substack{i\geq 1\\ l\geq 1}}$ (if internationally traded), and the price of the outside consumption good
Policy Parameters	$\left(\delta_i^{nk}\right)_{\substack{i\geq 1\\ n\geq 1\\ k\geq 1}}$
Endogenous Prices	$\left(p_i^n\right)_{\substack{i\geq 1\\ n\geq 1}}$, $\left(P_i^n\right)_{\substack{i\geq 0\\ n\geq 1}}$, $(P_i)_{i\geq 0}$, $(m_i)_{i\geq 1}$, $\left(v_i^k\right)_{\substack{i\geq 1\\ k\geq 1}}$, $\left(V_i^n\right)_{\substack{i\geq 1\\ n\geq 1}}$, $\left(w_i^l, r_i^l\right)_{\substack{i\geq 1\\ l\geq 1}}$ (except if internationally traded), $\left(W_i^l\right)_{\substack{i\geq 1\\ l\geq 1}}$, $(W_i)_{i\geq 1}$
Endogenous Quantities	$\left(C_{ij}^n\right)_{\substack{i\geq 0, j\geq 1\\ n\geq 1}}$, $\left(C_{i0}^n\right)_{\substack{i\geq 1\\ n\geq 1}}$, $\left(Q_i^n\right)_{\substack{i\geq 1\\ n\geq 1}}$, $\left(Z_i^n\right)_{\substack{i\geq 1\\ n\geq 1}}$, $\left(Z_i^{nk}\right)_{\substack{i\geq 1\\ n\geq 1\\ k\geq 1}}$, $(M_i)_{i\geq 1}$, $\left(M_{ij}\right)_{i,j\geq 1}$, $(F_i)_{i\geq 1}$,$\left(F_i^l\right)_{\substack{i\geq 1\\ l\geq 1}}$, $\left(F_{ij}^l\right)_{\substack{i\geq 1, j\geq 0\\ l\geq 1}}$, $\left(\pi_i^l\right)_{\substack{i\geq 1\\ l\geq 1}}$, $\left(Y_i^l\right)_{\substack{i\geq 1\\ l\geq 1}}$

and the entire set of milk prices. If a region i does not trade farm milk with any other region, then $M_{ij} = M_{ji} = 0$ for all $j \neq i$. Now consider regions that trade only with one other region. For each pair of such trading regions, there can only be one direction of trade, so there is only one unknown quantity variable. Since the milk prices are related by transport costs, there is also only one price unknown. Now consider regions that trade in groups of three. With two trade flows, there are three possible configurations: either the same region ships to the other two; or two regions ship to the third region; or one region ships to another which itself ships to the third one. In all these cases there are two unknown quantities (the shipments), but once one milk price is known the other two are determined as well. With a single trade flow, there are two price unknowns because one region is isolated from the other two, and a single quantity unknown (the milk shipment). Considering higher-order trade patterns leads to the same results: the number of unknown variables among bilateral trade flows and milk prices is only I. That means that the set of unknowns M_{ij} and m_i

Table 4.2: Number of equilibrium conditions

Equation in Text	Number of Conditions
(4.1)	$I \times (I + 1) \times N$
(4.2)	$I \times N$
(4.3)	$I \times N$
(4.4)	$I \times N \times K$
(4.5)	$I \times N$
(4.6)	I
(4.7)	$I \times K$
(4.8)	I
(4.10)	$I \times I \times L$
(4.11)	I
(4.12)	$I \times L$
(4.13)	$I \times L$
(4.15)	$I \times L$

actually only has $2 \times I$ unknowns (M_{ii} still needs to be identified). Therefore, the number of milk shipments $I \times I$ can be replaced simply by I, and the number of endogenous quantities is reduced further.

The total number of unknowns is therefore $I \times [N \times (I + 4 + K) + I \times L + 3 + 3L + K]$ and exhausts the number of conditions listed in Table 4.2, so the equilibrium system is well defined. Note that this is the maximum number of equations and unknowns, but depending on the data there may be fewer variables/conditions. For example, not all feed crops are exported and not all dairy products are imported.

4.3 Equilibrium in Relative Changes

I now express the equilibrium in relative changes to determine the minimum data necessary to calibrate the model and generate counterfactual simulation results. The algebra is standard and follows the approach utilized by Gouel and Laborde (2021).

Note that due to the longstanding nature of the milk marketing orders, the baseline scenario includes the milk component price wedges. That is, $\delta_i^{nk} > 1$ for some (i, n, k) combination. The main counterfactual scenario represents removal of the marketing order price wedges, and thus all $\delta_i^{nk} = 1$. The relative change in the price wedge, $\hat{\delta}_i^{nk}$, is therefore equal to one for the reference commodities and is lower than one for the commodities whose milk component use previously involved a premium.

The equilibrium in relative changes relates the exogenous change in the wedges, $\hat{\delta}_i^{nk}$, to the endogenous change in the system's prices and quantities, denoted with hats. The equilibrium is defined by a system of equations, with the following equations related to dairy product consumption:

$$\hat{C}_{ij}^n = \left(\hat{P}_j\right)^{\kappa-\epsilon} \left(\hat{P}_j^n\right)^{\sigma^n-\kappa} \left(\hat{p}_i^n\right)^{-\sigma^n} \qquad i = 0, \dots, I, \quad j = 1, \dots, I, \quad n = 1, \dots, N \tag{4.16}$$

$$\hat{C}_{i0}^n = \left(\hat{P}_0\right)^{\kappa_0-\epsilon_0} \left(\hat{P}_0^n\right)^{\sigma_0^n-\kappa_0} \left(\hat{p}_i^n\right)^{-\sigma_0^n} \qquad i = 1, \dots, I, \quad n = 1, \dots, N \tag{4.17}$$

$$\hat{P}_j = \left[\sum_{n\geq 1} b_j^n \left(\hat{P}_j^n\right)^{1-\kappa}\right]^{\frac{1}{1-\kappa}} \qquad j = 1, \dots, I \tag{4.18}$$

$$\hat{P}_j^n = \left[\sum_{i\geq 0} b_{ij}^n \left(\hat{p}_i^n\right)^{1-\sigma^n}\right]^{\frac{1}{1-\sigma^n}} \qquad j = 1, \dots, I, \quad n = 1, \dots, N \tag{4.19}$$

$$\hat{P}_0 = \left[\sum_{n\geq 1} b_0^n \left(\hat{P}_0^n\right)^{1-\kappa_0}\right]^{\frac{1}{1-\kappa_0}} \tag{4.20}$$

$$\hat{P}_0^n = \left[\sum_{i\geq 1} b_{i0}^n \left(\hat{p}_i^n\right)^{1-\sigma_0^n}\right]^{\frac{1}{1-\sigma_0^n}} \qquad n = 1, \dots, N \tag{4.21}$$

The following equations relate to production of dairy products, derived demand for milk components, and shipments of farm milk between regions:

$$\hat{Q}_i^n = \sum_{j\geq 0} a_{ij}^n \hat{C}_{ij}^n \qquad i = 1, \dots, I, \quad n = 1, \dots, N \tag{4.22}$$

$$\hat{Z}_i^{nk} = \hat{Q}_i^n \left(\hat{V}_i^n\right)^{\varsigma^n} \left(\hat{\delta}_i^{nk} \hat{v}_i^k\right)^{-\varsigma^n} \qquad i = 1, \dots, I, \quad n = 1, \dots, N, \quad k = 1, \dots, K \tag{4.23}$$

$$\hat{V}_i^n = \left[\sum_{k\geq 1} c_i^{nk} \left(\hat{\delta}_i^{nk} \hat{v}_i^k\right)^{1-\varsigma^n}\right]^{\frac{1}{1-\varsigma^n}} \qquad i = 1, \dots, I, \quad n = 1, \dots, N \tag{4.24}$$

$$\hat{p}_i^n = \psi_i^n \hat{V}_i^n + 1 - \psi_i^n \qquad i = 1, \dots, I, \quad n = 1, \dots, N \tag{4.25}$$

$$\hat{p}_0^n = 1 \qquad n = 1, \dots, N \tag{4.26}$$

$$\hat{M}_j = \sum_{i\geq 1} a_{ji} \hat{M}_{ji} \qquad j = 1, \dots, I \tag{4.27}$$

$$\sum_{n\geq 1}\chi_i^{nk}\hat{Z}_i^{nk} = \sum_{j\geq 1}\mu_{ji}\hat{M}_{ji} \qquad i=1,\ldots,I \quad k=1,\ldots,K \tag{4.28}$$

$$\hat{m}_i\sum_{j\geq 1}\mu_{ji}\hat{M}_{ji} = \sum_{k\geq 1}\theta_i^k\hat{v}_i^k\sum_{n\geq 1}\theta_i^{nk}\hat{\delta}_i^{nk}\hat{Z}_i^{nk} \qquad i=1,\ldots,I \tag{4.29}$$

$$\left(\hat{m}_i-\hat{m}_j\right)\mu_{ji} = 0 \qquad i=1,\ldots,I, \quad j=1,\ldots,I \tag{4.30}$$

$$\hat{m}_i = \phi_i\hat{W}_i + 1 - \phi_i \qquad i=1,\ldots,I \tag{4.31}$$

The final set of equations describes crop production and shipments of feed crops between regions:

$$\hat{F}_{ji}^l = \hat{M}_i\left(\hat{W}_i\right)^{\rho}\left(\hat{W}_i^l\right)^{\lambda-\rho}\left(\hat{w}_j^l\right)^{-\lambda} \qquad j=1,\ldots,I, \quad i=1,\ldots,I, \quad l=1,\ldots,L \tag{4.32}$$

$$\hat{W}_i = \left[\sum_{l\geq 1}\xi_i^l\left(\hat{W}_i^l\right)^{1-\rho}\right]^{\frac{1}{1-\rho}} \qquad i=1,\ldots,I \tag{4.33}$$

$$\hat{W}_i^l = \left[\sum_{j\geq 1}\xi_{ji}^l\left(\hat{w}_j^l\right)^{1-\lambda}\right]^{\frac{1}{1-\lambda}} \qquad i=1,\ldots,I, \quad l=1,\ldots,L \tag{4.34}$$

$$\hat{w}_i^l = \varphi_i^l\hat{r}_i^l + 1 - \varphi_i^l \qquad i=1,\ldots,I, \quad l=1,\ldots,L \tag{4.35}$$

$$\left(\hat{w}_i^l - 1\right)\rho_{i0}^l = 0 \qquad i=1,\ldots,I, \quad l=1,\ldots,L \tag{4.36}$$

$$\hat{Y}_i^l = \sum_{j\geq 0}\rho_{ij}^l\hat{F}_{ij}^l \qquad i=1,\ldots,I, \quad l=1,\ldots,L \tag{4.37}$$

$$\hat{Y}_i^l = \frac{\left(\hat{r}_i^l\right)^{\theta-1}}{\left[\pi_i^0+\sum_{l'\geq 1}\pi_i^{l'}\left(\hat{r}_i^{l'}\right)^{\theta}\right]^{\frac{\theta-1}{\theta}}} \qquad i=1,\ldots,I, \quad l=0,\ldots,L. \tag{4.38}$$

The equilibrium system (4.16)–(4.38) features a series of key share parameters. At the dairy product level, $b_j^n \equiv \frac{P_j^nC_j^n}{P_jC_j}$ is the budget share of product n in total dairy consumption in region j; $b_{ij}^n \equiv \frac{(\tau_{ij}^np_i^n)C_{ij}^n}{P_j^nC_j^n}$ is the share of product n from region i in total consumption of product n in region j, also known as the bilateral trade share; and $a_{ij}^n \equiv \frac{(\tau_{ij}^np_i^n)C_{ij}^n}{p_i^nQ_i^n} = \frac{\tau_{ij}^nC_{ij}^n}{Q_i^n}$ is the share of region i's production value for product n shipped to region j.

At the milk processing stage, $c_i^{nk} \equiv \frac{(\delta_i^{nk}v_i^k)Z_i^{nk}}{V_i^nZ_i^n}$ is the share of component k in the cost of 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 milk production stage, $a_{ji} \equiv \frac{\tau_{ji} m_j M_{ji}}{m_j M_j} = \frac{\tau_{ji} M_{ji}}{M_j}$ is the share of region j's milk value shipped to region i 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.

Finally, at the crop stage, $\xi_i^l \equiv \frac{W_i^l F_i^l}{W_i F_i}$ is the budget share of crop l in total expenditure on feed crops in region i; $\xi_{ji}^l \equiv \frac{(\tau_{ji}^l w_j^l) F_{ji}^l}{W_i^l F_i^l}$ is the share of crop l originating in region j in total expenditure on crop l in region i; and $\rho_{ij}^l \equiv \frac{(\tau_{ij}^l w_i^l) F_{ij}^l}{w_i^l Y_i^l} = \frac{\tau_{ij}^l F_{ij}^l}{Y_i^l}$ 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.

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

4.3.1 Welfare Effects

Endogenous prices and quantities expressed in relative changes may be used to directly calculate relative welfare effects.

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

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

The assumption of 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 in the counterfactual.

One may also be interested in the effect on consumer surplus in the ROW:

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

although the interpretation of this consumer surplus is delicate given that I am not modeling the supply of foreign dairy products, or the demand by the ROW for such products.

Total dairy product revenue is equal to the value of domestic consumption plus the value of exported dairy products. The data I use to represent dairy product consumption may be more accurately described as measuring wholesale revenue rather than retail sales to consumers. However, in this model I am interested in measuring the impact of FMMO pricing rules on dairy processors, and these data represent that stage of the dairy supply chain. I continue to use "dairy product consumption" to describe this revenue for simplicity, but note that total revenue from dairy product sales also includes retail markups. Total dairy product revenue, denoted as PC, is given by:

$$PC = \sum_{j\geq 1} P_j C_j + P_0 C_0 \, , \tag{4.39}$$

where $P_0 C_0$ represents the value of exported dairy products. Let $b_j \equiv \frac{P_j C_j}{PC}$ denote the share of the total value of dairy product consumption that is consumed in region $j \geq 0$. I can use this share to express the change in consumer surplus relative to the value of the dairy product market:

$$\frac{\Delta U_j}{PC} = b_j \left(\frac{1 - \hat{P}_j^{1-\epsilon}}{1-\epsilon} \right) . \tag{4.40}$$

Similarly, the change in foreign consumer surplus is:

$$\frac{\Delta U_0}{PC} = b_0 \left(\frac{1 - \hat{P}_0^{1-\epsilon_0}}{1-\epsilon_0} \right) . \tag{4.41}$$

Turning to crop production, each region $i \geq 1$ earns a profit equal to $r_i^l Y_i^l$ for crop $l \geq 0$. Total equilibrium profit is therefore equal to $\Pi \equiv \sum_{i \geq 1} \sum_{l \geq 0} r_i^l Y_i^l$, and the change in profit is:

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

Since there are no imports of crops, the total value of crop production is equal to $\sum_{i \geq 1} \sum_{l \geq 0} w_i^l Y_i^l$. The change in profit relative to the total value of crop production is:

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

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 $i \geq 1$ in the total value of crop production and $\rho_i^l \equiv \frac{w_i^l Y_i^l}{\sum_{l' \geq 0} w_i^{l'} Y_i^{l'}}$ is the share of crop $l \geq 0$ in the value of production in region $i \geq 1$. Note that these values include the value of production of the other crop category, so ρ_i^l and ρ^l are shares of total production value, not just feed crop production value.

For comparability with consumer effects, and to compute social welfare effects, I also express the change in profit relative to the value of dairy consumption, PC. For region i, this effect is simply

$$\frac{\Delta\Pi_i}{PC} = \frac{a\psi\phi\rho_i}{(1-\rho^0)(1-\xi_0)} \sum_{l \geq 0} \varphi_i^l \rho_i^l \left(\hat{r}_i^l \hat{Y}_i^l - 1 \right) \ , \tag{4.42}$$

where $a \equiv \frac{\sum_{i'} \sum_{n'} p_{i'}^{n'} Q_{i'}^{n'}}{PC}$ is the share of domestic production in the value of dairy product consumption, $\psi \equiv \frac{\sum_{i \geq 1} m_i M_i}{\sum_{i \geq 1} \sum_{n \geq 1} p_i^n Q_i^n}$ 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, $\rho^0 \equiv \frac{\sum_{i \geq 0} w_i^0 Y_i^0}{\sum_{l \geq 0} \sum_{i \geq 0} w_i^l Y_i^l}$ 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 internationally.

Due to the assumption of constant returns to scale, equilibrium profit is zero in the milk production and dairy product processing stages. In addition, since I assume that all other inputs to milk production have perfectly elastic supply functions, it is not possible to calculate the rents that would accrue to other important factors, such as milk producer human capital or dairy herd genetics. If such inputs had less than perfectly elastic supply, then it would be possible to calculate profit that accrues to the owners of these inputs. The same is true for dairy product processing, where all inputs other than milk components facing the industry have perfectly elastic supply.

However, the equilibrium in relative changes allows me to evaluate changes to the scale of these industries. For example, $\hat{m}_i \hat{M}_i$, the product of the change in milk price and the change in milk production, gives the change in milk production revenue in region i, allowing evaluation of the differential impact of FMMO policy changes on milk production revenue across regions. The same holds regarding the geography of crop production.

4.4 Specifying the Values of Model Parameters

With the model specified in relative changes, the share parameters needed to calibrate the model are clearly defined. Many of these shares can be calculated from available data, but mechanistic relationships between the parameters must also hold. In the following section, the parameter relationships are derived to determine which parameters can be calculated from available data and which will be deduced from the relationships.

4.4.1 Consumer Demand Parameters

As stated previously, total dairy product revenue, PC, is equal to the value of domestic consumption plus the value of exports. It must also be true that the difference between domestic consumption of dairy products and domestic production must be equal to net dairy product imports:

$$\sum_{j \geq 1} P_j C_j - \sum_{i \geq 1} \sum_{n \geq 1} p_i^n Q_i^n = \sum_{j \geq 1} \sum_{n \geq 1} \left(\tau_{0j}^n p_0^n \right) C_{0j}^n - P_0 C_0,$$

where $\sum_{i \geq 1} \sum_{n \geq 1} p_i^n Q_i^n$ is the value of domestic processed dairy products and $\sum_{j \geq 1} \sum_{n \geq 1} (\tau_{0j}^n p_0^n) C_{0j}^n$ is the total value of imports across all U.S. regions. Rearranging this expression, it follows that PC must also be equal to the value of domestic processed dairy products plus the value of imported dairy products:

$$PC = \sum_{i \geq 1} \sum_{n \geq 1} p_i^n Q_i^n + \sum_{j \geq 1} \sum_{n \geq 1} \left(\tau_{0j}^n p_0^n \right) C_{0j}^n \ ,$$

By expressing total dairy product revenue in both of the forms discussed above, it is clear that the budget share parameters b_{ij}^n and b_j^n are related to the shares of production value that are shipped between regions, a_{ij}^n:

$$b_j b_j^n b_{ij}^n = a a_i a_i^n a_{ij}^n \qquad n \geq 1, i \geq 1, j \geq 0 \tag{4.43}$$

$$b_j b_j^n b_{0j}^n = (1-a) a_0^n a_{0j}^n \qquad n \geq 1, j \geq 1 \tag{4.44}$$

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 $i \geq 1$ 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 $i \geq 1$, $a_0^n \equiv \frac{\sum_{j \geq 1} (\tau_{0j}^n p_0^n) C_{0j}^n}{\sum_{n'} \sum_{j \geq 1} (\tau_{0j}^{n'} p_0^{n'}) C_{0j}^{n'}}$ is the share of product n in the total value of dairy imports, and $a_{0j}^n \equiv \frac{(\tau_{0j}^n p_0^n) C_{0j}^n}{\sum_{j' \geq 1} (\tau_{0j'}^n p_0^n) C_{0j'}^n}$ is the share of region j in the value of imports of product n.

Summing Equations (4.43) and (4.44) over origin regions $i \geq 0$ yields:

$$b_j b_j^n = a \sum_{i \geq 1} a_i a_i^n a_{ij}^n + (1-a) a_0^n a_{0j}^n \qquad j \geq 0, n \geq 1 \tag{4.45}$$

with the convention that $a_{00}^n = 0$ since the ROW does not consume its own dairy products in the model (or, more accurately dairy products produced in the rest of the world are included in the ROW numeraire, rather than the CES aggregate which captures tradeoffs across dairy products of U.S. origin regions). The sum of Equations (4.45) over dairy products $n \geq 1$ is:

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

Therefore, if one knows a, a_i, a_i^n, and a_{ij}^n, one can deduce the values of b_j, b_j^n, and b_{ij}^n. The values of a, a_i, a_i^n, and a_{ij}^n are calibrated using data from the Commodity Flow Survey and the interpolation results from Chapter 3.

Parameters relating to international trade, including a, a_{i0}^n, a_{0j}^n, and a_0^n are calculated from data on imports and exports of dairy products from the U.S. Census Bureau and, where relevant, the value of processed dairy products from NASS.

4.4.2 Milk and Component Supply Parameters

The value of milk in a region is determined by the value of the milk components as they are used to produce dairy products. The share of component k in the value of milk in region i is given by θ_i^k, while the contribution of component k to the cost of components used to produce product n is given by c_i^{nk}. The relationship between the value of milk and the cost of producing dairy products can be expressed by:

$$a_i^n \psi_i^n c_i^{nk} = \theta_i \theta_i^k \theta_i^{nk} \qquad\qquad i \geq 1, n \geq 1, k \geq 1\ , \tag{4.46}$$

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.

The parameters θ_i^{nk} and θ_i^k can be determined using data from AMS on the values of milk and components in FMMO regions. Data on the value of farm milk and processed dairy products from AMS and NASS define θ_i. Summing Equation (4.46) over components k leads to:

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

If a_i^n is also known, ψ_i^n is fully determined by this expression. Once ψ_i^n is determined, one can use (4.46) to deduce c_i^{nk}.

Regarding the movement of milk across U.S. regions, the parameters a_{ij} and μ_{ij} are related through the relationship:

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

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. Thus, if one knows a_j, θ_j, ψ, μ_i, and μ_{ij} (the origins of milk used in each region), then one can deduce a_{ij} (the milk shipments in value). Note that whenever there is no milk shipment from i to j, then $a_{ij} = \mu_{ij} = 0$, so the previous relationship also holds.

4.4.3 Land and Crop Supply Parameters

Similar to the value of dairy product consumption, the total value of feed crop use is equal to the value of feed crops used in the dairy industry and the value of feed crops that are exported or used in other livestock industries domestically. Since there are no net imports of feed crops, this value must be equal to the total value of feed crop production across all producing regions and feed crops:

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

I 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 then establish the key relationship between feed crop consumption and feed crop production shares:

$$(1-\rho^0)\xi_i \xi^l_i \xi^l_{ji} = \rho_j \rho^l_j \rho^l_{ji} \qquad i \geq 0, j \geq 1, l \geq 1 \tag{4.47}$$

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 crop l in the total value of international crop exports, 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 international exports of crop l.

Equations (4.47) imply further restrictions across model parameters. First, summing over crop origin regions $j \geq 1$, leads to:

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

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

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

Therefore, if one knows the values of the parameters ρ^0, ρ_j, ρ^l_j, and ρ^l_{ji}, then one can recover the parameters ξ_i, ξ_i^l, and ξ_{ji}^l.

For each region, ϕ_i denotes the feed crop share of milk revenue, i.e., the total expenditure on feed crops in the dairy industry relative to the value of milk production. These regional values are deduced from the feed crop share of milk revenue, ϕ, and the regional shares of milk production value and feed crop use:

$$\phi_i = \frac{\xi_i \phi}{\mu_i(1-\xi_0)} \qquad\qquad i \geq 1 \; .$$

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

The share of land in region i used in production of crop l is related to the share of the land rent in the price of crop l and the share of crop l in total crop production value in region i. I can then rewrite the land share parameter, π_i^l, as:

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

Recall that $\varphi_i^l = \frac{r_i^l}{w_i^l}$ is the land share of crop revenue for crop l in region i. One could hope to set these parameters using region-specific information on crop budgets. Instead, let $\varphi_i \equiv \sum_{l \geq 0} \varphi_i^l \rho_i^l$ denote the overall land share of the crop dollar, i.e., the total value of cropland in region i relative to the total value of crop production in region i. Then:

$$\varphi_i^l = \frac{\pi_i^l \varphi_i}{\rho_i^l} \qquad\qquad i \geq 1, l \geq 0 \; . \tag{4.48}$$

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. In addition, I can rewrite the profit effect using Equation (4.48) as:

$$\frac{\Delta \Pi_i}{PC} = \frac{a \psi \phi \rho_i \varphi_i}{(1-\rho^0)(1-\xi_0)} \sum_{l \geq 0} \pi_i^l \left(\hat{r}_i^l \hat{Y}_i^l - 1 \right) \; .$$

4.5 Data and Calibration

The model is calibrated using data to calculate the share parameters defined by the equilibrium in relative changes. Table 4.3 summarizes the share parameters without listing the actual parameter values, which are far too numerous to list in the table. For the parameters that are not deduced from the mechanistic relationships with other parameters, Table 4.3 indicates the source of calibrating information.

4.5.1 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 AMS and provide the underlying observations for the share parameters related to milk production, utilization, and milk value.

The source of milk shipments between regions, M_{ij}, is the *Producer Milk Pooled by State of Origin* report. The report breaks down the total quantity of milk pooled in each FMMO by the state where the milk originated. I assign each origin state to an FMMO region and sum to the origin level to generate a table of M_{ij} values. Since I assume milk trade flows in one direction, I then calculate net flows in cases where there are bilateral shipments between regions. 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 bilateral trade on an annual basis. After accounting for net flows, I calculate total milk received in the destination region, j, and the share of milk received in region j that originated in region i, μ_{ij}.

AMS 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 received in each region after accounting for net trade flows, I 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. I 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}. The *Utilization* reports also provide data on monthly milk utilization by class, which I used to establish the use of milk that is not pooled in each region. This process is discussed in more detail

Table 4.3: Share Parameters Defined by Equilibrium in Relative Changes and Calibration Data Sources

Share	Index range	Definition	Data Source
b_j	$j \geq 0$	exp. share of region j in total dairy consumption	deduced
b_j^n	$j \geq 0, n \geq 1$	exp. share of product n in region j's dairy consumption	deduced
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
a		share of domestic production in value of total dairy consumption	observed: Census Bureau
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
a_{ij}	$i \geq 1, j \geq 1$	share of region i's milk value shipped to region j	deduced
μ_{ij}	$i \geq 1, j \geq 1$	share of milk used in region j shipped from region i	observed: USDA/AMS
μ_i	$i \geq 1$	share of region i in value of domestic milk production	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
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
ξ_i	$i \geq 0$	exp. share of region i in total feed crop consumption	deduced
ξ_i^l	$i \geq 0, l \geq 1$	exp. share of crop l in region i's feed crop consumption	deduced
ξ_{ji}^l	$i \geq 0, j \geq 1, l \geq 1$	exp. share of origin j in region i's consumption of crop l	deduced
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_i^l	$i \geq 1, l \geq 1$	land share of crop revenue for crop l in region i	deduced
ϕ		feed crop share of milk revenue	observed: Census Bureau; USDA/NASS
ψ		milk share of (domestic) dairy product revenue	observed: Census Bureau; USDA/AMS
ϕ_i	$i \geq 1$	feed crop share of milk revenue in region i	deduced
ψ_i^n	$i \geq 1$	cost share of milk comp. for product n in region i	deduced
π_i^l	$i \geq 1, l \geq 0$	share of crop l in region i's total cropland	observed: USDA/NASS

Note: Share parameters are from the equilibrium in relative changes defined by (4.16)–(4.38). Parameters with data sources listed are calculated from the observed data and parameters described as deduced are calculated from their relationship to the parameters calculated from observed data.

in Appendix A.

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 order. I 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 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 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, I compute the value of skim milk and then apportion this value between protein and other solids. Note that by using the whole quantity of skim milk in this calculation it implicitly values the water in milk. However, by attributing the skim milk value to protein and other solids, I are assigning no explicit value to water. I 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 AMS uses to assign individual component values to skim milk.

4.5.2 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 I assume the component prices are not distorted across product categories, I know the total value of components used in the unregulated region,

$v_i^k \sum_n Z_i^{nk}$, but without further information I 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, I 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 percent 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 I use the share of milk production among the remaining states to assign cheese production values. Among the states without specifically-reported cheese production, 34 percent of milk production is in Washington, therefore I assume about 260 million pounds of cheese was produced in Washington.

Once production values have been deduced for each state, I use conversion factors used by the USDA Economics Research Service to convert dairy product production values into milk component use by product.[3] I 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 I also need to include components used in beverage milk products. I 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.

4.5.3 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. Chapter 3 outlines the procedure for interpolating trade flows from available data on state-level values of

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[3] 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/

production and consumption. I then use the interpolated values to calculate the a^n_{ij} and ρ^l_{ij} parameters.

For dairy product shipments, calculating bilateral trade shares is straightforward since I 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 I define $W^l_j F^l_j$ 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^l_{ij}, $(\tau^l_{ij} w^l_i) F^l_{ij}$, must represent the value of the shipment of crop l from region i to region j actually used in the dairy industry. Therefore, I 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.

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, I 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 I include oilseed meals in the quantity used for animal feeds. For oilseed meals I 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 4.4. Note that both hay and silage are assumed to be used entirely for animal feed. I multiply these shares by the interpolated crop trade flows from Chapter 3 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. I 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. In Chapter 3 I calculated the number of FCAUs in each state following Conley, Nagesh, and Salame (2012). Summing across the six livestock categories yields a total

Table 4.4: 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: Author calculations based on USDA ERS *Feed Grains Yearbook* and *Oil Crops Yearbook* data.

FCAU value, from which I 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, I 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 percent of GCAUs in California were dairy cattle, so I assume that 49 percent 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 4.4, I assume 37 percent of the corn shipped to California is used as animal feed, of which 49 percent is used in the dairy industry. In other words, I assume that 18 percent 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, I 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.

Dairy Product Imports and Exports

The trade flow values interpolated in Chapter 3 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 I 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 4.4. Since I 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.

4.5.4 Values of Behavioral Parameters

In addition to the data used to calibrate the share parameters, this model includes a set of behavioral parameters that require calibration. As in Gouel and Laborde (2021), appropriate values are selected such that the elasticities of supply and demand match estimates from the literature.

Price Elasticities of Dairy Product Demand

Two parameters govern the elasticities of dairy product demand: ϵ is the price elasticity of demand for dairy products in general, and κ is the elasticity of substitution across dairy product categories. Together, these parameters define the elasticity of demand for each product category through the following expression, which is derived from equations (4.16) and (4.18):

$$\frac{\partial \ln C_j^n}{\partial \ln P_j^n} = (\kappa - \epsilon) b_j^n - \kappa. \tag{4.49}$$

Equation (4.49) implies that each dairy product elasticity is bounded between κ and ϵ depending on the budget share of the product. I assume that $\kappa > \epsilon$ such that a product with a larger budget share will have less elastic demand. For example, in regions where beverage milk products make up a larger share of consumer purchases I assume that demand for beverage products will change less in response to price changes. Additionally, since consumers may substitute between different dairy products as individual prices change, it makes sense for demand for dairy products as a category to be less elastic than demand for individual dairy products.

Gouel and Laborde (2021) refer to elasticities for food categories from a meta-analysis by Andreyeva, Long, and Brownell (2010). The study includes cheese, milk, and other dairy products among the food categories for which demand elasticities were evaluated, with 26 studies reporting milk demand elasticities, 20 for cheese, and 13 for dairy products in general. The mean demand elasticity for dairy products was −0.65, with a full range of 0.19 to 1.16 and 95 percent of the observations between 0.46 and 0.84 in absolute value. 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 aggregate categories are more inelastic than individual product groups.

For beverage milk, the mean elasticity was −0.59, a full range of 0.02 to 1.68, and a 95 percent range of 0.40 to 0.79 in absolute value. Cheese was found to be slightly more inelastic, with a mean elasticity of −0.44 and 95 percent range of 0.25 to 0.63, but with a wider total range from 0.01 to 1.95. Therefore, if this meta-analysis is used to suggest ranges for the elasticities of demand for beverage products and cheese, then a smaller value of ϵ must be chosen.

Okrent and Alston (2011) also survey the food demand literature to determine the range of elasticity estimates for food categories as well as estimating food demand elasticities. 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. However, when studies differentiate between food at home and food away from home, Okrent and Alston (2011) find an average dairy product demand elasticity of -0.85, with a range from -0.73 to -1.07. This suggests a much more elastic demand for dairy products, but the estimates for individual categories are more inelastic: -0.13 for cheese and -0.50 for fluid, evaporated, and dry milk. Since the individual product demand elasticities are smaller in absolute value, and since I model demand for dairy products at an intermediate level rather than retail demand, the first set of elasticities from Okrent and Alston (2011) provide another range to target.

A study by Chouinard et al. (2010) estimated 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 were between -0.628 and -0.742, while the elasticity for low-fat milk was found to be much more elastic at -2.052. The low-fat milk elasticity may be an outlier, but the authors do argue that with disaggregation across beverage milk products the resulting elasticities should be more elastic than for beverage milk as a whole, due to substitution across products with different fat contents. Therefore, since I are interested in targeting the elasticity of demand for beverage milk as a category, I may want to target a more inelastic value, as reported in the Andreyeva, Long, and Brownell meta-analysis. Additionally, across the remaining set of dairy products in the Chouinard et al. study, estimated own-price elasticities for cream and other soft products were between -0.407 and -0.911, for cheese products elasticities were between -0.404 and -0.734, and the own-price elasticity for butter was -0.295.

These studies provide a target range for elasticities of demand for the four dairy product categories used in this model. Choosing values of $\epsilon = 0.2$ and $\kappa = 0.5$ produces elasticities of

Table 4.5: Elasticity of Dairy Product Demand 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	-0.39	-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 World	–	-1.71	-1.56	-1.62

Source: Author calculations using Equation (4.49), $\epsilon = 0.2$, $\kappa = 0.5$. The share parameters b_j^n are deduced from relationships with parameters calculated using data from U.S. Census Bureau and Bureau of Transportation Statistics, Commodity Flow Survey.

demand for each product category across regions that are within the target ranges suggested by Andreyeva, Long, and Brownell, Okrent and Alston, and Chouinard et al. The resulting elasticities of dairy product demand are reported in Table 4.5.

Elasticity of Substitution Between Dairy Product Origins

Within each dairy product category, products are differentiated by origin regions, and dairy product trade flows are influenced by consumer demand in each destination region for products of different origins. Buyers of dairy products substitute between products of different origins according to the elasticity of substitution, σ^n, which takes on a specific value for each product category. Notice that σ^n varies across dairy product categories but not regions, implying that consumers in all regions share the same substitution elasticity. In combination with ϵ and κ, σ^n determines the elasticity of demand in region j for a given dairy product, n, originating from region i. The regional product demand elasticity is calculated from equations (4.16), (4.18), and

(4.19):

$$\frac{\partial \ln C_{ij}^n}{\partial \ln p_i^n} = (\kappa - \epsilon) b_j^n b_{ij}^n + (\sigma^n - \kappa) b_{ij}^n - \sigma^n. \tag{4.50}$$

By rearranging and substituting equation (4.49) into equation (4.50) it is clear that the regional product demand elasticity is bounded between the overall elasticity of demand for product n and the regional elasticity of substitution, σ^n:

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

Therefore, if products from origin i have a larger share of consumption of product n in region j, then the regional product demand elasticity will approach the overall product n demand elasticity. For an origin region with a smaller budget share in region j the elasticity will approach σ^n. The values of the regional product demand elasticities are detailed in Appendix B.

By assuming product differentiation across regions, this model follows the modeling framework established by Armington (1969). Armington-style models are often constructed with two levels of aggregation, with consumers first choosing between domestic goods and imports, with the bundle of imports aggregated across all foreign origins. This structure entails two elasticities of substitution, the first reflecting substitution between domestic and imported products and the second reflecting substitution between imports from different origins (Hillberry and Hummels, 2013). The parameter σ^n is the elasticity of substitution across all possible origins of product n, i.e., the domestic regions and imports from the rest of the world. Studies that estimate trade elasticities may focus on either the domestic-import elasticity of substitution or the substitution between origins of imports, while the appropriate σ^n may lie between these values.

A time series approach is used to estimate trade elasticities in several widely cited studies, which in many cases find relatively inelastic results. 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 to estimate domestic-import elasticities, but additionally extend their model to separately estimate short-run and long-run elasticities of substitution depending on available data. In general, Gallaway, McDaniel, and Rivera find that long-run elasticities of substitution are generally twice as large as short-run elasticities. They estimate elasticities of substitution of 1.003 for cheese in the short run and 1.346 in the long run and find identical estimates of 1.699 for butter in both the short run and long run. For condensed milk and ice cream the authors were only able to estimate short run elasticities, finding 0.590 for condensed milk and 0.496 for ice cream, and did not find a statistically significant estimate for fluid milk.

However, 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 estimated by these studies are different from import-origin substitution elasticities and the σ^n parameter used in this model. In relation to the Global Trade Analysis Project model, Hertel et al. (2007) recommend using a value for the import origin substitution elasticity that is twice the size of the domestic-import elasticity, but further analyses focus instead on substitution across origins.

Hertel et al. (2007) use cross-sectional changes in trade costs to identify the import-origin elasticity of substitution. 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 ranged from 1.81 to 7.76 with a median value of 4.03 and average of 4.31. Substitution elasticities for cheeses and related products ranged from 1.55 to 12.32 with a median value of 6.34 and average of 5.56. The estimated substitution elasticity for butter was 4.13, with dry and concentrated milk products elasticities ranging from 1.55 to 10.5 with a median of 3.6 and average of 4.82. For milk and cream as an aggregate category they find an estimate of 2.7 for the elasticity of substitution. In a more general sense, Broda and Weinstein (2006) find that estimated substitution elasticities are lower for more aggregate categories, and more elastic for products that could be considered commodities than those that are more differentiated.

While these studies provide a range of substitution elasticities applicable in an international trade context, far fewer studies consider trade elasticities that are 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 that this is not necessarily the case, estimating elasticities of substitution for regional trade that are comparable or even less elastic 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 between 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 while 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 this model are relatively highly aggregated, the findings in Broda and Weinstein suggest more inelastic substitution. Therefore, I 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, while the higher elasticity for butter and dry milk products is closer to the elasticity suggested by Hertel et al.

Price Elasticities of Foreign Demand for U.S. Dairy Products

In parallel to domestic demand for dairy products, I parameterize the demand for U.S. dairy products from the rest of the world using ϵ_0 as the overall price elasticity of foreign demand for U.S. dairy products, κ_0 as the elasticity of substitution between U.S. dairy products, and σ_0^n as the elasticity of substitution between origins for product n. Note that I only consider the demand for U.S.-produced dairy products from the rest of the world, not demand for dairy products in general. Therefore, foreign demand for U.S. dairy products should be much more elastic since foreign consumers can substitute for dairy products produced locally or in other parts of the world.

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. Reimer, Zheng, and Gehlhar (2012) estimate long-run elasticities of export demand for U.S. corn of -1.64, -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 ϵ_0 and κ_0 deserve further attention through sensitivity analyses.

With this in mind, I choose a more elastic value than suggested by Song and Kaiser (2016) for the overall elasticity of dairy product export demand and set $\epsilon_0 = 1.3$. By choosing $\kappa_0 = 1.8$, the elasticities of foreign demand for U.S. dairy products used in the model range from -1.71 for soft products to -1.56 for cheese, values which are more in line with those suggested by Reimer, Zheng, and Gehlhar (2012). The elasticities of foreign dairy product demand are also reported in Table 4.5.

As discussed in the previous section, it is likely that dairy products that reach the export market are less differentiated than those that are traded inter-regionally. Therefore, the values chosen for σ_0^n should be more elastic than the corresponding σ^n values. Following the result in Hertel et al. (2007), I choose a origin region substitution elasticity of 8 for soft products and cheeses and 10 for butter and dry milk powder products.

Elasticity of Substitution Between Milk Components as Inputs to Dairy Products

The three milk components, butterfat, protein, and other solids, and 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 percent butterfat, but some higher-fat butter may be produced with 82 percent butterfat. In the model the elasticity of substitution between milk components, ς^n, determines the extent to which the component proportions are more or less fixed within a specific dairy product category.

It is common for researchers to assume fixed-proportions technology 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 technology 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 if the production technology is not fixed-proportions exactly it is likely that the elasticities of substitution are small.

Given the broad dairy product categories I use in this model, it is important to allow for different component substitution elasticities for each product category. For cheese, butter, and powder products I set $\varsigma^n = 0.2$, allowing for a limited degree of substitution between milk components. Butter and powder products are often produced together since farm milk can be split into butterfat for use in butter and nonfat solids to be dried into nonfat dry milk. Since this dairy product category includes products with varying levels of required milk components, adjustments to the mix of product output provides a way to respond to changes in component prices.

Beverage products range in fat content from skim milk to whole milk, with even higher fat beverage products more 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. To reflect this, I 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 if different products are produced. Therefore, I set $\varsigma^n = 0.8$.

Elasticity of Substitution Between Feed Crops and Heterogeneity of U.S. Cropland

The elasticity of substitution between feed crops in livestock feed, ρ, determines the elasticity of dairy industry demand for feed crops. An expression for the feed crop elasticity of demand can be derived from equations (4.32) and (4.33):

$$\frac{\partial \ln F_i^l}{\partial \ln W_i^l} = -\rho \left(1 - \xi_i^l\right). \tag{4.51}$$

For crops that represent a large share of feed expenditure the elasticity of demand will be close to zero, while feed crops with a small share 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 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 -0.704 and -0.323. 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 -0.119 and for protein feeds of -0.046. Buccola and Iizuka (1997) use a hedonic cost modeling approach to evaluate the marginal cost of milk component production, 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 -0.234 and a long-run elasticity of -0.512.

These studies provide some guidance on choosing ρ, but the feed demand elasticity, along with the feed crop supply elasticity, also impacts the elasticity of milk supply. Therefore, ρ must 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 $\rho = 0.3$ results in a range of feed demand elasticities that are in line with those suggested by Beckman, Keeney, and Tyner (2011) but more inelastic than the findings in Casasnovas-Oliva and Aldanondo-Ochoa (2014). The elasticities are detailed in Table 4.6.

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

Table 4.6: Feed Crop Demand Elasticities by Region

Region	Grains	Oilseeds	Hay	Silage
Northeast	-0.25	-0.27	-0.24	-0.13
Appalachian	-0.26	-0.28	-0.25	-0.12
Florida	-0.23	-0.26	-0.22	-0.18
Southeast	-0.24	-0.27	-0.23	-0.16
Upper Midwest	-0.24	-0.27	-0.23	-0.16
Central	-0.26	-0.28	-0.24	-0.12
Mideast	-0.25	-0.27	-0.23	-0.15
California	-0.23	-0.26	-0.21	-0.19
Pacific Northwest	-0.24	-0.27	-0.23	-0.17
Southwest	-0.23	-0.26	-0.21	-0.19
Arizona	-0.23	-0.26	-0.21	-0.20
Unregulated	-0.25	-0.27	-0.23	-0.15

Source: Author calculations using Equation (4.51) and $\rho = 0.3$. The ξ_i^l share parameters are deduced from their relationships with parameters calculated using NASS Crop Production data.

substitutability between feed crops makes sense 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 fit for the context of my model.

The shape parameter of the Fréchet crop yield distribution, θ, determines the supply elasticities for crops. The crop elasticity of supply can be directly computed from equations (4.14) and (4.15):

$$\frac{\partial \ln Y_i^l}{\partial \ln w_i^l} = (\theta - 1)\frac{(1 - \pi_i^l)}{\varphi_i^l}. \tag{4.52}$$

This equation shows that the crop supply elasticity is decreasing in the amount of acreage in a region, with higher acreage crops having a more inelastic supply. The ϕ_i^l parameter is the ratio of land rent to crop price and is therefore bound between zero and one, with the elasticity increasing for crops with lower returns to land use.

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 supply elasticities for corn and soybeans of 0.29 and 0.26. 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

Table 4.7: Crop Supply Elasticities by Region

Region	Grains	Oilseeds	Hay	Silage	Other Crops
Northeast	0.15	0.14	0.12	0.13	1.01
Appalachian	0.31	0.23	0.18	0.25	1.32
Florida	0.27	0.23	0.14	0.17	0.34
Southeast	0.52	0.28	0.17	0.31	0.57
Upper Midwest	0.21	0.21	0.16	0.29	0.25
Central	0.23	0.29	0.18	0.31	0.11
Mideast	0.26	0.20	0.24	0.31	0.88
California	0.14	0.29	0.11	0.11	0.26
Pacific Northwest	0.19	2.39	0.45	0.48	0.53
Southwest	0.45	0.67	0.44	0.84	0.33
Arizona	0.74	0.84	0.83	0.59	2.80
Unregulated	0.25	2.89	0.38	0.94	0.26

Source: Author calculations using Equation (4.52) and $\theta = 1.1$. The π_i^l parameters are deduced from NASS Crop Production data. The φ_i^l parameters are deduced from their relationship to ϕ_i, the land share of crop revenue, π_i^l, and ρ_i^l, the share of crop l in the value of crop production in region i.

and 0.625 for soybeans. These studies provide a range to target for the elasticities of the grains and oilseeds categories.

Choosing $\theta = 1.1$ as a baseline value produces crop supply elasticities for grains and oilseeds that are plausible given the results in Hendricks, Smith, and Sumner (2014) and Miao, Khanna, and Huang (2016), though these elasticities vary across regions to a greater extent due to the differences in acreage shares. For example, oilseed crops are a small share of acres in the Pacific Northwest, leading to a calculated oilseed supply elasticity of 2.39. Gouel and Laborde (2021) also set $\theta = 1.1$ in their analysis, providing support for this choice. The remaining crop supply elasticities are detailed in Table 4.7.

4.5.5 Calculating the Implicit Elasticity of Milk Supply

Since this model does not include an explicit equation for milk supply, I cannot derive an equation for the elasticity of milk supply similar to equations (4.49)-(4.52). However, by expressing the equilibrium in relative changes I can use the results of the model to write out percentage changes in milk production and milk price, using the ratio to define the milk supply elasticity:

$$\frac{\%\Delta M_i}{\%\Delta m_i} = \frac{\frac{M_i' - M_i}{M_i}}{\frac{m_i' - m_i}{m_i}} = \frac{\hat{M}_i - 1}{\hat{m}_i - 1}. \tag{4.53}$$

Unlike the elasticities described up to this point, which are calculated before the model is solved with the chosen behavioral parameters and shares from the calibrating data, the milk supply elasticity is computed after the model is solved. Since I am using the endogenous variables $\hat{M}_i$ and $\hat{m}_i$ to calculate this elasticity it is affected by all of the model parameters. However, the milk supply elasticity is most directly affected by the ρ and θ parameters through the elasticity of demand for feed and the feed crop supply elasticity. With the assumption that the supply of milk is driven by the feed crop supplies, it is natural for the elasticity of milk supply to be most affected by the feed crop elasticities. Therefore, ρ and θ must be chosen to target the elasticities suggested by the literature for feed demand and crop supply, as discussed in the previous section, as well as to result in a reasonable elasticity of milk supply.

Milk supply estimation has a long history but with less focus in the recent literature. In this research I am interested in simulating the long-term response to removal of FMMO pricing rules so I 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 1.527 at 10 years to 4.787 at 29 years. Regional milk supply elasticities at the 10-year horizon range from 0.354 in the South Atlantic to 3.649 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 horizon of 0.890 with a range from 0.680 to 1.144 and at a 25-year horizon of 2.331 with a range of 1.726 to 3.084.

Table 4.8: Milk Supply Elasticities by Region

Region	Milk Supply
Northeast	2.19
Appalachian	2.22
Florida	7.10
Southeast	4.82
Upper Midwest	5.00
Central	2.85
Mideast	5.54
California	5.75
Pacific Northwest	9.15
Southwest	24.36
Arizona	16.13
Unregulated	12.72

Source: Author calculations from simulation results.

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. The implied elasticities are detailed in Table 4.8. Setting $\rho = 0.3$ and $\theta = 1.1$ produces elasticities of milk supply that appear reasonable but with some regional elasticities much larger than the target ranges. In general, the calculated elasticities of feed demand and crop supply are more inelastic than the targets from the literature while the implied elasticities of milk supply are more elastic. This tradeoff means that both ρ and θ are important targets of sensitivity analysis.

Another consideration is that these implied supply elasticities follow from the specific simulation and policy change I am analyzing. Removing the FMMO pricing rules reduces the incentive to ship farm milk from the unregulated region to FMMO regions, since producers in the unregulated region would no longer receive a regulated blend price. Therefore, a larger change in milk production in the unregulated region is expected in this context. The Southwest is one of the fastest growing milk-producing regions, with multiple dairy product manufacturing plants added or planned in Texas. To the extent that this growth is due to the higher milk prices received by producers under the FMMOs, the removal of the pricing rules could lead to a larger change in milk production.

4.6 Results and Discussion

In this section I explore a counterfactual scenario simulated using the calibrated model where the FMMO pricing regulations in each FMMO region are removed. In this scenario all price differentials from the FMMO policy are removed, resulting in a decrease in milk production and milk price, decreased shipments of milk between regions, and decreased value of dairy product manufacturing and exports.

Using the main counterfactual results, I perform a sensitivity analysis by varying the levels of the behavioral parameters. This analysis indicates which parameters have the greatest impact on the final simulation results and provides a range of potential outcomes under different behavioral assumptions.

4.6.1 Counterfactual Analysis: Removal of FMMO Pricing Rules

The counterfactual scenario explores removal of classified pricing in each FMMO region. Recall that milk components are priced differently depending on their end use across the four product classes. In this model the baseline value of the differential between component prices across classes is defined as δ_i^{nk} for component k used in product n in region i. I simulate a counterfactual scenario by setting the value of the differential in the counterfactual, represented by $(\delta_i^{nk})'$, equal to one so that the component prices are equal across classes. In the notation of relative changes used previously, this sets $\hat{\delta}_i^{nk} = 1/\delta_i^{nk}$. The results of the simulation then describe the relative changes that would occur at the new equilibrium.

Changes in Milk Production and Prices Received

Removing the FMMO pricing rules reduces the price received by milk producers and results in a decrease in the quantity of milk produced in each region. Removing the classified pricing system is a price shock, but equilibrium effects result in a smaller decline in milk price than might otherwise be expected. For example, in the Southwest region the initial shock from removing the price differentials would likely result in an overall milk price that is closer to the value of milk components used in manufactured dairy products. Given that the share of milk used in beverage products is lower in the Southwest, this would likely result in a larger decline in price than in the counterfactual results. However, the Southwest ships farm milk to Florida, where the share of milk used in beverage products is much higher. The milk price in Florida would be closer to the value of milk components used in beverage products, so the price in Florida would decline by a smaller amount after the initial shock. As a result of the trade in farm milk between the Southwest and Florida the equilibrium price decline is between the two initial price shocks in the Southwest and Florida. Table 4.9 displays the declines in milk production and price in each region.

It is not the case that every region trades farm milk with every other region, but enough trade linkages exist to require that the milk price falls by the same percentage across all regions. For any two regions that trade farm milk, the milk price in each region is linked by the potential for arbitrage such that the only difference in price between the two regions is due to the cost of transportation. Since I use the iceberg trade cost representation in this model, which defines transportation costs as proportional to the price of the traded good, the declines in price across regions are also equal on a percentage basis.[4]

While the percentage decline in farm milk price is equal across regions, the decline in milk production varies widely. Overall, U.S. milk production falls by 1.34 percent, with some regions seeing a greater decline and some a smaller decline. Recall that in this model the change in milk production in a given region is related to the overall change in shipments of milk out of that region and the change in feed crops available in the region (refer to equations 4.27 and 4.32) as well as the change in milk price. Since the milk price falls in each region the quantity of milk produced also declines, but the amount of that decline depends on the specific conditions in each region.

Some regions, such as the Northeast, Appalachian, and Central regions, have a relatively large share of cropland devoted to feed crops. The Northeast and Appalachian have a large share of cropland in forage crops and the Central region has a large share in grains and oilseeds. Even as the milk price declines, crop producers in these regions are less likely to shift away from production of feed crops. Therefore, milk production falls by a smaller amount than the national average in these regions since feed crops are still readily available. Additionally, the Northeast sees an increase in farm milk shipments to other regions, further counteracting the decline in milk production.

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[4] Iceberg trade costs are mathematically convenient, but it is likely that a per-unit trade cost would more accurately reflect farm milk transportation costs. Specifying the model with per-unit trade costs could be explored in future research.

Table 4.9: Change in Farm Milk Production, Milk Price Received, and Quantities of Farm Milk Shipped (Percent)

Region	Milk Production (%)	Milk Price (%)	Quantity Shipped Out (%)	Quantity Shipped In (%)	Milk Utilized (%)
Northeast	-0.39	-0.18	11.8	-100	-1.50
Appalachian	-0.40	-0.18	-12.3	-6.27	-0.95
Florida	-1.27	-0.18	-100	-47.8	-3.63
Southeast	-0.87	-0.18	-42.2	-9.16	-5.19
Upper Midwest	-0.90	-0.18	-98.2	30.4	0.58
Central	-0.51	-0.18	-24.9	-36.7	-0.94
Mideast	-0.99	-0.18	60.3	14.0	-4.84
California	-1.03	-0.18	-13.0	64.2	0.02
Pacific Northwest	-1.64	-0.18	967	-100	-3.79
Southwest	-4.37	-0.18	-5.46	-100	-5.00
Arizona	-2.89	-0.18	-100	-13.0	-2.73
Unregulated	-2.28	-0.18	-87.5	0.00	2.60
Total	-1.34	-0.18	-3.08	-3.08	-1.26

Note: “Quantity Shipped Out” and “Quantity Shipped In” are the change in total shipments to or from regions other than the local region. The change in Quantity Shipped In for the Unregulated region is equal to zero due to a lack of data in the baseline. “Milk Utilized” is change in the sum of milk shipped to the local region, including milk from local producers that was not shipped out.

The regions that see a larger decline in milk productions, Florida, Pacific Northwest, Southwest, Arizona, and the Unregulated region, have a larger share of land in other crops. Feed crop producers may be more likely to shift into other crop production as the price of milk falls and the returns to feed crop production fall in turn. The remaining regions that fall in between these two groups are those that have a large share of milk production in the baseline, such as the Upper Midwest, Mideast, and California.

The simulated declines in milk production are consistent with the results in 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 percent when both programs are removed, with milk production falling across all regions they consider except California. This confirms that the order of magnitude of my results is consistent with previous research.

Changes in Inter-Regional Milk Shipments

Table 4.9 also reports the change in the total quantity of milk shipped out of and shipped in to each region. The quantity shipped out of a region is defined as the total quantity of milk shipped to destinations other than the local region, with the quantity shipped in defined as the total quantity received in the region that did not originate from milk producers in the same region.

Overall, the total quantity of milk shipped between regions falls by 3.08 percent. This modest decline at the national level results from a mix of increases and decreases in shipments at the regional level. In Chapter 2 I demonstrated that the FMMO pricing rules encourage milk shipments from high milk production regions to low milk production regions, where the price differentials for milk used in beverage products are higher. The quantity of milk shipped out declines across most regions, with shipments from Florida and Arizona being eliminated completely and shipments out of the Upper Midwest declining by 98 percent. Similarly, the quantity of farm milk shipments received decline for most regions, with shipments to the Northeast, Pacific Northwest, and Southwest falling to zero. In general, farm milk shipments from regions with low beverage milk price differentials to regions with higher price differentials fall when the classified pricing system is removed.

However, the simulation results show that after removing the FMMO pricing rules farm milk shipments increase from several regions: the Northeast, the Mideast, and the Pacific Northwest. For the Pacific Northwest especially the increase appears dramatic in percentage terms, but this represents an increase in shipments from a negligible share of regional production, only 0.2 percent in the baseline, to a larger but still small share of production at 2.5 percent. The Northeast sees a small increase in shipments without any decreases, while the Mideast sees a large increase in shipments to the Upper Midwest after starting from a small shipment in the baseline. This is consistent with a general increase in farm milk shipments to regions with a larger share of dairy product manufacturing, as both the Upper Midwest and California see a large increase in shipments received.

The last column in Table 4.9 reports the change in the quantity of milk utilized in each region. The quantity of milk utilized is defined as local milk production, net of shipments to other regions, plus milk received from other regions. For most regions milk utilization falls, and in most cases the decline in milk utilization is greater than the decline in milk production. This occurs due to the combination of falling milk production and the decline in milk shipments received. However, three regions see an increase in milk utilization: the Upper Midwest, California, and the Unregulated region. For both the Upper Midwest and California this is due to an increase in milk shipments received, while the Unregulated region sees a fall in milk shipments to other regions and thus a greater share of local milk production is utilized in the region.[5] As mentioned previously, these regions also produce a large share of manufactured dairy products. With the incentives created by FMMO pricing rules removed, these regions end up processing more milk into dairy products, likely resulting in a more efficient outcome.

Table 4.10 reports the detailed simulated changes in individual shipments of farm milk between each pair of regions. Since I define farm milk trade as net flows in one direction, and not all regions trade farm milk in the observed data, the table is only populated with results where trade flows existed in the baseline. In cases where the reported value is zero, this indicates that the quantity of milk shipped did not change in the counterfactual. The results indicate that out of 42 trade flows 10 were unchanged, suggesting that in these cases the FMMO pricing rules did not create an additional incentive to ship milk beyond the underlying market conditions in the two trading regions. In contrast, 12 trade flows were eliminated completely, suggesting that the only reason milk was shipped between these regions was to take advantage of the FMMO pricing rules.

A few of the results in Table 4.10 deserve specific discussion due to the size of the percentage changes. Shipments between the Mideast and Upper Midwest, between the Pacific Northwest and California, and between the Southwest and California all increase by a substantial amount, but these increases are over small initial trade flows in the baseline. For example, in the Southwest ships about 2.5 million pounds of milk to California in the baseline, or about 0.01 percent of the 20 billion pounds of milk produced in the Southwest. The quantity of milk shipped between the Southwest and California increases to 664 million in the counterfactual, but this still represents only 3.5 percent of total Southwest milk production and only 1.7 percent of milk utilized in California.

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[5] Note that the data from AMS on milk shipments does not include shipments to the Unregulated region, and therefore the calibrated model does not include shipments to the Unregulated region in the baseline. As specified, the model does not allow for creation of new trade flows between regions that are not trading farm milk in the baseline. In general, restricting new trade flows does not seem inconsistent with removal of the incentives to ship milk, but for the Unregulated region this assumption may be too strong.

Table 4.10: Simulated Changes in Inter-Regional Milk Shipments (Percent)

	Order No.	1	5	6	7	30	32	33	51	124	126	131	Unreg.	Shipped Out
Northeast	1	-1.50	0.00	0.00	0.00			14.6						11.8
Appalachian	5		-1.90		-12.3									-12.3
Florida	6		-100	-1.30										-100
Southeast	7			-42.2	1.90									-42.2
Upper Midwest	30	-100	0.00		-100	-0.90								-98.2
Central	32		-100		-15.0	-28.9	4.80	0.00	0.00					-24.9
Mideast	33		-1.70		0.00	4,056		-7.00						60.3
California	51								-1.00			-13.0		-13.0
Pacific Northwest	124						-100		982	-3.70				967
Southwest	126		0.00	-100	0.00	0.00	-38.0	0.00	31,617		-3.80			-5.46
Arizona	131										-100	-2.40		-100
Unregulated	–					-100	-12.9	-100	-100	-100	-100		2.60	-87.5
Milk Shipped In		-100	-6.27	-47.8	-9.16	30.4	-36.7	-14.0	-64.2	-100	-100	-13.0	0.00	

Note: Results are included for each pair of regions that traded farm milk in the baseline. Blank spaces indicate that no farm milk was trade between those regions. Results of -100 indicate that the trade flow was eliminated, while results of zero are not true zero values but indicate that the change in farm milk shipments was small enough to round to zero.

Overall, I believe these results support my hypothesis that the FMMO pricing rules create incentives to ship milk between regions, but the decline in inter-regional farm milk shipments is smaller than I anticipated. The number of trade flows that remain unchanged in the counterfactual suggest that additional market forces encouraging milk shipments remain relevant even after removal of the FMMO pricing rules. Further research into the additional incentives to ship milk is warranted. Additionally, it would be valuable to respecify the model to allow for new trade flows to be created in the counterfactual to account for scenarios such as new shipments to the Unregulated region.

Another consideration is that the geographic structure of the Class I price differentials, exhibited in Figure 2.4 in Chapter 2, was adopted to partially represent the cost of transporting milk from high production regions, such as the Upper Midwest and California, to so-called "milk deficit" regions, such as the Southeast and Florida.[6] In general, the Class I price differentials increase as one moves away from high production regions towards regions that require additional supplies of milk. Several of the trade flows that exhibit increases in the counterfactual tend are in the opposite direction of the increasing Class I price differentials, suggesting that once this pricing structure is removed the new equilibrium would include shipments towards the high production regions.

Changes in Component Prices and Costs

With the end of classified pricing, the individual component prices will adjust to an equilibrium based on derived demand from each processed dairy product market. On a per pound basis, the price differential is largest for components used in beverage products. For example, butterfat receives a higher price when used in beverage products than if it is used to produce butter. When the component price differentials are removed, the cost of butterfat used in beverage products falls while the cost of butterfat used in butter rises until reaching a new equilibrium price that is identical across dairy product categories.

The first set of results in Table 4.11 shows the percentage change in component prices across regions. All three component prices increase in most regions, consistent with the removal of the price differentials across end-use product categories and new equilibrium prices that lie between

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[6] Milk in the New England and Other Marketing Areas, 64 Fed. Reg. 16,026, 16,108 (April 2, 1999).

Table 4.11: Change in Component Prices and Cost Indices (Percent)

Region	Component Price Butterfat (%)	 Protein (%)	 Other Solids (%)	Component Cost Index Beverage (%)	 Softs (%)	 Cheese (%)	 Butter-Powder (%)
Northeast	4.52	44.8	11.3	-17.7	5.19	1.68	11.7
Appalachian	5.65	47.6	47.6	-10.9	11.2	13.0	18.4
Florida	6.73	94.0	94.0	-7.88	15.5	27.6	22.6
Southeast	-2.06	72.8	72.8	-8.54	7.69	17.6	13.2
Upper Midwest	2.31	86.8	-29.4	-18.5	-0.45	0.10	3.33
Central	2.39	50.8	-3.33	-15.0	1.96	1.52	6.49
Mideast	2.19	48.7	4.29	-13.2	2.67	0.08	7.94
California	-0.22	11.8	13.8	-11.5	-0.57	-0.35	4.43
Pacific Northwest	1.28	50.5	-5.18	-14.7	0.56	0.31	5.53
Southwest	2.67	52.6	0.27	-18.2	2.56	3.39	9.69
Arizona	1.16	14.7	14.7	-17.4	2.93	2.18	11.5
Unregulated	-1.27	1.64	1.64	0.27	-0.18	-0.42	0.17

Note: The component cost index is defined by Equation (4.24) and reflects the cost of the milk component mix used in each product category.

the highest- and lowest-cost dairy product categories. In each region the new equilibrium component prices depend on the derived demand for components from each dairy product category. In regions where a higher share of milk is used to produce cheese, derived demand for protein for use in cheese will remain high and the equilibrium protein price will be closer to the price for protein used in cheese in the baseline.

The relative proportions of components used in each product category will also affect the change in component prices. The share of butterfat used in beverage products tends to be lower than in other categories, so the equilibrium butterfat price in the counterfactual is less affected by the removal of the price differentials than the nonfat solids prices. A few regions even see the butterfat price fall due to a combination of a decline in derived demand for butterfat and higher production of butter and cheese in those regions in the baseline.

In contrast, the protein price increases in every region, implying that the current FMMO pricing rules systematically undervalue protein. While I consider separate prices for butterfat, protein, and other solids across all product categories, the FMMO pricing rules only specify a separate price for protein used in cheese. This undervalues protein used in products other than cheese, and these results show that protein is substantially undervalued in some regions.

Changes to the other solids price are more mixed, with price increases of a similar magnitude to the increase in protein price in some regions and a small increase or decline in price in other regions. The Appalachian, Florida, Southeast, and Arizona orders pay farmers based on butterfat and skim milk quantities, which necessarily values protein and other solids at the same rate, while the other orders pay for butterfat, protein, and other solids using individual prices. Across the orders that pay producers for components separately it appears that some currently undervalue other solids, as with protein, while some overvalue them.

The changes to component prices in the Unregulated region are relatively small compared to the changes across the FMMO regions. Without end-use product category price differentials in the baseline, the component prices in the Unregulated region likely change solely due to changes in derived demand for components. These results suggest that the Unregulated region faces a decline in the derived demand for butterfat while derived demand for both protein and other solids increase.

Table 4.11 also displays the change in the component cost index, V_i^n, for each product category across regions. This cost index combines the individual changes in the prices of butterfat, protein, and other solids to reflect the overall change in the cost of components when used in each product category. The first column shows that the cost of components used in beverage products falls by between 8 and 19 percent in each of the FMMO regions. The beverage product component cost increases by about 0.3 percent in the Unregulated region, reflecting a general increase in derived demand for components in beverage products.

Component costs generally increase across the other dairy product categories, with cost increases generally lower for soft products and cheese and somewhat higher for the category of butter and powder products. In calibrating the simulation model I chose to define the price differential with the butter and powder category as the baseline dairy product category. That is, the parameter representing the price differential, δ_i^{nk}, was set equal to one for the butter-powder category and all other δ_i^{nk} are measured relative to the price of components used in butter and powder products. In the counterfactual, where all $(\delta_i^{nk})'$ are set equal to one, the cost of components used in butter and powder products increases the most to reach the new equilibrium level. Cost increases across these three categories are larger in regions that use a greater share of milk in beverage products, since derived demand for components in beverage products is correspondingly higher and the new equilibrium component price level is higher as a result. In other words, when a region uses a large share of milk components in beverage products the equilibrium component price level in the counterfactual will be closer to the cost of components in beverage products in the baseline.

Changes in Value of Dairy Product Production and Exports

The change in dairy product prices is proportional to the change in the component cost index for each category of dairy products, though the change in component costs is not fully passed through to the product prices. Therefore, the price of beverage products generally falls while soft products, cheeses, and butter and powder products generally increase in price. Table 4.12 shows the changes in quantities of each dairy product produced, total production value, and value of exported dairy products. Following from 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 only regions to see a decline in beverage production, but with larger increases in output elsewhere it is likely that more beverage products are being shipped to those regions as finished products. For example, the large increase in beverage production in the Southeast is in part due to more shipments of beverage products to Florida.

Regions that generally produce a large share of manufactured dairy products, as opposed to beverage products, such as the Upper Midwest, Mideast, California, and the Unregulated region see an increase in production of soft products and cheese as well as either a smaller decline or an increase in production of butter and powder products. Regions that tend to use a higher share of milk in beverage products in the baseline further specialize in beverage products and see a decline in production of other products.

In most regions production of butter and powder products declines, which is consistent with the decline in overall milk production seen across all regions. As discussed previously, the cost of components used in the butter and powder category also increases to a greater degree than other product categories, and the fall in output is certainly related to the increase in costs, at least in part. Producing butter and powder products also serves an additional purpose in regions that use a high share of milk in beverage products. Demand for beverage products is variable and the products

Table 4.12: Change in Dairy Product Production and Export Value (Percent)

Region	Production Quantity Beverage (%)	Softs (%)	Cheese (%)	Butter-Powder (%)	Total Production Value (%)	Export Value (%)
Northeast	1.20	-0.78	-0.26	-2.92	-0.48	-0.35
Appalachian	0.99	-5.20	-3.91	4.44	0.17	-3.31
Florida	-0.61	-8.26	-1.12	-10.3	-2.21	-6.10
Southeast	4.86	-8.22	-18.0	-31.1	-4.33	-18.5
Upper Midwest	3.75	1.03	0.41	6.36	1.28	4.67
Central	0.30	0.32	-0.56	-0.85	-0.23	1.29
Mideast	1.86	0.47	0.48	-23.9	-0.32	0.23
California	0.26	0.64	0.94	-1.45	0.23	1.61
Pacific Northwest	-0.19	0.14	0.03	-10.3	-1.19	-6.93
Southwest	1.31	-0.15	-6.56	-10.0	-1.81	-9.32
Arizona	1.72	-3.56	-2.85	-5.09	-1.70	-4.81
Unregulated	-2.05	0.73	1.01	7.48	1.13	7.12
Total					-0.16	-0.27

Note: The change in production quantity is calculate using $\hat{Q}_i^n$ determined by Equation (4.22). The change in total production quantity cannot be isolated from the change in production value when aggregated across product categories and regions. Hence, the change in total production value is reported. The same is true for the change in export value.

are costly to store, unlike butter and powder products. Moreover, the ratio of butter and nonfat dry milk produced can be adjusted to match the ratio of butterfat to nonfat solids in beverage milk products. Given that milk production is continuous and variable, and may not match the variability in beverage product demand, the amount of butter and nonfat dry milk produced may be adjusted and stored to utilize available milk.

In order to aggregate across dairy product categories, I calculate the change in the value of dairy products from the change in product prices and quantities produced. The change in production value ranges from a decline of 4.3 percent in the Southeast, due to a shift towards specialization in beverage products, to an increase of 1.3 percent in the Upper Midwest, the only region to see an increase in output of all dairy products categories. Overall, the value of U.S. dairy products falls by about 0.2 percent, meaning that the increases in production value in some regions approximately offset the declines in others.

Table 4.12 also shows the value of dairy product exports, declines by about 0.3 percent for the

U.S. as a whole. As argued in Chapter 2, I expected that FMMO regulations lead to increased production of tradable dairy products and a corresponding increase in dairy product exports. Table 4.12 reports the change in the value of exports from each region. Exports fall by a large amount for some regions, up to 18 percent in the Southeast, but these declines are offset by increases in regions that represent a larger share of exports in the baseline. Exports from the Upper Midwest increase by 4.7 percent and exports from California increase by 1.6 percent, both of which are already major exporters of dairy products in the baseline. While the overall decline in the value of exports is smaller than I expected, these results are consistent with the idea that regions become more specialized in the counterfactual scenario.

Simulated Impacts on Social Welfare

One advantage of the modeling structure that is used in this chapter, following Costinot, Donaldson, and Smith (2016) and Gouel and Laborde (2021), is that it allows for simple calculation of welfare impacts. Equations (4.40), (4.41), and (4.42) are used to calculate the change in consumer surplus for buyers of dairy products in each region, the change in consumer surplus for buyers of U.S. dairy product exports, and the change in profit for crop producers. The model has no welfare calculations for dairy farmers or dairy product manufacturers due to the assumption of constant returns to scale production and zero profit at these stages of the supply chain.

Simulation results show that removing the FMMO pricing rules would result in an increase in total social welfare of $210 million. Domestic consumer surplus increases by $323 million while foreign consumer surplus falls by $47 million. Profit for domestic crop producers decreases by $66 million. These results are outlined in Table 4.13.

In terms of domestic net welfare, these results are similar to FMMO welfare impacts calculated in previous research. 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. This suggests that the increase in domestic net welfare of $257 million calculated in the simulation is similar in magnitude to previous findings. However, it is important to note that Ippolito and Masson's calculation includes impacts to dairy producers while my calculation is primarily driven by changes in consumer surplus. Chouinard et al. (2010) summarize several studies that estimate

Table 4.13: Simulated Change in Consumer Surplus and Crop Producer Profit, Million USD

Region	ΔCS_i	$\Delta\Pi_i$	Net Welfare
Northeast	68.9	-10.0	58.9
Appalachian	18.0	-1.54	16.5
Florida	14.2	-0.89	13.4
Southeast	30.4	-0.69	29.8
Upper Midwest	18.3	-12.2	6.06
Central	48.1	-6.29	41.8
Mideast	27.9	-6.60	21.3
California	4.82	-11.6	-6.73
Pacific Northwest	22.4	-2.85	19.6
Southwest	46.1	-6.24	39.8
Arizona	19.5	-1.45	18.0
Unregulated	4.22	-5.14	-0.92
United States	323	-65.5	257
Rest of World	-47.2	–	-47.2
Total	276	-65.5	210

Note: The change in consumer surplus is calculated using Equations (4.40) and (4.41). The change in crop producer profit is calculated using Equation (4.42). Net welfare is the sum of the changes in consumer surplus and crop producer profit.

impacts of FMMO regulations on consumer surplus ranging between $225 million and $1.6 billion in 2022 dollars. My simulation results are towards the lower end of that range, but this suggests that the calculated $323 million increase in domestic consumer surplus is plausible.

As in previous results, the impacts on individual regions are important to consider separately, with some regions faring better than others in this counterfactual. The Southwest and Northeast regions see the largest gains in welfare, with increases of about $40 million and $59 million respectively. Only two regions see a loss in total welfare due to decreases in crop producer surplus that exceed the increase in consumer surplus: California loses $6.7 million in net welfare while the unregulated region loses just under $1 million. The simulated increase in consumer surplus in both regions is relatively small due to lower prices for dairy products in the baseline relative to other regions.

Crop producer profits fall across all regions, with losses ranging from $12 million in the Upper

Midwest to $0.7 million in the Southeast. The change in profits for crop producers is primarily driven by the decline in returns to forage production and the fall in production of forage crops, but is partially offset by an increase in production of other crops as acreage shifts away from forage production. Losses are higher in regions that produce a larger share of crops. For example, losses in California are greater due to a large decline in the return to forage crop production. While some acreage shifts out of forage production and production of other crops increases, the decline in returns to forage production multiplied by the large share produced in California leads to a greater loss of producer profit than other regions.

4.6.2 Summary of Impacts of Removing FMMO Pricing Rules

In general, the impacts of removing the FMMO pricing rules are small at the national level due to offsetting effects across regions. Ippolito and Masson (1978) estimate that Federal Order regulations lead to a 1.3 percent increase in milk production, identical to the results in this counterfactual simulation. However, they estimate that the price received by milk producers increases by 3.7 percent, a much different result than the 0.2 percent change in milk price found in this simulation. This may be due to the restriction that milk prices change by the same amount between regions that trade in farm milk, and perhaps regions would see larger changes in milk prices in the short run before prices equalize across regions over time. The changes in value of dairy product manufacturing and exports show that offsetting across regions may result in smaller effects in aggregate.

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. They estimate that FMMO regulations result in an increase in the Class I price of 9.3 percent and a decline in the price of manufacturing milk of 5.6 percent. Taken in aggregate, the simulated changes in component costs across regions seem consistent with these estimates. Ippolito and Masson also estimate an decline in consumption of beverage (Class I) products by 1.9 percent and an increase in consumption of other dairy products of 9.6 percent. Again, considering the changes in production of dairy products across regions, the simulation results appear consistent with Ippolito and Masson's findings.

4.6.3 Sensitivity of Results to Behavioral Parameters

The counterfactual results just discussed depend on the set of behavioral parameters that I chose through a review of the literature, so it is important to determine the extent to which each parameter affects the level of the results. In this sensitivity analysis I will focus on how the main outcomes of interest change for the U.S. in aggregate across various scenarios. Changes in milk production, milk price received by producers, quantity of milk shipped between regions, the value of dairy product manufacturing, and the value of dairy products exports are presented in Table 4.14 for different values of the behavioral parameters.

The benchmark scenario is the original set of behavioral parameters used to produce the counterfactual results. Note that all behavioral parameters are discussed in absolute value. The elasticity of dairy product demand, ϵ, is 0.2 and the elasticity of substitution between dairy product categories, κ, is 0.5. The elasticity of substitution between dairy products of different origins, σ^n, is equal to 2.5 for beverage products, 4.0 for soft products and cheeses, and 7.0 for butter and powder products. The corresponding demand parameters for the rest of the world are $\epsilon_0 = 1.3$, $\kappa_0 = 1.8$, and σ_0^n values of 8.0 for soft products and cheeses and 10 for butter and powder products.

The elasticity of substitution between feed crops for use in dairy rations, ρ, is set at 0.3 and the elasticity of substitution between feed crops from different origins, λ, is equal to 1.8. The shape parameter of the Fréchet distribution that determines crop yields, θ, is equal to 1.1.

In general, the sensitivity analysis scenarios are set to create a low-elasticity scenario and a high-elasticity scenario relative to the benchmark scenario. In cases where a pair of behavioral parameters are restricted in some way the scenarios are defined by changing both parameters at the same time. For example, since $\epsilon < \kappa$ the low-elasticity scenario for dairy product demand sets $\epsilon = 0.1$ and $\kappa = 0.25$.

Sensitivity to the Elasticity of Dairy Product Demand

The first scenario sets $\epsilon = 0.1$ and $\kappa = 0.25$, shifting the own-price elasticity of demand for each dairy product category to a more inelastic level following Equation (4.49). Setting $\epsilon = 0.1$ is consistent with the average dairy product demand elasticity found by Okrent and Alston (2011) across studies that do not differentiate between food at home and food away from home.

Table 4.14: Changes in Milk Production, Price, Shipments between Regions, Dairy Product Value, and Export Value across Behavioral Parameter Sensitivity Scenarios

Scenario	Milk Production (%)	Milk Price (%)	Quantity Shipped (%)	Product Value (%)	Export Value (%)
Benchmark	-1.338	-0.179	-3.083	-0.160	-0.267
$\epsilon = 0.1$, $\kappa = 0.25$	-1.296	-0.174	-3.033	-0.176	-0.268
$\epsilon = 0.4$, $\kappa = 0.9$	-1.398	-0.187	-3.154	-0.128	-0.265
$\epsilon_0 = 1.05$, $\kappa_0 = 1.4$	-1.326	-0.178	-3.054	-0.154	-0.045
$\epsilon_0 = 1.8$, $\kappa_0 = 2.6$	-1.360	-0.182	-3.142	-0.172	-0.706
$\sigma^n - 1$	-1.259	-0.170	-4.538	-0.152	-0.268
$\sigma^n + 1$	-1.413	-0.189	-1.627	-0.168	-0.265
$\sigma_0^n - 1$	-1.333	-0.179	-3.162	-0.160	-0.268
$\sigma_0^n + 1$	-1.343	-0.180	-3.005	-0.160	-0.265
ς^n each halved	-1.102	-0.150	-2.181	-0.126	-0.277
ς^n each doubled	-1.774	-0.232	-4.305	-0.225	-0.241
$\rho = 0.1$	-1.327	-0.216	-4.196	-0.165	-0.264
$\rho = 0.6$	-1.348	-0.142	-2.059	-0.156	-0.270
$\theta = 1.05$	-1.318	-0.263	-2.418	-0.171	-0.260
$\theta = 1.2$	-1.353	-0.110	-3.582	-0.152	-0.272

Note: ϵ is the elasticity of dairy product demand. κ is the elasticity of substitution between dairy product categories. σ^n is the elasticity of substitution between dairy product n from different origin regions. ϵ_0, κ_0, σ_0^n are the corresponding elasticities for the rest of the world. ς^n is the elasticity of substitution between milk components as inputs to dairy product n. ρ is the elasticity of substitution between feed crop categories in the dairy industry. λ is the elasticity of substitution across feed crops from different origins. θ is the shape parameter of the Fréchet distribution that determines crop yields.

The second scenario makes the dairy product demand elasticity more elastic, setting $\epsilon = 0.4$ and $\kappa = 0.9$. This produces a range of dairy product demand elasticities that are similar to the most elastic results in Chouinard et al. (2010).

When dairy product demand is more inelastic removing classified pricing reduces milk production, milk price, and the quantity of milk shipped by a smaller amount while the value of dairy products falls by a larger amount. In the scenario with more elastic demand for dairy products the opposite effects occur, with milk production, milk price, and quantity of milk shipped fall by a larger amount than in the benchmark and dairy product value falling by a smaller amount. In both cases the value of dairy product exports is essentially unaffected.

In the third and fourth scenarios the demand in the rest of the world for U.S. dairy products is made more inelastic and more elastic. The scenario with more inelastic demand sets $\epsilon_0 = 1.05$, the level suggested by Song and Kaiser (2016) for the elasticity of foreign demand for dairy products. The literature on foreign demand for U.S. dairy products was limited, so the scenario with more elastic foreign demand is not reflected by a specific study. However, since foreign consumers of dairy products have a range of options available from other dairy product exporting countries and local producers, I believe this range of elasticities is plausible.

Across the two foreign demand scenarios the effects on milk production, milk price, and quantity of milk shipped are similar to the domestic demand scenarios, though the range between the two scenarios is slightly smaller. The effect of the foreign demand parameters on the decline in the value of dairy products is opposite of the domestic demand parameters: when foreign demand is more inelastic the value of U.S. dairy products falls by a smaller amount and a larger amount when foreign demand is more elastic. Unsurprisingly, the biggest difference from the two domestic demand scenarios is the impact on the value of dairy product exports. When foreign demand is more inelastic the decline in export value decreases to only 0.05 percent, while the more elastic foreign demand scenario results in a 0.7 percent decline in export value, more than double the benchmark result.

Sensitivity to the Elasticity of Substitution between Dairy Products of Different Origins

The elasticity of substitution between dairy products of different origins has a large impact on the results. In models of international trade, the Armington elasticity typically has a large effect on the outcome of the model, and the same is true in this model.

The two scenarios I investigate are defined by adding and subtracting one from the σ^n values used in the benchmark. In the inelastic scenario the elasticity of substitution for beverage products is set to 1.5, 3.0 for soft products and cheese, and 6.0 for butter and powder products. The elastic scenario has 3.5 for the elasticity of substitution for beverage products, 5.0 for soft products and cheese, and 8.0 for butter and powder products.

Compared to other behavioral parameters, the value of σ^n has the largest impact on the decline in milk production other than the elasticity of substitution between milk components, ς^n. When substitution between dairy products of different origins is more inelastic milk production falls by a lesser amount, given that consumers will continue to demand dairy products from each region. If dairy products or more homogenous across regions, then milk production will fall by a greater amount as regions with more dairy product output ship products to a wider range of consumers.

In contrast, the quantity of milk shipped between regions fall by a larger amount when dairy products are more differentiated. If products are more differentiated by region, then farm milk is more likely to stay in the region where it was originally produced. Therefore, fewer shipments occur between regions and the quantity of milk shipped falls. The opposite is true when dairy products are more homogeneous.

I use the same method to set low and high elasticity scenarios for the foreign elasticity of substitution between U.S. dairy products of different origins. The low elasticity scenario sets the elasticity of substitution for soft products and cheese to 7 and the elasticity of substitution for butter and powder products to 9. In the high elasticity scenario these levels are 9 for soft products and cheese and 11 for butter and powder products.

The impact of σ_0^n on the changes in milk production, milk price, and quantity of milk shipped is the same as the impact of σ^n, though to a lesser degree. Surprisingly, the impact on the decline in export value is exactly the same as the impact of σ^n. Given that the foreign elasticity of substitution across dairy products of different origins is already highly elastic at the benchmark values, the results are not very sensitive to the range of elasticities tested in these scenarios.

Sensitivity to the Elasticity of Substitution between Milk Components in Dairy Products

In the low elasticity scenario the benchmark ς^n values are halved, resulting in 0.15 for beverage products, 0.4 for soft products, and 0.1 for cheese, butter, and powder products. For cheese, butter, and powder products this moves the production technology closer to fixed proportions. The high elasticity scenario doubles the benchmark ς^n values, setting the elasticity of substitution to 0.6 for beverage products, 1.6 for soft products, and 0.4 for cheese, butter, and powder products. In this scenario, substitution between milk components used in soft products is elastic, in contrast to the elasticities for each other product and in each other scenario.

The level of the elasticity of substitution between milk components used in dairy products has the largest impact on the simulation results across the behavioral parameters. When milk component substitution is more inelastic milk production falls by a much smaller amount. If processors cannot substitute between milk components as readily, then it follows that they will require a more consistent supply of milk to produce the same amount of dairy products. Similarly, the smaller decline in quantity shipped may be due to processors seeking milk components from a wider range of producers, leading to more shipments of farm milk than in the benchmark scenario.

The reduced impact on milk production and shipments is also consistent with both the smaller decline in farm milk price and dairy product value in the low elasticity scenario. The milk price falls by a smaller amount due to more inelastic derived demand for milk components, and the smaller decline in price is passed through to dairy product price reducing the decline in dairy product value. The opposite occurs in the high elasticity scenario: a larger decline in milk production, milk price, quantity shipped, and product value.

Sensitivity to Feed Crop Demand and Supply Parameters

The elasticity of demand for feed crops from the dairy industry, defined by Equation (4.51), is determined by the elasticity of substitution between feed crops for use in dairy rations. In the low elasticity scenario, the feed crop substitution elasticity, ρ, is set equal to 0.1, and in the high elasticity scenario I set $\rho = 0.6$.

The level of the feed crop substitution elasticity has the largest impact on the farm milk price and the quantity of farm milk shipped between regions. When FMMO pricing rules are removed the return to forage crop production falls due to the decline in milk production. The upward-sloping marginal cost of milk production follows from the cost of feed crops, and if dairy farmers are less able to substitute between feed crops in dairy rations then declines in forage crop prices will more directly translate to the milk price. In the low elasticity scenario a smaller decline in milk production corresponds to a larger decline in returns to forage crop production due to the more inelastic demand from the dairy industry, resulting in a larger decline in the farm milk price compared to the benchmark scenario.

The decline in the quantity of milk shipped between regions is also affected by the feed crop substitution elasticity. In the low elasticity scenario a larger share of milk production remains in the original production region, similar to the low elasticity scenario for the elasticity of substitution between dairy products of different origins. When dairy producers have more flexibility between feed crops used in dairy rations, they can more readily substitute from forage crops to grains and oilseeds, meaning that milk production is less tied to local production of forage crops. Therefore, the decline in shipments of farm milk is lower in the high elasticity scenario as larger milk production regions more readily supply milk to lower production regions.

Recall that the shape parameter of the Fréchet distribution that determines crop yields, θ, also governs the elasticity of crop supply, defined in Equation (4.52). The shape parameter determines the homogeneity of U.S. cropland, with a higher θ value implying that cropland is more homogeneous. The crop supply elasticity increases with θ because acreage use will be more elastic with more homogeneous cropland. Based on equation (4.52), setting $\theta = 1.05$ for the low elasticity scenario and $\theta = 1.2$ for the high elasticity scenario is equivalent to halving and doubling the elasticities of crop supply.

As with the feed crop substitution elasticity, in the scenario with less elastic feed crop supply a small change in demand for feed crops will lead to a larger decline in crop prices. Therefore, the low elasticity scenario leads to a larger decline in milk price due to the relationship between the farm milk price and crop prices. The impact of the crop supply elasticity on the decline in milk production and milk price is greater than the impact of the feed crop substitution elasticity, with a smaller decline in milk production corresponding to a larger decline in milk price in the low elasticity scenario.

The quantity of milk shipped falls by a smaller amount in the low elasticity scenario, in contrast to the impact of the feed crop substitution elasticity on milk shipments. In the high elasticity scenario cropland is assumed to be more homogeneous, and therefore the differences between regions with high milk production and low milk production are less distinct. If milk production is more homogeneous across regions, then the decline in milk shipments will be greater since regions are better able to meet local demand for milk.

4.7 Conclusion

This chapter builds on the previous two chapters to develop and calibrate a partial equilibrium model of regional U.S. milk production, feed crop production, and dairy product manufacturing and the trade linkages between each stage of the dairy supply chain. I use data representing the dairy industry in 2017, which therefore reflects the presence of the Federal Milk Marketing Orders, to calibrate a baseline scenario. Starting from a baseline where FMMO pricing rules are in place, I simulate a counterfactual scenario where the FMMO pricing rules are removed.

The quantitative results derived through simulation are consistent with the qualitative implications of the two-class, two-region conceptual model laid out in Chapter 2. Calibration of the simulation model used to derive those results relies on the detailed data that I described in Chapter 3.

The simulation results indicate that removing the price discriminating effects of FMMO classified pricing leads to a decline in milk production and the farm milk price in all regions, an overall decline in the quantity of milk shipped between regions, and a decline in the values of U.S.-produced processed dairy products and dairy product exports.

While the aggregate decline in farm milk shipments supports the hypothesis that the FMMOs create an incentive to ship milk between regions, these results also demonstrate the importance of modeling the regional impacts in detail. The impact on inter-regional shipments of farm milk differs across regions, with some regions shipping out or receiving more milk than in the baseline and some trade flows eliminated completely. Some of the farm milk shipments that increase in the counterfactual are to regions with a greater share of U.S. milk production and dairy product manufacturing, trade flows that are in the opposite direction of the increase in beverage milk price differentials under the FMMO pricing rules. Further research could expand the model to allow for new trade flows between regions that do not trade farm milk in the baseline.

The simulation results also include calculation of welfare effects from removing the FMMO pricing rules. Dairy product buyers in the United States would gain $323 million in consumer surplus as a result of the changes in dairy product prices, while buyers of U.S. dairy products in the rest of the world would lose $47 million as exports increase in price. Due to the decline in milk production, and corresponding decline in demand for feed crops from the dairy industry, producers of feed crops would lose $66 million as returns to forage crops fall. As with other simulation results, it is valuable to separately calculate welfare impacts for each region. Net welfare would increase in most regions if FMMO pricing rules were removed, but net welfare declines in regions with a large share of crop production or low dairy product prices in the baseline. Overall, net welfare for the United States would increase by $257 million.

I relate the geography of milk production to the geography of crop production, and the marginal cost of milk production is derived from the cost of feed crops. However, other differences across regions may further explain the differences in regional milk production. For example, dairies in the West tend to operate much larger herds than in other parts of the country, and herd sizes in the Upper Midwest have steadily increased due to consolidation and adoption of different production technologies. Developing a better understanding of supplemental drivers behind milk production technology could provide an alternative method to determine the position and own-price elasticity milk supply functions.

An advantage of the specification of crop production as determined by land productivity is that producer profit in the crop production stage can be calculated as the return to land productivity. If milk production technology were specified with a factor that could allow for similar returns, then further research could also calculate the impact on milk producer profits from removal of the FMMO pricing rules. Additionally, since some milk producers also grow their own feed crops some share of crop producer profits may also accrue to those milk producers.

Another opportunity for future analysis is to consider whether perfect competition in the market for farm milk is an appropriate assumption for the counterfactual scenario. To simplify the analysis, this study largely ignores the role of cooperatives in the dairy industry. The size and national scope of the major dairy cooperatives 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 facilitate the terms of trade between milk producers and milk buyers. Extending the model to allow for 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.

Extending this model to an international context would also be a natural exercise, which would allow for calculation of the impacts of FMMO regulations and dairy policies in other countries on international trade in dairy products. I include dairy product imports from the rest of the world and exports of U.S. dairy products to the international market in the simulation, but international prices are treated as exogenous to reduce complexity. Considering the equilibrium in the international market for dairy products would allow analysis of the extent to which the United States affects international prices and the impact of various dairy policies on international trade flows.

Based on the results of the counterfactual simulation, this study shows that removal of the system of classified pricing, price differentials, and revenue pooling implemented by the Federal Milk Marketing Orders leads to decreased milk production, reduces incentives to ship farm milk between regions, and decreases the values of dairy products and dairy product exports. Dairy product buyers are negatively impacted by the price discrimination between milk used to produce dairy products in different categories while feed crop producers benefit from the increase in demand for forage crops. By conducting the analysis at a regional level I am able to calculate the differential impacts across regions and determine which regions are more or less impacted by marketing order pricing rules. The Federal Milk Marketing Orders provide additional benefits to dairy farmers such as testing milk samples, market information, and product promotion efforts, but this research demonstrates that classified pricing and revenue pooling disrupt the dairy market across the dairy supply chain.

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Appendix A

Milk Pooling Decisions in FMMO Regions

Participation in the Federal Milk Marketing Order system is not mandatory for all handlers of milk. In general, a handler that buys milk for use in beverage products must include that quantity of milk in the revenue pool. This is also described as “pooling” the milk on an FMMO. Handlers that purchase milk for use in other products may choose whether or not to pool that quantity of milk depending on the relationship between the FMMO minimum prices. When handlers choose not to pool a quantity of milk it is referred to as “depooling” that milk, which can impact the market dynamics within the region and the blend price received by farmers.

When milk is depooled it is not reported to the FMMOs, and therefore is not included in the data published by AMS. The total quantity of milk produced in a state is reported by NASS, and calculating the difference between milk production and milk pooled on an FMMO gives some measure of the quantity of milk not pooled. For example, Texas produced about 12 billion pounds of milk in 2017. The total quantity of milk pooled across the FMMOs that originated in Texas was about 10.6 billion pounds, leaving about 1.4 billion pounds of milk produced in Texas unaccounted for in AMS data.

In order to accurately calibrate the model in Chapter 4, it is not only necessary to account for the quantity of milk not pooled but also to establish what that milk was used to produce. No data exist that can be used to directly determine the utilization of depooled milk, but it is possible to impute the utilization shares by using the available data and an understanding of what causes handlers to depool milk.

A.1 Understanding Pooling Regulations and Causes of Depooling

To better understand the decision to depool milk, it is first necessary to understand the regulations that affect handlers when they choose to participate in an FMMO pool. When milk handlers purchase milk from dairy farmers in an FMMO region they face two obligations. First, they must pay the FMMO blend price to any dairy farmers from whom they purchase milk. The blend price is likely different from the minimum class price they are required to pay when using milk to produce certain dairy products. The minimum class prices establish the classified value of milk purchased by a handler.

If the handler's classified value is greater than the amount owed to dairy farmers, the blend price multiplied by the quantity of milk purchased, then the handler must pay the difference to the FMMO. However, if the classified value is less than the amount owed to dairy farmers, then the handler will receive a payment from the FMMO equal to the difference. For example, suppose a handler buys 1 million pounds of milk from dairy farmers and the FMMO blend price is $15.00 per cwt. The handler uses all of the purchased milk to produce cheese, so the classified value will be determined at the minimum Class III price. If the minimum Class III price is $14.00, then the classified value of the milk would be $140,000. Since the handler owes $150,000 to the dairy farmers from whom the milk was purchased, the difference between the obligation to dairy farmers and the classified value is $10,000. The handler would then receive a payment from the FMMO equal to $10,000, meaning that the actual amount they paid for milk was equal to the Class III minimum price.

This example demonstrates a scenario when the handler would be willing to participate in the FMMO revenue pool in order to receive a payment from the FMMO, referred to as a "pool draw." In general, if the minimum class price that the handler is obligated to pay is less than the blend price paid to farmers, then the handler has an incentive to pool. However, suppose instead that the Class III minimum price in the example above were $16.00 per hundredweight. Then, the handler would be obligated to pay $10,000 to the FMMO and would instead have an incentive to depool the milk used for cheese production. If the handler chose not to participate in the revenue pool but offered to purchase milk for $15.00 per hundredweight, the same price as the FMMO blend price, then dairy farmers would be no worse off selling milk to a depooled handler compared to one participating in the FMMO pool.

To simplify this example, I have left out some details related to when payments are due and when minimum class prices are set. Payments to dairy farmers and handler obligations are calculated on a monthly basis and finalized in the month following the purchase of milk. The Class I price is announced prior to the month to which it applies, while the Class II, Class III, and Class IV minimum prices are announced following the end of the month to which they apply. That is, if a handler purchases milk from a dairy farmer and uses it to produce a dairy product in January, then the final payments and obligations will be calculated and due in February. Since the Class I minimum price for January is announced in December, the handler knows in advance what they will be required to pay if they purchase milk for use in beverage products. However, without knowing the other minimum class prices until the month is over, handlers cannot precisely calculate the blend price that will be paid to farmers for milk purchased in January, so they also cannot precisely calculate their incentive to pool or not pool. Despite the importance of these nuances, for the sake of this analysis I will calculate the depooling incentive for a given month as if a handler could know this information at the time of their decision to pool or not pool.

A.2 Milk Produced in Federal Order Regions but Not Pooled

Using the *Milk Production* report from NASS and the *Producer Milk Pooled by State of Origin* report from AMS, I calculate the quantity of milk not pooled as the difference between each state's quantity of milk produced and the quantity of milk pooled in any FMMO (the sum of all shipments to an FMMO region). Given the quantity of milk not pooled, the next steps are to establish both *where* and *how* the milk is utilized.

To the first point, I assume that milk not pooled is utilized in the same region it is produced. The only source of data indicating shipments of farm milk between regions is the *Producer Milk Pooled by State of Origin* report from AMS, which only reports shipments of farm milk which are then pooled in the destination region. However, if milk is not being pooled in the same region where it is produced, then it is likely that it is not being shipped between regions due to the high cost to transport farm milk.

To impute the utilization of milk not pooled, I 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, I calculate the annual average utilization share by class and the deviations between the monthly utilization share and the annual average. Then, I divide the quantity of milk pooled by the number of days in the month to determine the average daily milk pooled. Since I am calculating deviations from average, this step ensures that I can compare January and February without the number of days impacting the comparison. I 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.

I 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 percent 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 percent, suggesting that milk that would be used in cheese production was depooled in those months. I 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, I calculate these sums for Class II, Class III, and Class IV. Using the total deviations for Classes II, III, and IV, I calculate the share of the depooled quantity attributable to each class. In the Central Federal Order about 70 percent of the quantity deviations were from Class III, so I assume that 70 percent of depooled milk from the Central region was used in cheese manufacturing. Table A.1 reports the imputed utilization shares for each class and each region.

Table A.1: Imputed Utilization Shares for Milk Not Pooled (Percent)

Order	Softs Products	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: Author 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.

Appendix B

Elasticities of Demand for Dairy Product from Specific Origins

Following the standard convention established in Armington (1969), dairy products are differentiated across regions and buyers of dairy products substitute between dairy products of different origins according to the elasticity of substitution σ^n. A different elasticity of substitution is specified for each dairy product category, meaning that buyers may be more willing to substitute between butter from different origin regions than between differentiated cheese products, but the same set of elasticities is shared across regions.

The own-price elasticity of demand in destination region j for dairy product category n originating from region i is defined by equation (4.50), reproduced below:

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

The parameters that affect this elasticity are the overall elasticity of dairy product demand, ϵ, the elasticity of substitution between dairy products categories, κ, and the elasticity of substitution within each dairy product category between products from different origins. The elasticity is also calculated using the share of region j spending on dairy products from category n, b_j^n, and the share of spending in region j on products from category n originating in region i, b_{ij}^n.

Table B.1 lists the own-price elasticities of demand for buyers in the destination region purchasing dairy products from the origin region.

Table B.1: Elasticities of Demand for Dairy Products Originating from Each Region

Origin	Destination	Beverage	Softs	Cheese	Butter-Powder
Northeast	Northeast	0.852	1.798	2.004	2.587
Northeast	Appalachian	2.146	3.293	3.493	6.253
Northeast	Florida	2.386	3.428	3.588	6.108
Northeast	Southeast	2.257	3.586	3.579	6.237
Northeast	Upper Midwest	2.382	3.702	3.831	6.514
Northeast	Central	2.378	3.634	3.843	6.531
Northeast	Mideast	2.323	3.651	3.617	5.987
Northeast	California	2.470	3.848	3.936	6.814
Northeast	Pacific Northwest	2.447	3.837	3.915	6.845
Northeast	Southwest	2.408	3.713	3.777	6.527
Northeast	Arizona	2.456	3.669	3.901	6.819
Northeast	Unregulated	2.435	3.772	3.888	6.851
Appalachian	Northeast	2.407	3.942	3.985	6.711
Appalachian	Appalachian	1.459	3.086	3.556	3.342
Appalachian	Florida	2.432	3.894	3.961	5.327
Appalachian	Southeast	2.305	3.876	3.945	5.196
Appalachian	Upper Midwest	2.455	3.960	3.991	6.859
Appalachian	Central	2.440	3.944	3.990	6.651
Appalachian	Mideast	2.426	3.948	3.982	5.576
Appalachian	California	2.484	3.980	3.997	6.799
Appalachian	Pacific Northwest	2.480	3.981	3.996	6.893
Appalachian	Southwest	2.452	3.954	3.984	6.418
Appalachian	Arizona	2.479	3.953	3.994	6.586
Appalachian	Unregulated	2.471	3.972	3.994	6.864
Florida	Northeast	2.480	3.992	3.993	6.991
Florida	Appalachian	2.441	3.978	3.977	6.981
Florida	Florida	0.870	2.966	3.374	6.297
Florida	Southeast	2.366	3.954	3.950	6.955
Florida	Upper Midwest	2.484	3.995	3.994	6.992
Florida	Central	2.475	3.990	3.994	6.990
Florida	Mideast	2.480	3.991	3.991	6.988
Florida	California	2.491	3.995	3.997	6.996
Florida	Pacific Northwest	2.490	3.996	3.997	6.997
Florida	Southwest	2.470	3.984	3.984	6.985
Florida	Arizona	2.488	3.990	3.994	6.994
Florida	Unregulated	2.485	3.993	3.995	6.997
Southeast	Northeast	2.483	3.991	3.996	6.986
Southeast	Appalachian	2.427	3.964	3.981	6.961
Southeast	Florida	2.452	3.947	3.985	6.890
Southeast	Southeast	1.939	3.347	3.746	6.081

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Table B.1 – continued from previous page

Origin	Destination	Beverage	Softs	Cheese	Butter-Powder
Southeast	Upper Midwest	2.485	3.994	3.996	6.989
Southeast	Central	2.472	3.987	3.994	6.979
Southeast	Mideast	2.479	3.989	3.994	6.958
Southeast	California	2.491	3.994	3.998	6.988
Southeast	Pacific Northwest	2.492	3.995	3.998	6.994
Southeast	Southwest	2.465	3.979	3.984	6.947
Southeast	Arizona	2.490	3.990	3.996	6.976
Southeast	Unregulated	2.487	3.993	3.997	6.992
Upper Midwest	Northeast	2.471	3.884	3.497	6.340
Upper Midwest	Appalachian	2.453	3.790	2.964	6.161
Upper Midwest	Florida	2.476	3.785	3.080	6.040
Upper Midwest	Southeast	2.435	3.786	2.922	6.059
Upper Midwest	Upper Midwest	1.103	1.912	1.552	3.182
Upper Midwest	Central	2.421	3.572	2.878	4.618
Upper Midwest	Mideast	2.453	3.786	2.924	5.822
Upper Midwest	California	2.490	3.916	3.780	6.771
Upper Midwest	Pacific Northwest	2.477	3.903	3.681	6.685
Upper Midwest	Southwest	2.466	3.825	3.245	6.375
Upper Midwest	Arizona	2.484	3.853	3.663	6.777
Upper Midwest	Unregulated	2.471	3.839	3.553	6.723
Central	Northeast	2.440	3.851	3.839	6.726
Central	Appalachian	2.380	3.735	3.599	6.607
Central	Florida	2.445	3.725	3.689	6.372
Central	Southeast	2.294	3.658	3.586	6.271
Central	Upper Midwest	2.344	3.705	3.585	6.046
Central	Central	1.195	2.697	2.668	4.909
Central	Mideast	2.392	3.693	3.648	6.110
Central	California	2.473	3.876	3.913	6.746
Central	Pacific Northwest	2.446	3.878	3.892	6.792
Central	Southwest	2.378	3.544	3.653	6.301
Central	Arizona	2.447	3.828	3.858	6.720
Central	Unregulated	2.415	3.759	3.806	6.727
Mideast	Northeast	2.403	3.117	3.765	6.775
Mideast	Appalachian	2.324	2.876	3.593	6.780
Mideast	Florida	2.443	3.235	3.737	6.780
Mideast	Southeast	2.313	2.685	3.675	6.780
Mideast	Upper Midwest	2.382	3.430	3.810	6.733
Mideast	Central	2.372	2.994	3.826	6.746
Mideast	Mideast	1.009	1.499	2.737	5.667
Mideast	California	2.475	3.765	3.956	6.959
Mideast	Pacific Northwest	2.471	3.825	3.945	6.956
Mideast	Southwest	2.438	3.721	3.834	6.884

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Origin	Destination	Beverage	Softs	Cheese	Butter-Powder
Mideast	Arizona	2.472	3.565	3.929	6.955
Mideast	Unregulated	2.454	3.721	3.922	6.960
California	Northeast	2.474	3.958	3.853	6.803
California	Appalachian	2.454	3.918	3.706	6.739
California	Florida	2.468	3.883	3.595	6.580
California	Southeast	2.414	3.872	3.609	6.638
California	Upper Midwest	2.463	3.934	3.830	6.674
California	Central	2.433	3.900	3.785	6.643
California	Mideast	2.473	3.952	3.817	6.815
California	California	0.714	1.494	1.534	2.289
California	Pacific Northwest	2.380	3.775	3.358	6.331
California	Southwest	2.422	3.878	3.440	6.493
California	Arizona	2.331	3.148	2.738	6.293
California	Unregulated	2.286	3.663	3.193	6.445
Pacific Northwest	Northeast	2.473	3.992	3.963	6.956
Pacific Northwest	Appalachian	2.454	3.987	3.932	6.950
Pacific Northwest	Florida	2.474	3.983	3.916	6.937
Pacific Northwest	Southeast	2.423	3.984	3.916	6.948
Pacific Northwest	Upper Midwest	2.459	3.990	3.954	6.925
Pacific Northwest	Central	2.436	3.981	3.950	6.931
Pacific Northwest	Mideast	2.471	3.991	3.953	6.972
Pacific Northwest	California	2.420	3.957	3.848	6.931
Pacific Northwest	Pacific Northwest	0.817	1.907	2.440	2.622
Pacific Northwest	Southwest	2.448	3.979	3.906	6.951
Pacific Northwest	Arizona	2.449	3.972	3.902	6.975
Pacific Northwest	Unregulated	2.338	3.936	3.748	6.862
Southwest	Northeast	2.463	3.959	3.946	6.954
Southwest	Appalachian	2.410	3.896	3.868	6.918
Southwest	Florida	2.434	3.822	3.834	6.737
Southwest	Southeast	2.191	3.806	3.821	6.713
Southwest	Upper Midwest	2.449	3.939	3.930	6.917
Southwest	Central	2.362	3.882	3.888	6.872
Southwest	Mideast	2.452	3.952	3.924	6.855
Southwest	California	2.450	3.921	3.897	6.843
Southwest	Pacific Northwest	2.460	3.946	3.930	6.943
Southwest	Southwest	1.009	2.019	3.028	4.205
Southwest	Arizona	2.421	3.801	3.746	6.785
Southwest	Unregulated	2.427	3.909	3.816	6.902
Arizona	Northeast	2.494	3.994	3.987	6.966
Arizona	Appalachian	2.490	3.991	3.972	6.946
Arizona	Florida	2.492	3.984	3.965	6.856
Arizona	Southeast	2.484	3.985	3.963	6.859

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Origin	Destination	Beverage	Softs	Cheese	Butter-Powder
Arizona	Upper Midwest	2.490	3.997	3.985	6.945
Arizona	Central	2.487	3.981	3.980	6.917
Arizona	Mideast	2.494	3.993	3.983	6.901
Arizona	California	2.489	3.958	3.933	6.594
Arizona	Pacific Northwest	2.485	3.986	3.973	6.921
Arizona	Southwest	2.473	3.952	3.921	6.676
Arizona	Arizona	0.886	3.084	3.072	2.726
Arizona	Unregulated	2.465	3.964	3.947	6.852
Unregulated	Northeast	2.487	3.950	3.890	6.880
Unregulated	Appalachian	2.478	3.910	3.797	6.851
Unregulated	Florida	2.487	3.879	3.750	6.803
Unregulated	Southeast	2.462	3.904	3.750	6.826
Unregulated	Upper Midwest	2.480	3.905	3.857	6.779
Unregulated	Central	2.457	3.854	3.828	6.757
Unregulated	Mideast	2.486	3.951	3.863	6.905
Unregulated	California	2.467	3.785	3.730	6.784
Unregulated	Pacific Northwest	2.417	3.522	3.299	6.549
Unregulated	Southwest	2.468	3.861	3.695	6.792
Unregulated	Arizona	2.463	3.613	3.623	6.871
Unregulated	Unregulated	1.190	1.924	2.516	2.289
ROW	Northeast	–	3.962	3.697	6.796
ROW	Appalachian	–	3.982	3.986	6.969
ROW	Florida	–	3.910	3.944	6.753
ROW	Southeast	–	3.967	3.977	6.903
ROW	Upper-Midwest	–	3.993	3.977	6.918
ROW	Central	–	3.987	3.776	6.928
ROW	Mideast	–	3.986	3.977	6.913
ROW	California	–	3.930	3.907	6.929
ROW	Pacific-Northwest	–	3.888	3.993	6.951
ROW	Southwest	–	3.977	3.993	6.920
ROW	Arizona	–	3.984	3.999	6.992
ROW	Unregulated	–	3.992	3.998	7.000

Source: Calculated using equation (4.50) and budget share parameters calculated from U.S. Census Bureau and Bureau of Transportation Statistics, Commodity Flow Survey.

A separate set of elasticities of substitution between dairy products from different origins is defined for buyers in the rest of the world, σ_0^n. The elasticities of rest-of-world demand for dairy products from different U.S. regions are then defined by equation (4.50 with the destination region $j = 0$ for the rest of the world and using σ_0^n. Table B.2 lists the own-price elasticities of demand in the rest of the world for products from each dairy product category originating in each U.S. region.

Table B.2: Elasticities of Rest of World Demand for Dairy Products from Individual U.S. Regions

Origin	Destination	Softs	Cheese	Butter-Powder
Northeast	ROW	6.668	7.507	9.556
Appalachian	ROW	7.637	7.906	9.864
Florida	ROW	7.669	7.638	9.546
Southeast	ROW	7.731	7.956	9.987
Upper Midwest	ROW	7.499	6.922	9.246
Central	ROW	7.247	7.449	9.160
Mideast	ROW	6.748	7.810	9.915
California	ROW	7.309	5.872	6.828
Pacific Northwest	ROW	7.839	7.683	8.981
Southwest	ROW	7.593	7.485	9.208
Arizona	ROW	7.852	7.961	9.835
Unregulated	ROW	7.921	7.373	9.499

Source: Calculated using equation (4.50) and budget share parameters calculated from U.S. Census Bureau and Bureau of Transportation Statistics, Commodity Flow Survey.