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ESTIMATING MARKET POWER OF U.S. DAIRY COOPERATIVES IN THE FLUID MILK MARKET

METIN CAKIR AND JOSEPH V. BALAGTAS

A structural econometric model of vertical relationships is adopted to identify pricing behavior in the supply chain for fluid milk in the United States. The model consists of a system of equations that allows estimation of oligopoly power of dairy co-operatives and downstream firms, exploiting federal milk marketing order regulations to identify co-operatives' marginal cost. A key finding is that co-operatives use their market power to raise the farm price of milk by almost 9% above marginal cost, resulting in an income transfer of more than $600 million per year in markets regulated by federal milk marketing orders.

Key words: dairy co-operatives, market power, markups, milk marketing orders, sequential oligopoly.

JEL Codes: L13, L44, Q13, Q18.

Federal regulations are the basis for prominent institutional features of U.S. dairy markets, with potentially important implications for market performance. The 1922 Capper–Volstead Act partially exempts U.S. farm co-operatives from antitrust laws, allowing farms to coordinate on milk marketing and input purchases. The 1937 federal Agricultural Marketing Agreement Act and similar state legislation established milk marketing orders that regulate farm milk prices. One of the stated goals of each of these policies is higher milk prices for dairy farmers. We investigate the extent to which co-operatives and marketing order regulations raise farm prices of milk through accrued market power of farmer co-operatives.

We address two important questions: How much market power accrues to dairy co-operatives? and, What are the welfare implications of market power in U.S. milk markets? Economists have paid relatively little attention to these fundamental questions, which are central to the functioning of government regulations in contemporary dairy markets. The objective of this study is to fill this void by applying modern industrial organization concepts and econometric methods in order to shed light on economic consequences of market structure in the U.S. milk markets.

While empirical studies of market power in agricultural markets are common, relatively few have addressed the market power of co-operatives, and even fewer have considered dairy co-operatives. Masson and Eisenstat (1980) infer that co-operatives have market power based on observations on premia extracted by co-operatives from milk processors. They conclude that such market power generated an income transfer from processors to co-operatives and a social cost of $70 million per year in the 1970s. But Masson and Eisenstat (1980) neither estimate nor test for market power. Madhavan, Masson, and Lesser (1994) regressed premia on the market share of a large dairy co-operative operating across multiple regions in the 1970s and found that the premia increased with co-operative market share and that premia fell after the Department of Justice ordered the co-operative to cease certain practices. But this approach suffers from well-known shortcomings, among them difficulty in measuring costs and endogeneity of the market share (Perloff, Karp, and Golan 2007, pp. 31–34). Moreover, both of these papers assume that processors and retailers are price-takers. This assumption is tenuous in the current environment where milk processors and grocery

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retailers are concentrated, and we show that market power exercised by downstream firms affects market power by co-operatives.

In a more recent study, Prasertsri and Kilmer (2008) recognize the potential for processors to exercise market power, and model a bargaining game between co-operatives and buyers. They use a Nash bargaining model to derive and estimate the relative bargaining power of dairy co-operatives and milk processors in Florida from 1998 to 2004 and find that co-operatives have greater bargaining power than processors. The authors concluded that the ability of co-operatives to sell milk to other markets combined with transactions costs incurred by processors for milk brought in from out of state are major factors contributing to the relative bargaining strength enjoyed by co-operatives. But the paper fails to take into account the effect of milk marketing orders on processors' market power. We note that under regulated minimum prices, processors' marginal expenditure is constant and cannot be reduced further through reduced purchases; that is, marketing orders preclude oligopsony pricing by processors. No such price regulations affect output prices of processors and retailers. Thus, we believe that sequential oligopoly is the relevant model of behavior.

In this article we employ an extension of the *new empirical industrial organization* (NEIO) approach pioneered by Appelbaum (1979, 1982), Bresnahan (1982), and Lau (1982) to estimate the market power of dairy co-operatives. We advance the literature by modeling and estimating imperfect competition at multiple stages of the supply chain in fluid milk markets. We adopt an econometric model of a vertical relationship between co-operatives and processor-retailers to evaluate the degree of market power and its economic implications. Our econometric model exploits institutional features of federal milk marketing order (FMMO) regulations in order to identify market power.

The NEIO techniques have been widely applied to analyze competition in food processing and marketing (e.g., Azzam 1997; Bresnahan 1989; Sexton and Lavoie 2001). The approach allows us to estimate markups above marginal cost and the nature of competition in fluid milk markets. We adopt an extension of the model that allows for sequential vertical-pricing games between upstream and downstream firms (Raper, Love, and Shumway 2000; Villas-Boas and Hellerstein 2006).

Industry Background

Contemporary dairy markets have been shaped by a complex menu of government policies as well as dramatic changes in technological and economic conditions. U.S. dairy policy has included milk marketing orders, price supports, deficiency payments, export subsidies, and import restrictions. Milk marketing orders are the centerpiece of U.S. dairy policy and are particularly relevant to the current study. Marketing orders have three key effects (Cox and Chavas 2001):

- *Price discrimination* Minimum processor prices are set such that fluid milk plants pay a higher price for farm milk than do other types of dairy processors.
- *Revenue pooling* The regulated farm price is an average of minimum prices in various uses, eliminating the incentive for farmers to compete for the high-value fluid market.
- *Regionalization* Marketing orders use restrictions on cross-region milk shipments to maintain regional differences in minimum prices and prices received by farmers.

While details of milk marketing order regulations have evolved over time, these key elements of marketing orders have remained intact.

Meanwhile, the structure of the U.S. dairy industry has changed dramatically. Dairy farms have become larger, more specialized, and more productive. Also, under the protection of the Capper–Volstead Act, dairy co-operatives have evolved to hold dominant positions in the marketing of raw milk and the manufacture of some dairy products, including butter and milk powder. In 2002, co-operatives marketed 83% of all farm milk in the United States. In the same year, co-operatives produced 40% of the cheese, 71% of the butter, and 85% of the milk powder produced in the United States (USDA 2005). Dairy co-operatives are also important suppliers of milk to fluid milk plants, and they extract premia above the marketing order minimum prices.

The fluid milk processing and food retailing sectors are also marked by concentration (Economic Research Service 2010). From 1997 to 2002 the national four-firm concentration ratio for fluid milk plants grew faster than any other food processing sector, and many

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cities are currently supplied by relatively few fluid milk plants (e.g., Prasertsri and Kilmer 2008). National concentration in grocery retailing also has grown over time, with four-firm concentration ratios near unity in many locations. Concentration in milk processing and grocery retailing raises the potential for noncompetitive behavior in these industries.

However, marketing order regulations limit noncompetitive pricing by processors. The minimum price for milk used in fluid products (i.e., class 1 milk) truncates the farm supply curve at the regulated minimum price, so that fluid processors' marginal expenditure is constant over the relevant range of production. Thus while concentration may afford fluid processors market power in their output market, milk marketing order regulations make processors price-takers in the market for their primary input. Moreover, if, as Prasertsri and Kilmer (2008) posit, processors are able to bargain for a lower price, both co-operatives and processors will have incentive to increase quantity so that the equilibrium outcome is always on the demand curve. Thus we model the market for fluid milk as a successive oligopoly.

The Model

We adopt Villas-Boas and Hellerstein's (2006) model of successive oligopoly. We model a two-stage industry where dairy farms and co-operatives sell milk to a combined processing-retailing sector that manufactures fluid milk for sale to final consumers.[1] The model allows both dairy co-operatives and processors to potentially exercise market power in their respective output markets, but processors are assumed to be price-takers in their input market.

The inverse demand facing downstream firms, i.e., processor-retailers, is specified as

$$(1) \qquad P^d = D(Q^d, Z)$$

where P^d is output price, Z is a vector of demand shifters, and Q^d is the quantity. Assuming fixed proportions, we set downstream (retail) and upstream (farm) quantities equal, $Q = Q^d = Q^u$. Next, define marginal costs of firms as $C^d = P^u + c^d(W)$ and $C^u = c^u(V)$, respectively, where P^u is the upstream firms' output price, c^d and c^u are the constant per-unit costs, and W and V represent exogenous supply shifters. The downstream firms' perceived marginal revenue, PMR^d, can be derived as $P^d + \lambda^d D'(Q)Q$, where $\lambda^d \in [0,1]$ is a parameter index of oligopolistic market power, also known as conjectural elasticity, indicating the belief of a firm about how aggregate output responds to its own output. At the two extremes, $\lambda^d = 0$ and $\lambda^d = 1$, the market is characterized as perfectly competitive and as a monopoly, respectively. Setting PMR^d equal to C^d gives the downstream firms' pricing equation:

$$(2) \qquad P^d = P^u - \lambda^d D'(Q)Q + c^d(W).$$

The system is completed by deriving the pricing equation for upstream firms (i.e., co-operatives). From equation (2) the inverse derived demand is given by $P^u = P^d + \lambda^d D'(Q)Q - c^d(W)$. The upstream firms' perceived marginal revenue, PMR^u, is: $P^u + \lambda^u \left(D'(Q)Q + \lambda^d D''(Q)Q^2 + \lambda^d D'(Q)Q\right)$. Setting PMR^u equal to C^u gives the upstream firms' pricing equation:

$$(3) \qquad P^u = c^u(V) - \lambda^u \left(D'(Q)Q + \lambda^d D''(Q)Q^2 + \lambda^d D'(Q)Q\right).$$

To motivate our empirical work, it is convenient to rewrite both pricing equations in terms of elasticities. Equation (2) can be rewritten as

$$(4) \qquad P^d = \left(1 + \frac{\lambda^d}{\eta^d}\right)^{-1} \left(P^u + c^d(W)\right)$$

where $\eta^d = (D'(Q)\frac{Q}{P^d})^{-1}$ is the price elasticity of retail demand and the term $(1 + \frac{\lambda^d}{\eta^d})^{-1} \in [1, \infty)$ measures downstream firms' markup. Similarly, assuming a linear demand schedule, equation (3) can be rewritten as

$$(5) \qquad P^u = \left(1 + \frac{\lambda^u}{\eta^u}\right)^{-1} c^u(V)$$

where $\eta^u = ((1 + \lambda^d)D'(Q)\frac{Q}{P^u})^{-1}$ is the price elasticity of derived demand and the term $(1 + \frac{\lambda^u}{\eta^u})^{-1} \in [1, \infty)$ is the upstream firms' markup.

[1] Transactions between milk processors and retailers are potentially interesting and important. However, we are not able to investigate these interactions because of a lack of data on wholesale milk prices.

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Equations (4) and (5) are the standard expressions of the oligopoly pricing equations estimated in the NEIO literature. These expressions have implications for estimates of the conduct parameters, λ^u and λ^d, which to our knowledge have not been discussed in the literature. For prices to be defined, the conduct parameter must be less than the absolute value of the relevant price elasticity of demand: in our case, $\lambda^d < |\eta^d|$ and $\lambda^u < |\eta^u|$. Thus, for example, if elasticity of demand is –0.2 (a typical finding for retail milk demand in the United States), then the conduct parameter must be less than 0.2.

Also, note that the elasticity of derived demand in equation (4) can be expressed as

$$(6) \qquad \eta^u = \frac{\eta^d}{(1+\lambda^d)} \frac{P^u}{P^d}.$$

Equation (6) has two important implications for studies of market power. First, note that the derived demand elasticity is a function of both the primal demand elasticity, η^d, and the conduct parameter of the downstream firm, λ^d. Thus, market power by downstream firms affects the derived demand elasticity and thus the upstream conduct parameter. Also, equation (6) implies that $|\eta^u| \leq |\eta^d|$. That is, under the assumption of linear demand and constant marginal cost, the derived demand is more inelastic than primary demand.

The system comprising equations (1), (4), and (5) can be estimated simultaneously to obtain the direct estimates of the markups and the elasticity of primary demand. Estimates of the conjectural elasticities and the elasticity of derived demand can then be obtained indirectly. However, any specification errors in estimating primary demand can significantly affect the indirect estimate of the derived demand elasticity. Furthermore, a limitation of the Cournot model of a vertical relationship in the supply chain is that it does not allow different definitions of market boundaries for each stage of production. We chose the market boundary that best fits our objective of estimating co-operatives' market power, which is determined by FMMO region. Although FMMO regions represent appropriate market boundaries to measure the oligopoly power of dairy co-operatives, these market boundaries can be too large to estimate retailers' oligopoly market power. Therefore, we also develop an alternative model in which we directly estimate derived demand together with equation (5), specifying derived demand as

$$(7) \qquad P^u = D(Q, P^d, W).$$

The Empirical Model

We apply the model to each of $i = 1, \ldots, N$ regional markets observed in each of $t = 1, \ldots, T$ periods. Our regions correspond to the geographic areas defined by milk marketing orders. The retail demand for fluid milk is specified as

$$(8) \qquad Q_{it} = \alpha_1 + \sum_{i=2}^{N} \alpha_i R_i + \left(\delta_1 + \sum_{i=2}^{N} \delta_i R_i\right) P_{it}^d + \gamma Z_{it} + \epsilon_{it}$$

where Q is per capita quantity, R is a regional dummy, and Z is the matrix of demand shifters, which includes prices of related goods, per capita income, and demographics. The regional dummies allow demand to differ across regions. We evaluate sensitivity of our estimates to functional form by also estimating a log-linear version of the primary demand equation. Genesove and Mullin (1998) estimated a range of linear and nonlinear functional forms for demand in an application to the sugar refining industry and found that their industry conduct parameter was insensitive to the linearity assumption of the demand form.

The empirical analog to equation (4), the downstream pricing equation, is given as

$$(9) \qquad P_{it}^d = \beta_0 + \beta_1 P_{it}^u + \beta_2 MB_{it} + v_{it}$$

where the USDA's marketing bill, MB, is included as a proxy for processor-retailers' marginal nonmilk cost of production. Although we estimate a single markup, $\beta_1 = (1 + \frac{\lambda^d}{\eta^d})^{-1}$, for all geographic markets, differences in demand allow for different conduct parameters across markets.

To specify the upstream pricing equation, we consider the role of regulated minimum prices set by milk marketing orders. In a competitive, regulated equilibrium (i.e., co-operatives do not possess oligopsony power), the regulated minimum price for class 1 milk is the equilibrium price, such that $P^u = P^{min}$. That

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is, P^{min} is co-operatives' marginal cost of supplying milk to processors ($c^u(V)$ in equation (5)). This has important implications for modeling. First, processors' marginal expenditure is constant at P^{min}, so that the regulated minimum price eliminates the ability of processors to reduce the farm price of milk by reducing quantity purchased. At the same time, co-operatives' oligopoly power can be measured by their ability to raise prices above the regulated minimum price. The estimated co-operatives' pricing equation is specified as

$$(10) \quad P_{it}^u = \zeta P_{it}^{min} + \omega_{it}.$$

The co-operative markup $\zeta = (1 + \frac{\lambda^u}{\eta^u})^{-1}$ reflects co-operatives' ability to raise the farm price of fluid milk above the minimum class 1 price. Thus we interpret the co-operative conduct parameter λ^u in this instance as an indicator of co-operatives' market power in fluid milk markets given milk marketing order regulations.

Alternatively, we also estimate upstream pricing equation (10), together with a direct expression of derived demand:

$$(11) \quad Q_t = \alpha_1^{dd} + \sum_{i=2}^{10} \alpha_i^{dd} R_i + \left(\delta_1^{dd} + \sum_{i=2}^{10} \delta_i^{dd} R_i \right) P_t^u + \beta_1^{dd} P_t^d + \beta_2^{dd} MB_t + \epsilon_t^{dd}.$$

As in the three-equation model, we also estimate a log-linear version of the derived-demand equation to evaluate sensitivity of the estimates to functional form.

Estimation

Typically the econometric problem of NEIO models is a simultaneous-equation model (SEM) in which demand and supply equations are estimated together with pricing equations. To obtain direct estimates of conjectural elasticities, researchers usually employ a computationally demanding nonlinear SEM estimator (e.g., Merel 2009; Raper, Love, and Shumway 2000). However, in our study we exploit FMMO price policy to derive an estimable version of the NEIO model that is linear in markups. As discussed in the Model section, the minimum prices enforced by FMMOs allow us to identify co-operatives' markup by setting $c^u(V) = P^{min}$. The derived system comprising equations (8), (9), and (10) is then linear in parameters and can be estimated simultaneously to obtain estimates of markups and retail demand elasticity. We combine these estimates with markup formulas and equation (6) to obtain indirect estimates of the elasticity of derived demand and conjectural elasticities for each market.

We use Bayesian methods to estimate both the three-equation and the two-equation models. For notational convenience, we write the $M = \{2, 3\}$ equation model compactly as

$$(12) \quad [y_j = X_j \psi_j + e_j \quad j = 1, \ldots, M]$$

where y_j is a NT-dimensional vector of observations on dependent variables, X_j is a $NT \times K_j$ matrix of K_j explanatory variables, e_j is a NT-dimensional disturbance vector, and ψ_j is a K_j-dimensional vector of parameters to be estimated. The errors are assumed to be distributed multivariate normal defined as: $e = [e_1, \ldots, e_M]' \sim N(0_{M\times 1}, H^{-1} \otimes I_{NT})$, where H is an $M \times M$ precision matrix. To control for endogeneity of output prices, P^d and P^u, we allow for the correlation between the error terms, i.e., $H^{-1} = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{pmatrix}$ for; $M = 2$. Note that for each $M = 2$ and $M = 3$, the model is in the form of a triangular SEM, such that the Jacobian of the transformation is equal to unity. The likelihood function for $\psi = [\psi_1, \ldots, \psi_M]'$ and H is given by:

$$p(y|\psi, H) = (2\pi)^{-NTM/2} |H|^{NT/2} \times exp(-0.5(y - X\psi)' \times (H \otimes I_{NT})(y - X\psi))$$

where $X = diag\{X_1, \ldots, X_M\}$ and $y = [y_1, \ldots, y_M]$. Given the form of the likelihood function, the posterior simulation proceeds as for a seemingly unrelated regressions model (Geweke 2005, p. 165). To obtain the joint posterior, we define a non-informative prior[2] as:[3] $p(\psi, H) \propto |H|^{(M+1)/2} I_S(\psi)$, where $I(.)$ denotes the standard indicator function and S denotes

[2] The prior is non-informative in the sense that it effectively imposes only the inequality restrictions on slope parameters of demand and on markup parameters of pricing equations.

[3] Estimation results are the same under alternative assignments of diffuse initial values of H, such as $H^0 = 0.1 I_M$, $H^0 = 0.01 I_M$ and $H^0 = 0.001 I_M$.

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the feasible region of the parameters to accommodate inequality restrictions, such that: $I_S(\psi) = 1$ if $\psi \in S$ (0 otherwise). We impose restrictions from economic theory: that the own-price elasticity of demand is negative; that markups are not less than unity; and that conjectural elasticities are within the unit interval. Because the conjectural elasticities are not estimated directly, we impose the restrictions through an acceptance sampling algorithm.

Using Bayes' theorem, the joint posterior of the parameters $p(\psi, H|y)$ is proportional to the product of the likelihood function, $p(y|\psi, H)$, and the joint prior distribution of the parameters: $p(\psi, H|y) \propto p(y|\psi, H)p(\psi, H)$. The complete conditional distributions of ψ and H used to construct a Gibbs sampler are given by

$$\psi|H, y \sim N(D_\psi d_\psi, D_\psi)I_S(\psi)$$
$$H|\psi, y \sim W(A, NT)$$

where $d_\psi = X'(H \otimes I_{NT})y$, $D_\psi = (X'(H \otimes I_{NT})X)^{-1}$, $A = (\sum_{t=1}^{NT}(y_t - X_t\psi)'(y_t - X_t\psi))^{-1}$ and $W(.)$ denotes the Wishart distribution with degrees of freedom parameter NT and scale parameter A (Geweke 2005, p. 165). Since drawing from a multivariate truncated normal distribution is nontrivial, each coefficient, $\psi_j; j = 1, \ldots, K_j$, is sampled individually using its conditional distribution, which is univariate truncated normal (see Geweke 2005, pp. 170–171, and Koop, Poirier, and Tobias 2007, pp. 146–148, for derivation). The basic steps to our Gibbs sampler are:

1. Initialize the sample with starting values for ψ and H. In our application we set $\psi = 0$. Then, to generate a starting value for H we drew 2,000 Gibbs samples and used the average of the last 500 draws of H as its starting value.
2. Draw each of $\psi_j|\psi_{-j}, H, y$ individually from its univariate truncated normal posterior.
3. Check whether market power parameters are within the unit interval. If so, proceed to the next step. If not, redraw $\psi_j|\psi_{-j}, H, y$.
4. Draw H using equation (13).
5. Repeat steps 2–4 until satisfied that convergence of the Markov chain has been achieved.

In this study we make 15,000 draws from the Gibbs sampler and discard the first 5,000 to remove the dependence on our starting values.

Data

To estimate the model, we obtain monthly industry data on prices and quantities of fluid milk, prices of related products, and demographics, spanning 2000 through 2007. The data reflect prices and quantities of milk in each of the geographic regions pertaining to the ten FMMOs.

Data on retail prices, farm prices, the quantity of milk used in fluid products, and population in each FMMO region are obtained from the online database maintained by the USDA Agricultural Marketing Service. The database reports the monthly average retail prices of whole milk in gallons in the largest and second largest food store chains and the largest convenience store chain for 36 cities. We construct the retail price of fluid milk in each region by assigning each city to an FMMO region and taking the simple average across the three types of stores and across cities in a region. We convert the retail price to \$/lb. assuming that 1 gallon of milk weighs 8 lbs. Similarly, the USDA reports the FMMO class 1 price and the co-operative class 1 price for 36 cities. The co-operative class 1 price is announced by the largest co-operative operating in a city. We assign each city to an FMMO region and calculate the simple average FMMO class 1 price and co-operative class 1 price for each FMMO region.[4] We also account for the impact of the Northeast Dairy Compact on the minimum class 1 price in the Northeast region between January 2000 and September 2001. Accordingly, we set the minimum class 1 price equal to \$14.96/cwt whenever the FMMO minimum class 1 price is lower than \$14.96/cwt during the

[4] In this study we use the co-operative class 1 price as the transaction price for the fluid milk between co-operatives and processors. The announced class 1 prices are the only public record that can be used for this purpose, and to our knowledge there is not an academic publication or any other public record to verify whether these prices are systematically higher or lower than the actual transaction prices paid to co-operatives. However, from our informal discussions with several economists, we understand that some economists believe that over-order payments include charges for the cost of services performed by co-operatives and tend to be higher than actual transaction prices for fluid milk. We discuss the implications of this case in the next section.

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Table 1. Description of Data

Variable	Description	Units	Mean
Class 1 Milk Qty.	Per capita utilization of Class 1 milk	lbs.	15.78 (2.60)
Retail Price	Retail price of fluid milk	$ per lb.	0.40 (0.05)
Co-operative Price	Co-operative announced price of Class 1 milk	$ per lb.	0.18 (0.03)
Cheese Price	CPI of cheese and related products	Index	96.25 (5.44)
Cereal Price	CPI of breakfast cereal	Index	99.48 (2.45)
Coffee-Tea Price	CPI of beverage materials including coffee and tea	Index	96.90 (3.97)
Juices	CPI of juices and non-alcholic beverages	Index	99.62 (3.44)
Black	Percent of population identified as African American	Percentage	10.12 (6.06)
HHs with Kids	Percent of households with kids under age 18	Percentage	47.11 (13.15)
Personal Income	Annual per capita income	$ thousand	22.91 (2.49)
Marketing Bill	Cost of processing and distribution	Index	95.09 (11.14)
Class 1 Price	FMMO announced price of Class 1 milk (minimum price)	$ per lb.	0.16 (0.03)

Note: Standard deviations are reported in parantheses. All indexes are normalized at Dec 2005 = 100

period that the Compact price was in effect.[5] Finally, the milk marketing order database includes annual census data for each FMMO region. All prices and income are adjusted for inflation using the Consumer Price Index for all goods.

Previous studies of milk demand have included various combinations of related product prices and demographics (Cakir and Balagtas 2010; Schmit and Kaiser 2004). We obtained U.S. price indexes for breakfast cereal, cheese, coffee, tea, juices, and nonalcoholic beverages from the Bureau of Labor Statistics of the U.S. Department of Labor. We also gathered annual demographics data from the American Community Survey. The demographics data, including information on race, percentage of households with children, and personal income, were obtained at the county level and aggregated to match FMMO regions.[6] Summary statistics are presented in table 1.

Results

Table 2 reports posterior means and standard deviations for the directly estimated model parameters. The co-operative price coefficient in three-equation models is the estimated processor-retailer markup. The estimated co-operative markup is the class 1 price coefficient reported in all models. The results show that the estimates of both processor-retailer and co-operative markups are robust across models. We report the Bayesian information criterion (BIC) to determine which of the models best fits the data.[7] Between both the three-equation and the two-equation models, the log-linear versions are preferred by the data.

To make inference on market power, we turn to posterior means and standard deviations of demand elasticities and conduct parameters,

[5] We thank an anonymous referee for pointing out the role of the Northeast Dairy Compact on class 1 minimum prices.

[6] We matched the demographics data from the American Community Survey with FMMO regions based on the county FIPS code. On occasions where a county falls within the boundaries of two FMMO regions, we included the demographics data of the county in average calculations of both FMMO regions.

[7] For linear models, we compute BIC as $BIC_j = 2logp(y|(\psi = \hat{\psi}_j)) - K_j logNT$, where $\hat{\psi}_j$ denotes the posterior mean estimates for model *j*. The BICs of log-linear models are not directly comparable with the BICs of their counterparts due to the log form of the demand equation. We use change of variable formula to derive comparable BIC statistics for log-linear models as: $BIC_j = 2log|J|p(y|(\psi = \hat{\psi}_j)) - K_j logNT$, where $|J| = \left| \frac{\partial e}{\partial y'}(y|\psi) \right|$ denotes the Jacobian of transformation.

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Table 2. Posterior Mean and (Standard Deviation) of Key Model Parameters

Parameter	Linear, Three-Equation Model	Log-linear, Three-Equation Model	Linear, Two-Equation Model	Log-linear, Two-Equation Model
Retail Price	−6.8255	−0.2415	2.4996	0.0511
	(1.4557)	(0.0316)	(1.4258)	(0.0474)
Cereal Price	−0.0139	−0.0386		
	(0.0142)	(0.0297)		
Cheese Price	0.0253	0.0645		
	(0.0113)	(0.0214)		
Coffee–Tea Price	0.0143	−0.0255		
	(0.0133)	(0.0156)		
Juices	0.0979	0.1214		
	(0.0277)	(0.0541)		
Black	0.1548	0.2149		
	(0.1690)	(0.0290)		
HHs with Kids	0.0090	0.0491		
	(0.0065)	(0.090)		
Personal Income	0.0282	0.0275		
	(0.0149)	(0.0239)		
Co-operative Price	1.0043	1.0041	−10.0702	−0.1732
	(0.0043)	(0.040)	(1.6797)	(0.0469)
Marketing Bill	0.0004	0.0124	0.0113	0.2241
	(0.0002)	(0.0109)	(0.0033)	(0.1768)
Class 1 Price	1.0879	1.0879	1.0885	1.0885
	(0.0016)	(0.0017)	(0.0017)	(0.0016)
σ_{11}	1.4186	0.0060	1.2182	0.0063
	(0.1341)	(0.0005)	(0.0667)	(0.0011)
σ_{22}	0.0017	0.0018	0.0003	0.0005
	(0.0005)	(0.0003)	(0.0001)	(0.0001)
σ_{33}	0.0010	0.0010		
	(0.0007)	(0.0002)		
σ_{12}	0.0231	0.0014	−0.0023	−0.0002
	(0.0041)	(0.0002)	(0.0006)	(0.0001)
σ_{13}	−0.0031	−0.0012		
	(0.0008)	(0.0003)		
σ_{23}	−0.0003	−0.0007		
	(0.0001)	(0.0001)		
BIC	6849.4000	6853.2000	3423.8000	3433.6000

Note: σij denotes the ij'th element of covariance matrix. Reported parameter of retail price (co-operative price) in 3-equation models (2-equation models) is the average across all regions at each iteration.

reported in table 3. The estimates of linear (log-linear) demand models are reported in the upper (lower) panel of the table. The key findings are robust across models, viz., that all the demand elasticities are highly inelastic, that all the conduct parameters are small, and that the processor-retailer conduct parameter is even smaller than the co-operative conduct parameter in each region. Also, the estimated retail demand elasticities, η^{retail}, are consistent with previous research that finds aggregate retail milk demand to be highly inelastic (e.g., Schmit and Kaiser 2004). It follows from equation (6) that derived demand for milk in fluid products is even more inelastic. For example, results from the two-equation log-linear model indicate more elastic, but still inelastic, derived demand than the three-equation log-linear model for all but two regions. In the remainder of the paper we focus on results from the three-equation log-linear model, based on its better fit as measured by the BIC. However, the robust key findings in table 3 combined with the robust estimates of markups in table 2 imply that model selection is not critical for our main conclusions.

The small estimates of the conduct parameters themselves indicate little market power. Posterior means of the processor-retailer conduct parameters are all less than 0.01 (a value consistent with a 100-firm, symmetric oligopoly); however, all the estimates have mass around zero. As mentioned in the Model section, this result can be driven by

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Table 3. Posterior Mean and (Standard Deviation) of Demand Elasticities, ηi, and Market Power, λi, by FMMO Region

FMMO	Linear Demand, 3-Equation Model				Linear Demand, 2-Equation Model	
	η^{retail}	λ^{retail}	η^{coop}	λ^{coop}	η^{coop}	λ^{coop}
Northeast	−0.0445	0.0002	−0.0205	0.0017	−0.0826	0.0067
	(0.0349)	(0.0003)	(0.0161)	(0.0013)	(0.0261)	(0.0021)
Appalachian	−0.0982	0.0004	−0.0501	0.0041	−0.1660	0.0135
	(0.0639)	(0.0006)	(0.0326)	(0.0026)	(0.0395)	(0.0032)
Florida	−0.1979	0.0008	−0.0993	0.0080	−0.1884	0.0153
	(0.1031)	(0.0010)	(0.0517)	(0.0042)	(0.0644)	(0.0052)
Southeast	−0.1968	0.0008	−0.0810	0.0065	−0.1544	0.0126
	(0.1010)	(0.0010)	(0.0415)	(0.0034)	(0.0527)	(0.0043)
Upper Midwest	−0.0166	0.0001	−0.0069	0.0006	−0.0342	0.0028
	(0.0151)	(0.0001)	(0.0063)	(0.0005)	(0.0236)	(0.0019)
Central	−0.1723	0.0007	−0.0752	0.0061	−0.1493	0.0121
	(0.0825)	(0.0008)	(0.0360)	(0.0029)	(0.0393)	(0.0032)
Mideast	−0.1171	0.0005	−0.0554	0.0045	−0.0817	0.0066
	(0.0653)	(0.0006)	(0.0309)	(0.0025)	(0.0343)	(0.0028)
Pacific Northwest	−0.2843	0.0012	−0.1043	0.0084	−0.0510	0.0041
	(0.0627)	(0.0011)	(0.0230)	(0.0019)	(0.0284)	(0.0023)
Southwest	−0.2013	0.0008	−0.0930	0.0075	−0.1638	0.0133
	(0.0905)	(0.0010)	(0.0418)	(0.0034)	(0.0561)	(0.0046)
Arizona-Las Vegas	−0.5413	0.0023	−0.2116	0.0171	−0.1050	0.0085
	(0.1120)	(0.0024)	(0.0437)	(0.0035)	(0.0470)	(0.0038)

FMMO	Log-linear Demand, 3-Equation Model				Log-linear Demand, 2-Equation Model	
	η^{retail}	λ^{retail}	η^{coop}	λ^{coop}	η^{coop}	λ^{coop}
Northeast	−0.0197	0.0001	−0.0091	0.0007	−0.0642	0.0052
	(0.0168)	(0.0001)	(0.0077)	(0.0006)	(0.0506)	(0.0041)
Appalachian	−0.1978	0.0008	−0.1010	0.0082	−0.2674	0.0218
	(0.0878)	(0.0009)	(0.0448)	(0.0036)	(0.0721)	(0.0059)
Florida	−0.2142	0.0009	−0.1074	0.0100	−0.2476	0.0201
	(0.1064)	(0.0010)	(0.0533)	(0.0043)	(0.1038)	(0.0085)
Southeast	−0.1606	0.0007	−0.0661	0.0058	−0.2179	0.0177
	(0.0903)	(0.0008)	(0.0371)	(0.0030)	(0.1024)	(0.0083)
Upper Midwest	−0.0234	0.0001	−0.0098	0.0008	−0.0434	0.0035
	(0.0229)	(0.0002)	(0.0096)	(0.0008)	(0.0355)	(0.0029)
Central	−0.1815	0.0007	−0.0793	0.0069	−0.2010	0.0163
	(0.0863)	(0.0008)	(0.0377)	(0.0030)	(0.0613)	(0.0050)
Mideast	−0.1574	0.0006	−0.0745	0.0065	−0.1207	0.0098
	(0.0860)	(0.0008)	(0.0407)	(0.0033)	(0.0645)	(0.0053)
Pacific Northwest	−0.3442	0.0014	−0.1263	0.0105	−0.0648	0.0053
	(0.0739)	(0.0015)	(0.0271)	(0.0022)	(0.0407)	(0.0033)
Southwest	−0.3310	0.0013	−0.1529	0.0128	−0.2584	0.0210
	(0.0984)	(0.0014)	(0.0454)	0.0037	(0.0847)	(0.0069)
Arizona-Las Vegas	−0.5634	0.0023	−0.2203	0.0178	−0.1378	0.0112
	(0.0865)	(0.0021)	(0.0337)	0.0027	(0.0552)	(0.0045)

the limitation of the three-equation models that impose FMMO region as the geographic boundary for the processor-retailer market. Contrary to these results, previous studies (Carman and Sexton 2005; Chidmi, Lopez, and Cotterill 2005) that analyzed only retailers' market power in fluid milk markets with smaller geographic boundaries found significant evidence that retailers' pricing behavior was not competitive.

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Table 4. Posterior Mean and (Standard Deviation) of Welfare Implications of Market Power in US Milk Markets

FMMO	Quantity of Class 1 Milk million lbs.	Co-operative Mark-up $/cwt.	Wealth Transfer to Co-operatives million $/year	Retailer Mark-up $/gallon	Wealth Transfer to Retailers million $/year
Northeast	10,611	1.458	154.74	0.013	16.82
	(42)	(0.028)	(2.92)	(0.012)	(16.46)
Appalachian	4,295	1.415	60.79	0.012	6.52
	(20)	(0.027)	(1.15)	(0.011)	(5.90)
Florida	2,508	1.560	39.13	0.014	4.56
	(16)	(0.030)	(0.74)	(0.012)	(4.07)
Southeast	4,739	1.439	68.21	0.014	8.28
	(19)	(0.027)	(1.28)	(0.013)	(8.10)
Upper Midwest	4,279	1.336	57.17	0.014	7.67
	(26)	(0.025)	(1.08)	(0.013)	(7.02)
Central	4,594	1.370	62.94	0.013	7.14
	(29)	(0.026)	(1.19)	(0.012)	(6.99)
Mideast	6,575	1.360	89.41	0.012	9.62
	(30)	(0.026)	(1.69)	(0.011)	(9.42)
Pacific Northwest	2,149	1.349	28.99	0.014	3.78
	(11)	(0.026)	(0.55)	(0.013)	(3.70)
Southwest	4,097	1.472	(60.32)	0.013	6.65
	(18)	(0.028)	(1.14)	(0.012)	(6.22)
Arizona-Las Vegas	1060	1.389	14.73	0.013	1.75
	(15)	(0.026)	(0.28)	(0.012)	(1.71)
All FMMO Regions	44,908	1.415	636.44	0.013	73.08
	(262)	(0.027)	(12.02)	(0.012)	(69.60)

Note: Quantities are the annual weighted averages for each region. Reported mark-ups are the dollar equivalents of the estimated percentage mark-ups. For the processor-retailer mark-up we assume one gallon of milk weighs 8 pounds. Retailer Mark-up refers to the combined processor-retailer mark-up. Wealth Transfer to Co-operatives (Retailers) is the estimated co-operative (processor-retailer) mark-up times the annual quantity of Class 1 milk.

On the other hand, posterior means of the co-operative conduct parameters are larger and are estimated more precisely. We find that nine of the estimates of co-operative market power have mass away from zero. However, in only four marketing order regions (Florida, Pacific Northwest, Southwest, and Arizona–Las Vegas) do we find a conduct parameter greater than 0.01. Our findings of small conduct parameters are consistent with findings from previous applications to the NEIO framework to farm commodity markets (see Sexton 2000 for a review).[8]

However, recalling that the markup at each stage of production is expressed as $(1+\frac{\lambda^i}{\eta^i})^{-1}, i=\{retail, co\text{-}op\}$, note that markup at each stage of production is determined not by the conduct parameter alone but by the conduct parameter relative to the elasticity of demand, or the Lerner index. For a given conduct parameter, the resulting markup and the wealth transfer associated with it are decreasing in the absolute value of the elasticity of demand; markups will be larger where demand is more inelastic, *ceteris paribus*. In the case of U.S. fluid milk markets, the fact that demand is so inelastic means that even an apparently small conduct parameter could generate a large markup and an economically significant wealth transfer.

We estimate the markups to be 1.0041 (SD, 0.0040) for milk processor-retailers and 1.0879 (0.0017) for co-operatives (table 2). That is, given the elasticity of retail demand, combined processor-retailers are able to use their market power to raise the retail price by approximately 0.4% over marginal cost; given the elasticity of derived demand for milk, co-operatives are able to use their market power to raise the price of milk purchased by fluid milk plants by approximately 9% over the minimum price enforced by FMMOs.[9]

[8] As mentioned in footnote 4, in this study we interpret the announced class 1 price as the transaction price for fluid milk between co-operatives and processors. If, however, the over-order payments include unobservable co-operative costs associated with serving the fluid milk market, our estimates of co-operatives' markup and market power can be interpreted as upper limits. Note that this interpretation reinforces our finding that co-operative conduct parameters are small.

[9] The results that the co-operative's markup is almost 9% and that the co-operative market conduct parameters are small and

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To quantify the key welfare implications at each draw, we calculate the income transfers that result from market power by processor-retailers and by co-operatives in fluid milk markets regulated by FMMOs.[10] The income transferred from milk buyers to co-operatives as a result of co-operative market power is equal to the product of the estimated co-operative markup and the quantity of class 1 milk. Similarly, the income transferred from final milk consumers to processor-retailers as a result of processor-retailer market power is the product of the estimated retail markup and the quantity of class 1 milk. We report posterior means and standard deviations of welfare implications for each FMMO region and for all FMMO regions in table 4. The key findings are that the estimated annual income transfer to co-operatives is approximately $636 million, with a mass away from zero, and the estimated annual income transfer to processor-retailers is approximately $73 million, with a mass around zero.

Conclusion

Concentration in milk marketing, processing, and retailing in the United States has created the potential for firms in the milk supply chain to exercise market power. In the case of the marketing of farm milk, market structure is influenced by two aspects of federal policy: the Capper–Volstead Act, which grants farmer co-operatives partial exemption from antitrust laws, and FMMO regulations that effectively prevent fluid milk plants from exercising market power in their input market. We derive a structural model of the supply chain for beverage milk in order to estimate oligopoly power in sequential stages of production.

In our application to fluid milk markets in the United States, we make use of FMMO regulations, which determine the geographic extent of markets and enforce minimum prices, which in turn determine co-operatives' marginal opportunity cost. A key finding is that while the estimated conduct parameter for dairy co-operatives is small (e.g., 0.0027 for the Northeast region), the fact that the derived demand for milk facing co-operatives is very inelastic allows co-operatives to exact markups of approximately 9%. The resulting estimate of annual income transfer from milk buyers to dairy farmers, in the regions subject to FMMO regulations, is approximately $636 million, with a mass away from zero. Retail demand for fluid milk is also quite inelastic, but the estimated conduct parameter for processor-retailers is relatively small, so that the retail markup is less than 1%. The resulting estimate of annual income transfer from final milk consumers to processor-retailers is approximately $73 million, with a mass around zero.

are estimated more precisely are the same in the less restrictive two-equation models.

[10] It follows from our estimates of small conduct parameters that efficiency losses are small relative to wealth transfers, which Sexton (2000) also found to be the case for previous studies of market power in the food chain.

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