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California's Climate Policy and the Dairy Manufacturing Industry: How Does a Federal Milk Marketing Order Matter?

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The welfare consequences of any climate program depend on preexisting market and regulatory distortions. This paper examines the impact of California's climate policy on the dairy manufacturing industry with explicit modeling of major milk pricing policies. Numerical simulations indicate that climate policy leads to a diversion of farm milk from manufactured products to fluid products. The establishment of a Federal Milk Marketing Order in California reduces the distorting effect of milk pricing policies. As a consequence, consumers of fluid products would enjoy a bigger welfare gain from climate policy under the Federal Milk Marketing Order.

Key words: climate policy, dairy, milk marketing order, milk quota

Introduction

Existing and proposed policies to address climate change have mostly been local or regional in nature, though from an efficiency perspective a global carbon pricing mechanism, either a carbon tax or a carbon cap-and-trade program, is preferable (Montgomery, 1972). Accompanying any unilateral initiative to reduce greenhouse gas (GHG) emissions is the concern that the local economy would be negatively affected: Local industries would face higher energy costs and thus be less competitive, and local consumers would face higher product prices and be worse off. Moreover, climate policy is not implemented in a vacuum. The economic impact of climate policy is affected by preexisting market and regulatory conditions (Fullerton and Muehlegger, 2019). In this paper, I investigate the impact of California's climate policy on the dairy manufacturing industry with explicit modeling of major milk pricing policies.

California's Global Warming Solutions Act of 2006, also known as Assembly Bill 32, requires a reduction of GHG emissions to 1990 levels by 2020. In 2016, California Senate Bill 32 further specifies a GHG reduction goal of 40% below 1990 levels by 2030. The California Air Resources Board (ARB) has adopted many GHG reduction measures, such as the Cap-and-Trade program and Low Carbon Fuel Standard. Many of these measures make fossil-fuel-based energy more expensive. California produces more than 18% of all U.S. milk, and the dairy manufacturing industry has the highest value of of shipments within the food manufacturing sector in California, representing 21.2% of the total value of processed food.[1] Using a multi-market model, I investigate how an increase in energy price resulting from GHG reduction measures affects the dairy manufacturing industry

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[1] See https://www.census.gov/programs-surveys/asm.html [Accessed August 1, 2021].

in California. This study draws inspiration from general equilibrium analyses of the distributional effects of environmental policy (see, e.g., Fullerton and Heutel, 2007, 2010). This research also contributes to the literature that examines environmental policy in a second-best setting (see, e.g., Fowlie, 2009; Lade and Bushnell, 2019).

Milk prices in the United States are influenced by government policies, particularly marketing orders. California maintained its own state milk marketing order (MMO) until November 2018, when a California order was created as part of the Federal Milk Marketing Order (FMMO) system. The California and federal orders are similar in their goals and implementation. They establish minimum prices, based on ultimate utilization, that processors must pay for Grade A milk and pool milk revenue from different end uses. Moving from the California system to an FMMO leads to some changes. Most importantly, the new FMMO is likely to generate a higher minimum price of milk for cheese due to a higher value attributed to whey, a by-product from cheese manufacturing. Milk pricing in California is also affected by a milk quota program. The California milk quota does not directly restrict production, marketing, or allocation to end-use markets. A premium of $1.70 per hundredweight (cwt) has been given to quota owners from the MMO pool since 1994. With the implementation of an FMMO in California, the California Department of Food and Agriculture (CDFA) now administers a stand-alone quota program. The Quota Implementation Program (QIP) stipulates that all Grade A milk be assessed to fund the quota premium and the administrative costs of the program. Because the QIP assess all Grade A milk rather than just milk within the marketing order pool (as under the previous quota program), the revenue taken out of the new FMMO pool is expected to be smaller.

I construct a multi-market model to investigate how an increase in the price of energy, resulting from the GHG reduction measures, affects California's dairy manufacturing industry. The setup of the model reflects the linkages between fluid and manufactured dairy products in both production and consumption and captures two major features of milk pricing policies: (i) price discrimination by marketing orders and revenue pooling, combined with (ii) a milk quota program that takes revenue from the pool. I first solve analytically for all changes in equilibrium prices and quantities that result from an exogenous energy price shock. I then demonstrate that when the output market equilibrium effect is stronger than the input substitution effect (i.e., the equilibrium cross-price elasticity of input demand is negative), the various prices of milk will decrease. Given that milk pricing policies affect the prices of milk relative to energy, the impact of climate policy on the dairy market is distorted. I show that marketing orders amplify reductions in the price of milk for manufactured products but dampen reductions in the price of milk for fluid products. On the other hand, the milk quota program dampens reductions in the prices of milk for both fluid and manufactured products. Since the two policies influence the impact of climate policy on the price of milk for fluid products in the same direction, energy-price-induced reductions in the price of milk for fluid products are smaller in the presence of milk pricing policies.

Using simulations, I quantify the potential impact of climate policy on the California dairy industry under alternative milk pricing scenarios. For the 2017 California dairy market, a 30% increase in energy price would induce 0.87% and 0.73% reductions in the prices of milk for manufactured and fluid products, respectively. The quantity of milk for manufactured products would decrease by 0.59%, but the quantity of milk for fluid products would increase by 0.70%. Climate policy leads farm milk to be diverted from manufactured products to fluid products because fluid products are less energy intensive than manufactured products and the demand for fluid products is inelastic. I also assess the increase in out-of-state production in response to the reduction in California's production. With a calculated market transfer rate of 0.46, production of manufactured dairy products transferred outside California represents 0.57% of California's production.

I simulate how the two potential changes under the new FMMO would influence the impact of climate policy on the dairy industry in California. Both an increase in the price of milk for manufactured products and a reduction in quota payment taken out of the milk revenue pool reduce the distorting effect of milk pricing policies. Because both milk pricing policies work in the same direction for the price of milk for fluid products, climate policy would divert more milk to fluid products and lead to a bigger reduction in the price of fluid products. Consequently, consumers of fluid dairy products would enjoy a bigger welfare gain from climate policy under the new FMMO.

Milk Pricing Policies in California

Government policy has played an important role in the U.S. dairy market. One of the major interventions is marketing orders. Beginning with the passage of the Young Act in 1935, California maintained its own state MMO until November 2018, when a California order was created as part of the FMMO system. [2] The California and federal orders are similar in their goals and implementation. They establish minimum prices, based on ultimate utilization, that processors must pay for Grade A milk received from dairy farmers, and pool milk revenue from different end uses. Moving from the California system to an FMMO leads to a few changes in milk pricing regulations. First, some dairy products need to be reclassified. The utilization of milk was divided into five classes under the California MMO: the class 1 price applies to milk for fluid products; class 2 and 3 prices apply to milk for soft and frozen products; the class 4a price applies to milk for butter and nonfat dry milk; and the class 4b price applies to milk for cheese. The FMMO system recognizes four classes of milk: classes I, II, III, and IV, with soft and frozen products in class II, cheese in class III, and butter and nonfat dry milk in class IV. Second, processors were generally required to participate under the California MMO; with the exception of class I plants, they are now allowed to periodically opt out of the FMMO. Third, the FMMO is likely to generate a higher minimum price of milk for cheese due to a higher value attributed to whey, a by-product from cheese manufacturing. Differences in pricing formulae existed, particularly between California 4b and FMMO III. The motivation for California milk producers to switch to an FMMO was the perception that the minimum prices of milk for cheese would be higher using the FMMO formula.

Though changes in regulated minimum milk prices are happening in California, the underlying market mechanism that determines milk supply and demand remains (Sumner, 2018). Marketing orders set higher minimum prices for milk for fluid products that face more localized markets and less elastic demand. The existence of a marketing order in California—whether the old California system or the new FMMO—has two important economic implications for the prices of milk. First, the price of milk for fluid products is higher than the price of milk for manufactured products. Second, through revenue pooling, a marketing order distributes the revenue gain from fluid products within the order and raises the supply price of farm milk (Balagtas, 2004). The stylized model that I use to discuss the impact of climate policy reflects these two features.

Milk pricing in California is also affected by a milk quota program, which was enacted in July 1969 following the passage of the Gonsalves Milk Pooling Act. The California milk quota does not directly restrict production or marketing or allocation to end-use markets. The quota was initially allocated to producers in proportion to their sales of milk for class 1 production and was expanded with increases in fluid utilization until 1991. A fixed premium of $1.70/cwt has been given to quota owners since 1994 (California Department of Food and Agriculture, 2008).[3] A profit-maximizing competitive dairy farm chooses its milk production such that its marginal cost of production equals the nonquota pool price, which is the average price after the quota payment has been deducted from the revenue pool (Sumner and Wolf, 1996).

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[2] Marketing orders regulate the sale of Grade A (or “market grade”) milk, which can be used for both fluid products and manufactured products, but not the sale of Grade B (or “manufacturing grade”) milk, which can be used only for manufactured products. In 2017, Grade B milk accounted for only 2.7% of the California’s total milk supply (California Department of Food and Agriculture, 2017a).

[3] The quota milk price received by an individual dairy depends on the deduction for the regional quota adjuster, which is an adjustment to the quota premium based on the location of the dairy farm.

With the implementation of an FMMO in California, the CDFA now administers a stand-alone quota program. The current QIP stipulates that all Grade A milk received from California farmers at a California plant be assessed to fund the quota premium to be paid to quota holders and the administrative costs of the program. Since the premium of \$1.70/cwt to quota owners is maintained under the QIP, the asset value of milk quota is not affected by the policy change. Under the California MMO, quota payment was deducted from the revenue pool. The QIP now defines the assessable milk for quota payment to be all Grade A milk, which consists of more than just pool milk. For example, Grade A milk processed by nonpool plants did not contribute to quota payment but now will be assessed under the QIP. Thus, the revenue taken out of the new FMMO pool will be smaller and the supply price of farm milk (i.e., the nonquota pool price) will be higher.[4]

A Model of the Dairy Industry in California

I use a multi-market model of the dairy manufacturing industry to demonstrate analytically the importance of milk pricing policies in determining the effects of an increase in energy price on the dairy market equilibrium. I model two product categories: fluid and manufactured products. This distinction between final products facilitates the modeling of price discrimination under marketing orders. Both the California system and the new FMMO maintain the same price discrimination feature. To keep the analytical exposition tractable, I assume that the production of each final product requires two inputs: milk and energy. In numerical simulations, I include a composite of processing inputs, and for sensitivity analysis, I allow the composite input to be either a substitute or a complement to milk and energy.

I use Q and P to denote the quantities and prices of final products and X and W to denote the quantities and prices of inputs. Superscripts m and f denote manufactured and fluid dairy products, respectively, and subscripts 1 and 2 denote inputs of milk and energy, respectively. The demand for each dairy product is a function of prices for both products.

$$Q^m = \mathrm{Q^m}(P^m, P^f), \tag{1}$$

$$Q^f = \mathrm{Q^f}(P^m, P^f). \tag{2}$$

I assume that the markets for final products are perfectly competitive and that the production technology of each final product exhibits constant returns to scale at the industry level. The first-order condition of profit maximization under perfect competition is that price equals marginal cost. The assumption of constant returns to scale implies that marginal cost equals average unit cost, $\mathrm{C^m}(W_1^m, W_2)$ and $\mathrm{C^f}(W_1^f, W_2)$. The following two equations describe the pricing of fluid and manufactured products:[5]

$$P^m = \mathrm{C^m}(W_1^m, W_2), \tag{3}$$

$$P^f = \mathrm{C^f}(W_1^f, W_2). \tag{4}$$

The derived demand functions for factors used in the production of fluid and manufactured products are obtained by applying Shephard's lemma (i.e., by taking the first derivative of the cost function with respect to the respective factor price), as indicated by the subscripts of the unit cost function.

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[4] Petitions have also been submitted to the CDFA requesting for termination of the QIP (see Hastings, 2019).

[5] W_1^m and W_1^f are the milk prices paid by processors and manufacturers, including over-order premiums.

$$X_1^m = \partial \mathrm{C}^{\mathrm{m}}(W_1^m, W_2)Q^m / \partial W_1^m = \mathrm{C}_1^{\mathrm{m}}(W_1^m, W_2)Q^m, \tag{5}$$

$$X_2^m = \partial \mathrm{C}^{\mathrm{m}}(W_1^m, W_2)Q^m / \partial W_2 = \mathrm{C}_2^{\mathrm{m}}(W_1^m, W_2)Q^m, \tag{6}$$

$$X_1^f = \partial \mathrm{C}^{\mathrm{f}}(W_1^f, W_2)Q^f / \partial W_1^f = \mathrm{C}_1^{\mathrm{f}}(W_1^f, W_2)Q^f, \tag{7}$$

$$X_2^f = \partial \mathrm{C}^{\mathrm{f}}(W_1^f, W_2)Q^f / \partial W_2 = \mathrm{C}_2^{\mathrm{f}}(W_1^f, W_2)Q^f. \tag{8}$$

The following two equations describe the milk pricing policies in California. In equation (9), price discrimination instituted by a marketing order raises the price of milk for fluid products by a fixed amount, *d*, relative to the price of milk for manufactured products (Balagtas and Kim, 2007). In equation (10), the nonquota pool price of milk (W_1) is calculated by first removing the quota payment (R) from the milk revenue pool and dividing the residual revenue by the total milk supply. R is calculated by multiplying the per-pound quota premium, \$0.0170, by the number of pounds of quota in circulation. Equation (10) captures the main effect of the milk quota program in California. The existence of milk quota lowers the supply price of milk:

$$W_1^f = W_1^m + d, \tag{9}$$

$$W_1 = \frac{W_1^m X_1^m + W_1^f X_1^f - R}{X_1}, \tag{10}$$

where d and R are exogenous policy parameters.

The following two equations express the supply of milk and energy. Sumner and Wolf (1996) demonstrate that the supply of milk depends only on the nonquota pool price of milk.

$$X_1 = \mathrm{X}_1(W_1), \tag{11}$$

$$X_2 = \mathrm{X}_1(W_2). \tag{12}$$

The following market-clearing conditions complete the model of the equilibrium of California's dairy industry:

$$X_1 = X_1^m + X_1^f, \tag{13}$$

$$X_2 = X_2^m + X_2^f. \tag{14}$$

An equilibrium displacement approximation is used to solve for proportional changes in endogenous prices and quantities (Muth, 1964; Alston, Norton, and Pardey, 1995; Alston and James, 2002). Totally differentiating equations (1)–(14) and converting to elasticity form yields a set of equations that are linear in proportional changes. Using the symbol E to denote proportional changes, the model is described by equations ($1'$)–($14'$). Model parameters are summarized in Table 1 and discussed below.

$$EQ^m = \eta^m EP^m + \eta^{mf} EP^f, \tag{1'}$$

$$EQ^f = \eta^{fm} EP^m + \eta^f EP^f, \tag{2'}$$

$$EP^m = s_1^m EW_1^m + s_2^m EW_2, \tag{3'}$$

$$EP^f = s_1^f EW_1^f + s_2^f EW_2, \tag{4'}$$

$$EX_1^m = \tilde{\eta}_{11}^m EW_1^m + \tilde{\eta}_{12}^m EW_2 + EQ^m, \tag{5'}$$

$$EX_2^m = \tilde{\eta}_{21}^m EW_1^m + \tilde{\eta}_{22}^m EW_2 + EQ^m, \tag{6'}$$

$$EX_1^f = \tilde{\eta}_{11}^f EW_1^f + \tilde{\eta}_{12}^f EW_2 + EQ^f, \tag{7'}$$

$$EX_2^f = \tilde{\eta}_{21}^f EW_1^f + \tilde{\eta}_{22}^f EW_2 + EQ^f, \tag{8'}$$

$$EW_1^f = \gamma EW_1^m, \tag{9'}$$

$$EW_1 = \phi^m (EW_1^m + EX_1^m) + \phi^f (EW_1^f + EX_1^f) - EX_1, \tag{10'}$$

$$EX_1 = \varepsilon_1 EW_1, \tag{11'}$$

$$EX_2 = \varepsilon_2 EW_2, \tag{12'}$$

$$EX_1 = \theta_1^m EX_1^m + \theta_1^f EX_1^f, \tag{13'}$$

$$EX_2 = \theta_2^m EX_2^m + \theta_2^f EX_2^f. \tag{14'}$$

The above system includes 14 endogenous changes in prices and quantities relative to an initial equilibrium. Model parameters include elasticities and shares. η^m and η^f are the own-price elasticities of demand for manufactured and fluid products. η^{mf} and η^{fm} are cross-price elasticities of demand between manufactured and fluid products. s_i^m and s_i^f are the shares of factor i for $i \in (1,2)$ in the cost of producing manufactured and fluid products, respectively (e.g., $s_1^m = W_1^m X_1^m / P^m Q^m$). $\tilde{\eta}_{ij}^m$ and $\tilde{\eta}_{ij}^f$ are the output-constant elasticities of demand for factor i with respect to the price of factor j in the production of manufactured and fluid products, respectively. Given that I only model two inputs, $\tilde{\eta}_{ii} < 0$ and $\tilde{\eta}_{ij} > 0 \; \forall \; i, j$ (i.e., the two inputs must be substitutes). ε_i is the elasticity of supply for factor i. $\gamma = W_1^m / W_1^f$ is the ratio of the price of milk for manufactured products to the price of milk for fluid products. $\phi^m = (W_1^m X_1^m)/(W_1 X_1)$ and $\phi^f = (W_1^f X_1^f)/(W_1 X_1)$ are the shares of milk revenue net of quota payment from manufactured and fluid products, respectively. Define $\phi^R = R/(W_1 X_1)$. I have $\phi^m + \phi^f - \phi^R = 1$. θ_i^m and θ_i^f are the shares of factor i for manufactured and fluid products, respectively (e.g., $\theta_1^m = X_1^m / X_1$), and $\theta_i^m + \theta_i^f = 1$.

Milk Pricing Policies and Dairy Market Equilibrium

In this section, I first solve analytically for all changes in equilibrium prices and quantities of the dairy market that result from an exogenous shock to the supply of energy. I then discuss how milk pricing policies affect the changes in the equilibrium prices of milk.

Table 1. Endogenous Variables and Model Parameters

Description	Notation
Endogenous variables	
Price of manufactured products	P^m
Price of fluid products	P^f
Price of milk for manufactured products	W_1^m
Price of milk for fluid products	W_1^f
Supply price of milk	W_1
Price of energy	W_2
Quantity of manufactured products	Q^m
Quantity of fluid products	Q^f
Quantities of inputs for manufactured products	X_i^m
Quantities of inputs for fluid products	X_i^f
Quantities of inputs supplied	X_i
Model parameters	
Own-price elasticities of demand for final products	η^m, η^f
Cross-price elasticities of demand for final products	η^{mf}, η^{fm}
Output-constant elasticities of demand for inputs	$\tilde{\eta}_{ij}^m, \tilde{\eta}_{ij}^f$
Elasticities of input supply	ε_i
Ratio of the prices of milk for manufactured products to fluid products	γ
Shares of inputs in the costs of final products	s_i^m, s_i^f
Shares of residual milk revenue from final products	ϕ^m, ϕ^f
Shares of inputs for final products	θ_i^m, θ_i^f

Notes: Superscripts m and f denote manufactured and fluid dairy products, respectively, and subscripts $i, j = 1, 2$ denote inputs of milk and energy, respectively.

Impact of Climate Policy on Dairy Market Equilibrium

The impact of climate policy is introduced in the model as a vertical shift, δ, in the supply of energy.[6] δ is defined to be positive. The equilibrium displacement model is then solved under a simplifying assumption: The supply of energy to the dairy processing and manufacturing industry is perfectly elastic. Under this assumption, I have $EW_2 = \delta$ (i.e., climate policy leads to a $(100 \times \delta)\%$ increase in energy price). Because the dairy manufacturing industry is a small part of the economy, this is a reasonable assumption under most situations. The solution derived under this assumption can be seen as an upper bound of the impact of climate policy on the dairy manufacturing industry.

Appendix A shows how to use equations ($1'$) and ($14'$) to solve for proportional changes in the prices and quantities of milk and dairy products. Here, I focus on understanding the changes in the prices of milk:

$$EW_1^m = \frac{-(\alpha_1^m \eta_{12}^m + \alpha_1^f \eta_{12}^f)}{\alpha_1^m \eta_{11}^m + \alpha_1^f \eta_{11}^f - \rho_1}\delta, \tag{15}$$

$$EW_1^f = \gamma EW_1^m = \frac{-\gamma(\alpha_1^m \eta_{12}^m + \alpha_1^f \eta_{12}^f)}{\alpha_1^m \eta_{11}^m + \alpha_1^f \eta_{11}^f - \rho_1}\delta, \tag{16}$$

where $\alpha_1^m = \theta_1^m + \varepsilon_1(\theta_1^m - \phi^m)$, $\alpha_1^f = \theta_1^f + \varepsilon_1(\theta_1^f - \phi^f)$ and $\rho_1 = \varepsilon_1(\phi^m + \gamma\phi^f)$.

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[6] Climate policy could affect the prices of other inputs, such as milk and packing materials, and consumer preferences for different dairy products, but changes in energy costs are the dominant channel through which climate policy affects manufacturing industries (Ganapati, Shapiro, and Walker, 2020).

The existence of milk pricing policies distorts the dairy market equilibrium. As shown in equation (A5) in Appendix A, α_1^m and α_1^f can be seen as the "effective" shares of the quantity of milk for manufactured and fluid products respectively. In the absence of a marketing order ($d = 0$) or milk quota ($R = 0$), $\alpha_1^m = \theta_1^m$ and $\alpha_1^f = \theta_1^f$, where θ_1^m and θ_1^f are the shares of the quantity of milk for manufactured and fluid products, respectively. Similarly, ρ_1 is the "effective" elasticity of milk supply, which is positive and equals ε_1 when the effects of milk pricing polices are removed.

The ηs are "equilibrium elasticities," as defined in Appendix A (e.g., $\eta_{12}^m = \tilde{\eta}_{12}^m + \eta^m s_2^m + \eta^{mf} s_2^f$). Equilibrium elasticities are elasticities of input demand when the output market is in equilibrium. The first term in an equilibrium elasticity is equal to the output-constant elasticity of demand, which represents the pure substitution effect. The other two terms in an equilibrium elasticity represent the output market equilibrium effect. The output market equilibrium effect comprises the output response effect and the output-price response effect. In the case of constant returns to scale, the cost minimizing inputs are chosen for any level of output; hence, the output market effect comprises only the output-price response effect. The equilibrium own-price elasticities of input demand are always negative as long as the output demand is downward sloping (Heiner, 1982). The signs of equilibrium cross-price elasticities of input demand are theoretically indeterminate. When the output market equilibrium effect is stronger than the input substitution effect, the equilibrium cross-price elasticity of input demand is negative.

Appendix A shows that the denominator of equation (15), $\alpha_1^m \eta_{11}^m + \alpha_1^f \eta_{11}^f - \rho_1$, is negative when the supply of farm milk is not too elastic. Using data for 2017, this condition is satisfied as long as the elasticity of milk supply is less than 5.43, which is the case in the literature.[7] The sign of EW_1^m is in general ambiguous. In addition to milk pricing policies, the sign of the numerator of equation (15), $\alpha_1^m \eta_{12}^m + \alpha_1^f \eta_{12}^f$, depends on the substitution effect between milk and energy, the shares of energy in the cost of production, and the own-price and cross-price elasticities of demand for both final products. In a simple model of two factors and a single output, an increase in the price of one factor would lead to an ambiguous effect on the price of the other factor, depending on the relative strength of the output market equilibrium effect and the input substitution effect. I anticipate the same ambiguity here and expect more complexity as I model a two-product industry under distortionary input pricing policies. When the output market equilibrium effect is weaker than the input substitution effect, the equilibrium cross-price elasticity of input demand is positive (i.e., $\eta_{12}^m > 0$ and $\eta_{12}^f > 0$). In this case, $EW_1^m > 0$ and $EW_1^f > 0$. When the output market equilibrium effect is stronger than the input substitution effect, the equilibrium cross-price elasticity of input demand is negative (i.e., $\eta_{12}^m < 0$ and $\eta_{12}^f < 0$). In this case, which is more likely for milk and energy, $EW_1^m < 0$ and $EW_1^f < 0$.

Later, I use numerical simulations to discuss changes in the equilibrium quantities of milk and the prices and quantities of dairy products.

Influence of Milk Marketing Orders

Given that milk pricing policies affect the price of milk relative to energy, the impact of climate policy on the dairy market equilibrium is distorted. Marketing orders raise the price of milk for fluid products, increasing the price of milk relative to energy for fluid products and reducing the price of milk relative to energy for manufactured products. I thus expect marketing orders to dampen the effect of a given increase in energy price on the price of milk for fluid products but amplify the effect on the price of milk for manufactured products.

In the model, I use the ratio of the price of milk for manufactured products to the price of milk for fluid products, γ, to represent the discriminatory effect of marketing orders. To investigate how marketing orders influence the changes in the market equilibrium, I examine how energy-price-

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[7] Chavas and Klemme (1986) estimated that the elasticity of milk supply over a 10-year period is 2.46.

induced changes in the equilibrium prices and quantities depend on γ.[8] Let us use A to denote the numerator of equation (15), $\alpha_1^m\eta_{12}^m + \alpha_1^f\eta_{12}^f$, and D to denote the denominator of equation (15), $\alpha_1^m\eta_{11}^m + \alpha_1^f\eta_{11}^f - \rho_1$. If the output market equilibrium effect is stronger than the input substitution effect for both manufactured and fluid products, then $\eta_{12}^m < 0$ and $\eta_{12}^f < 0$. Appendix B shows that $\frac{\partial D}{\partial \gamma} < 0$ when the elasticity of demand for manufactured products with respect to the price of fluid products, η^{mf}, is moderate in size. Note that A does not depend on γ and is negative. Thus,

$$\text{(17)} \qquad \frac{\partial EW_1^m}{\partial \gamma} = \frac{A\delta}{D^2}\frac{\partial D}{\partial \gamma} > 0,$$

Moreover, $\frac{\partial EW_1^f}{\partial \gamma} = EW_1^m + \gamma\frac{\partial EW_1^m}{\partial \gamma} < 0$ when the elasticity of EW_1^m with respect to γ is greater than -1 (inelastic), as reasonably expected. Recall that $EW_1^m < 0$ and $EW_1^f < 0$ when the output market equilibrium effect is stronger than the input substitution effect. Thus, an increase in the difference between the prices of milk for fluid and manufactured products (i.e., a smaller γ) would lead to a larger reduction in W_1^m but a smaller reduction in W_1^f. That is, marketing orders amplify reductions in the price of milk for manufactured products but dampen reductions in the price of milk for fluid products in response to energy price increases.

Influence of the Milk Quota Program

The influence of the milk quota program on the effects of an increase in energy price is more intricate since milk quota does not directly affect the relative prices of milk to energy. Payment to milk quota holders reduces the supply price of milk (W_1) and milk production and through the equilibrium of the farm milk market increases the prices of milk for both manufactured and fluid products (W_1^m and W_1^f). Thus, the milk quota program indirectly raises the relative prices of milk to energy for both fluid and manufactured products. I expect the milk quota program to dampen the effect of a given increase in energy price on the prices of milk for both fluid and manufactured products.

In the model, the influence of milk quota is represented by ϕ^m and ϕ^f, which are the shares of milk revenue net of quota payment from manufactured and fluid products, respectively. Given that $\phi^R = R/(W_1X_1)$, by definition $\phi^m + \phi^f - \phi^R = 1$. To simplify the derivation, I discuss the influence of milk quota on changes in dairy market equilibrium assuming no MMO (i.e., $\gamma = 1$). Under this simplifying assumption, ϕ^R will be the only model parameter through which milk quota affects the dairy market equilibrium. In Appendix B, I show that when the output market equilibrium effect is stronger than the input substitution effect for both products (i.e., $\eta_{12}^m < 0$ and $\eta_{12}^f < 0$),

$$\text{(18)} \qquad \frac{\partial EW_1^m}{\partial \phi^R} = \frac{-\delta}{D^2}\left(\frac{\partial A}{\partial \phi^R}D - \frac{\partial D}{\partial \phi^R}A\right) = \frac{-\delta}{D^2}\varepsilon_1(\varepsilon_1 + 1)(\theta_1^m\eta_{12}^m + \theta_1^f\eta_{12}^f) > 0.$$

Moreover, $\frac{\partial EW_1^f}{\partial \phi^R} = \gamma\frac{\partial EW_1^m}{\partial \phi^R} > 0$. Recall that $EW_1^m < 0$ and $EW_1^f < 0$ when the output market equilibrium effect is stronger than the input substitution effect. An increase in quota payment (i.e., a larger ϕ^R), would lead to smaller reductions in both W_1^m and W_1^f.[9] The energy-price-induced reductions in the prices of milk are dampened in the presence of the milk quota program.

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[8] An increase in the differential (d) between the prices of milk for fluid and manufactured products would lead to a smaller γ (i.e., $\frac{\partial \gamma}{\partial d} < 0$).

[9] An increase in quota payment reduces milk revenue net of quota payment and raises the ratio of quota payment (i.e., $\frac{\partial \phi^R}{\partial R} > 0$).

Table 2. 2017 California Dairy Market Statistics

Description	Units	Value
Price of milk for manufactured products	\$/cwt	$W_1^m = 15.23$
Price of milk for fluid products	\$/cwt	$W_1^f = 17.99$
Supply price of milk	\$/cwt	$W_1 = 15.19$
Price of manufactured products	\$/lb	$P^m = 1.80$
Price of fluid products	\$/gallon	$P^f = 2.50$
Quantity of milk for manufactured products	million lb	$X_1^m = 33,745$
Quantity of milk for fluid products	million lb	$X_1^f = 4,957$
Quantity of milk supply	million lb	$X_1 = 38,702$
Quantity of manufactured products	million lb	$Q^m = 7,186$
Quantity of fluid products	thousand gals	$Q^f = 621,781$
Quota rent	\$mil.	$R = 151.5$

Notes: Prices of milk are from the California Department of Food and Agriculture (2017b) and prices of dairy products are calculated using information from the U.S. Department of Agriculture (2017, 2018). Quantities of milk and dairy products are from the California Department of Food and Agriculture (2017a).

The two milk pricing policies influence the impact of climate policy on W_1^f in the same direction. The energy-price-induced reductions in the price of milk for fluid products are smaller in the presence of milk pricing policies. The two milk pricing policies influence the impact of climate policy on W_1^m in the opposite direction. I use numerical simulations to assess the extent to which an increase in energy price affects W_1^m and the prices and quantities of farm milk and final products in the presence of milk pricing policies.

Parameters in Numerical Simulations

I now turn to numerical simulations to quantify the impact of climate policy on the dairy industry in California. In this section, I first describe the equilibrium of the California dairy market in 2017 and then discuss the potential values of model parameters from the literature.

Baseline Equilibrium

The baseline equilibrium quantities of milk are taken from the California Department of Food and Agriculture (2017a). Grade A milk production is used as the equilibrium quantity of farm milk in the MMO pool. In 2017, Grade A milk production was $X_1 = 38,702$ million pounds. The utilization of pooled milk indicate that $X_1^m = 33,745$ million pounds of farm milk was used for manufactured products and $X_1^f = 4,957$ million pounds of farm milk was used for fluid milk products.[10] The amount of quota milk in 2017 was 8,911 million pounds.[11] I calculate quota payment, R, as the amount of quota multiplied by the premium (\$0.017/lb) for quota milk. Thus, $R =$ \$151.5 million in 2017. In 2017, the minimum price of class 1 milk was \$17.99/cwt, and the minimum prices of class 4a and class 4b were \$15.08/cwt and \$15.31/cwt, respectively (California Department of Food and Agriculture, 2017b).[12] I use the weighted average of the minimum prices of classes 2, 3, 4a, and 4b milk as the price of milk for manufactured products. In the simulation, $W_1^f =$ \$17.99/cwt and $W_1^m =$ \$15.23/cwt. I calculate the supply price of milk using equation (10). In 2017, $W_1 =$ \$15.19/cwt.

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[10] The breakdown of the utilization of pooled milk on the total solids was 616.1 million pounds for fluid products (class 1) and 4,193.9 million pounds for manufactured products (classes 2, 3, 4a, and 4b). I calculate $X_1^f = 616.1/(616.1 + 4,193.9) \times 38,702 = 4,957$.

[11] 1,107.5 million pounds of total solids were produced by quota owners in 2017. The quantity of quota is calculated as $1,107.5/(616.1 + 4,193.9) \times 38,702 = 8,911$.

[12] Class 2 and 3 prices are 2-month averages of the class 4a price with small fixed differentials.

Quantities of fluid and manufactured products are also obtained from the California Department of Food and Agriculture (2017a). In 2017, California produced 621,781 thousand gallons of fluid products, including whole, reduced fat, lowfat, and skim/nonfat milk, and half and half. In addition to some soft and frozen products, California produced 534.4 million pounds of butter, 608.9 million pounds of nonfat dry milk (NFDM) and dry buttermilk, and 2,513.3 million pounds of cheese. The aggregate production of classes 2, 3, 4a, and 4b, $Q^m = 7,186$ million pounds, is used as the baseline quantity of manufactured products. Wholesale market prices of fluid dairy products are not widely reported. Information from the U.S. Department of Agriculture (2017) is used to infer the wholesale price of fluid products. $P^f = \$2.50$/gallon is used in the simulation. The Chicago Mercantile Exchange prices of Grade AA butter and block cheddar cheese are used as the wholesale prices of butter and cheese. The CDFA reported the weighted average price received for NFDM sold by California processors. Information from the U.S. Department of Agriculture (2018) is used to infer the wholesale prices of other manufactured products. $P^m = \$1.80$/lb is used in the simulation.

Table 2 summarizes the equilibrium prices and quantities. Under the 2017 market equilibrium, I have the following model parameters: $\gamma = W_1^m / W_1^f = 0.847$, $\phi^m = (W_1^m X_1^m)/(W_1 X_1) = 0.874$, $\phi^f = (W_1^f X_1^f)/(W_1 X_1) = 0.152$, $\theta_1^m = X_1^m / X_1 = 0.872$, and $\theta_1^f = X_1^f / X_1 = 0.128$. Table 3 summarizes the model parameters.

Cost Shares of Inputs

In the simulation, I consider three inputs in the production of dairy products: milk, energy, and a composite input consisting of capital, labor, and other processing materials. Two sources provide information to assess the cost shares of inputs for California dairy manufacturing industry: *Manufacturing Cost Annual*, a publication of the California Department of Food and Agriculture (2018), and the NBER Manufacturing Industry Database (Bartelsman and Gray, 1996). The Manufacturing Cost Unit of the CDFA gathered and summarized processing cost information from plants producing products of class 4a, 4b, or both (California Department of Food and Agriculture, 2018).[13] In 2016, the last release of data, processing costs were \$0.19/lb for butter, \$0.21/lb for NFDM, and \$0.25/lb for cheddar cheese. Processing costs do not include the cost of milk. I use the minimum prices and the utilization of milk reported by the California Department of Food and Agriculture (2017a) to calculate the cost of milk. Zhang and Alston (2018) report the cost shares of factors for the U.S. dairy manufacturing industry using the NBER Manufacturing Industry Database. The cost shares of factors can be very different between the California dairy manufacturing industry and the aggregate U.S. dairy manufacturing industry because of the differences in factor prices and the portfolios of products. In the simulation, I assume that $s_1^m = 0.65$, $s_2^m = 0.03$, $s_3^m = 0.32$, $s_1^f = 0.45$, $s_2^f = 0.01$, and $s_3^f = 0.54$.

Using the price indices included in the NBER Manufacturing Industry Database (Bartelsman and Gray, 1996), I calculate the quantity indices of energy, labor, capital, and other processing materials for fluid and manufactured products. In the simulation, I use 0.75 and 0.70 as the base values of the shares of energy and the composite input for manufactured products in California, respectively. That is, $\theta_2^m = 0.75$ and $\theta_2^f = 0.25$, and $\theta_3^m = 0.70$ and $\theta_3^f = 0.30$.

Elasticities

Published estimates of the own-price elasticity of retail demand range from -0.652 to -0.039 for fluid milk (Huang, 1993; Schmit and Kaiser, 2004; Chouinard et al., 2010) and range from -0.741 to -0.078 for other dairy products (Huang, 1993). Fluid dairy products are highly perishable and are mainly consumed in local markets, but most of the manufactured dairy products are traded across

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[13] In 2016, manufacturing costs were collected from plants representing, respectively, 99.35% and 97.44% of the butter and NFDM processed in California. Cheese volumes and percentages were not reported to protect confidentiality.

Table 3. Model Parameters

Description	Value
Own-price elasticities of demand for manufactured products	$\eta^{m} = -6.0$
Own-price elasticities of demand for fluid products	$\eta^{f} = -0.2$
Cross-price elasticity of demand for final products	$\eta^{mf} = \eta^{fm} = 0.02$
Output-constant own-price elasticities of demand for milk	$\tilde{\eta}_{11}^{m} = \tilde{\eta}_{11}^{f} = -0.1$
Output-constant elasticities of demand for milk with respect to the price of energy	$\tilde{\eta}_{12}^{m} = \tilde{\eta}_{12}^{f} = 0.02$
Output-constant elasticities of demand for milk with respect to the price of the composite input	$\tilde{\eta}_{13}^{m} = \tilde{\eta}_{13}^{f} = 0.08$
Output-constant own-price elasticities of demand for energy	$\tilde{\eta}_{22}^{m} = \tilde{\eta}_{22}^{f} = -0.3$
Output-constant elasticities of demand for energy with respect to the price of milk	$\tilde{\eta}_{21}^{m} = \tilde{\eta}_{21}^{f} = 0.2$
Output-constant elasticities of demand for energy with respect to the price of the composite input	$\tilde{\eta}_{23}^{m} = \tilde{\eta}_{23}^{f} = 0.1$
Output-constant own-price elasticities of demand for the composite input	$\tilde{\eta}_{33}^{m} = \tilde{\eta}_{33}^{f} = -0.4$
Output-constant elasticities of demand for the composite input with respect to the price of milk	$\tilde{\eta}_{31}^{m} = \tilde{\eta}_{31}^{f} = 0.38$
Output-constant elasticities of demand for the composite input with respect to the price of energy	$\tilde{\eta}_{32}^{m} = \tilde{\eta}_{32}^{f} = 0.02$
Elasticity of milk supply	$\varepsilon_1 = 0.5$
Elasticity of energy supply	$\varepsilon_2 = \infty$
Elasticity of the composite input supply	$\varepsilon_3 = 1$
Ratio of the prices of milk for manufactured products to fluid products	$\gamma = 0.847$
Share of milk in the cost of manufactured products	$s_1^{m} = 0.65$
Share of energy in the cost of manufactured products	$s_2^{m} = 0.03$
Share of the composite input in the cost of manufactured products	$s_3^{m} = 0.32$
Share of milk in the cost of fluid products	$s_1^{f} = 0.45$
Share of energy in the cost of fluid products	$s_2^{f} = 0.01$
Share of the composite input in the cost of fluid products	$s_3^{f} = 0.54$
Share of residual milk revenue from manufactured products	$\phi^{m} = 0.874$
Share of residual milk revenue from fluid products	$\phi^{f} = 0.152$
Share of milk for manufactured products	$\theta_1^{m} = 0.872$
Share of milk for fluid products	$\theta_1^{f} = 0.128$
Share of energy for manufactured products	$\theta_2^{m} = 0.75$
Share of energy for fluid products	$\theta_2^{f} = 0.25$
Share of the composite input for manufactured products	$\theta_3^{m} = 0.70$
Share of the composite input for fluid products	$\theta_3^{f} = 0.30$

Notes: Elasticities are chosen to reflect published estimates in the literature. Cost shares are calculated using mainly information from California Department of Food and Agriculture (2018) and quantity shares are calculated using price indices included in Bartelsman and Gray (1996).

states in the country and internationally. The demand for California's manufactured dairy products is a residual demand, which is equal to the world demand less the supply from the rest of the world. Thus, the price elasticity of demand for California's manufactured products depends on the elasticity of demand for manufactured products in all regions, the market share of California's manufactured products, and the elasticity of supply of manufactured products from the rest of the world, including the rest of the United States.[14] I use −6.0 and −0.20, respectively, as the baseline values of own-price elasticities of demand for manufactured and fluid products. Huang (1993) estimated cross-

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[14] See the Online Supplement (www.jareonline.org) for details of how I assess the price elasticity of residual demand for California's manufactured products.

price elasticities among dairy products. The elasticities of fluid milk consumption with respect to the prices of cheese, evaporated and dry milk, butter, and frozen dairy products are, respectively, $0.008, -0.060, 0.021$, and -0.032. In the simulation, I use 0.02 as the baseline value of the elasticity of demand for fluid products with respect to the price of manufactured products, and vice versa. In the Online Supplement, I show how simulated changes in equilibrium prices and quantities respond to changes in elasticities.

The relevant elasticity of milk supply should apply to an intermediate time horizon, allowing milk production to adjust in response to what is perceived to be a permanent change in the relative price of milk. Chavas and Klemme (1986) estimate that the intermediate-run supply elasticity ranges from 0.22 to 1.17 over 3–6 years. Helmberger and Chen (1994) estimate that between 1966 and 1990, the short-run supply elasticity was 0.081 and the long-run supply elasticity was 0.583. When examining the effects of reforms of dairy policy in the United States, Cox and Chavas (2001) use a 5-year milk supply elasticity of 0.37. I use 0.50 as the baseline value of the elasticity of supply of farm milk in California. The supply of energy to the dairy manufacturing industry in California is assumed to be perfectly elastic, and the supply of the composite input to the industry is assumed to be unit elastic, which is a reasonable value of the elasticity of supply of capital, labor, and other processing inputs in the intermediate run.

Zhang and Alston (2018) estimate the factor demand relationships of the U.S. dairy manufacturing industry. The estimated output-constant price elasticities of factor demand are similar in magnitude between fluid and manufactured dairy industries. The estimated own-price elasticity of demand for milk ranges from -0.07 to -0.18, for energy from -0.06 to -0.70, and for capital, labor, and materials from -0.26 to -0.84. The elasticity of demand for milk with respect to the price of energy is estimated to be positive but smaller than 0.03, and the elasticity of demand for energy with respect to the price of milk is estimated to be between 0.04 and 0.91. I use the following elasticities in the baseline simulation: $\tilde{\eta}_{11}^{m} = \tilde{\eta}_{11}^{f} = -0.1$, $\tilde{\eta}_{12}^{m} = \tilde{\eta}_{12}^{f} = 0.02$, $\tilde{\eta}_{22}^{m} = \tilde{\eta}_{22}^{f} = -0.3$, $\tilde{\eta}_{21}^{m} = \tilde{\eta}_{21}^{f} = 0.2$, $\tilde{\eta}_{33}^{m} = \tilde{\eta}_{33}^{f} = -0.4$, and $\tilde{\eta}_{32}^{m} = \tilde{\eta}_{32}^{f} = 0.02$. The rest of the cross-price elasticities are chosen such that the linear homogeneity of a cost function for each final product is satisfied.

Simulated Impact of Climate Policy

I first simulate a 30% increase in energy price (i.e., $\delta = 0.3$) under the California MMO.[15] To explore how milk pricing policies affect the energy-price-induced changes in dairy market equilibrium, I then simulate a 30% increase in energy price combined with two potential changes under the new FMMO—an increase in the price of milk for manufactured products and a reduction in quota payment taken from the milk revenue pool—separately and together. I also discuss the implications of a higher energy price for the market transfer of dairy production from California to trade-related regions and the abatement and leakage of CO_2 emissions from the dairy manufacturing industry.

Impact of Climate Policy under California MMO

Table 4 summarizes simulated changes in equilibrium prices and quantities, induced by a 30% increase in energy price, under different milk pricing scenarios. As a comparison, I also simulate a model with no milk policy (i.e., $\gamma = 1$, $\phi^{m} = \theta^{m}$, and $\phi^{f} = \theta^{f}$). To put the percentage changes in perspective, I calculate level changes using the baseline equilibrium values. Under the California MMO, the increase in energy price would induce a 0.87% and a 0.73% reduction in the prices of milk for manufactured and fluid products, respectively. The supply price of farm milk would fall

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[15] It is challenging to predict the changes in energy prices under Senate Bill 32. In addition to the GHG Cap-and-Trade program, a suite of renewable energy and energy efficiency programs are being implemented in California.

Table 4. Effects of a 30% Increase in Energy Price under Alternative Milk Pricing Policies

			No Policy		California MMO		40% Reduction in *d*		40% Reduction in *R*		Hypothetical MMO	
Prices and Quantities	**Notation**	**2017 Equilibrium**	**% Change**	**Level Change**	**% Change**	**Level Change**	**% Change**	**Level Change**	**% Change**	**Level Change**	**% Change**	**Level Change**
Price of milk for manufactured products (cents/cwt)	W_1^m	1,523	−0.860	−13.10	−0.866	−13.19	−0.863	−13.14	−0.869	−13.23	−0.866	−13.19
Price of milk for fluid products (cents/cwt)	W_1^f	1,799	−0.860	−15.48	−0.734	−13.20	−0.784	−14.10	−0.736	−13.24	−0.786	−14.14
Supply price of milk (cents/cwt)	W_1	1,519	−0.860	−13.07	−0.853	−12.96	−0.858	−13.03	−0.843	−12.80	−0.847	−12.87
Price of manufactured products (cents/lb)	P^m	180	0.208	0.37	0.207	0.37	0.207	0.37	0.206	0.37	0.206	0.37
Price of fluid products (cents/gallon)	P^f	250	−0.312	−0.78	−0.250	−0.62	−0.275	−0.69	−0.250	−0.62	−0.275	−0.69
Quantity of milk for manufactured products (million lb)	X_1^m	33,745	−0.599	−202.08	−0.591	−199.51	−0.595	−200.78	−0.585	−197.46	−0.589	−198.87
Quantity of milk for fluid products (million lb)	X_1^f	4,957	0.719	35.65	0.695	34.45	0.705	34.95	0.695	34.46	0.705	34.95
Quantity of milk supply (million lb)	X_1	38,702	−0.430	−166.47	−0.427	−165.10	−0.429	−166.03	−0.421	−163.03	−0.424	−163.97
Quantity of manufactured products (million lb)	Q^m	7,186	−1.252	−89.94	−1.245	−89.49	−1.249	−89.75	−1.240	−89.08	−1.243	−89.34
Quantity of fluid products (thousand gallons)	Q^f	621,781	0.067	413.81	0.054	336.45	0.059	366.85	0.054	336.07	0.059	367.19
Consumer surplus of manufactured products ($millions per year)				−26.68		−26.57		−26.64		−26.45		−26.52
Consumer surplus of fluid products ($millions per year)				4.85		3.89		4.27		3.88		4.27
Producer surplus of milk farmers ($millions per year)				−50.47		−50.05		−50.34		−49.43		−49.71

Notes: Changes in the prices and quantities of energy and the composite input are omitted. Table 3 summarizes model parameters used in the simulations under the California MMO. Where there is no policy, $\gamma = 1$, $\phi^m = \theta^m$, and $\phi^f = \theta^f$. The hypothetical MMO is implemented with both a 40% reduction in d and a 40% reduction in R.

by 0.85%. The reductions in the prices of milk reflect the fact that the output market equilibrium effect is stronger than some of the input substitution effects, at least for one of the final products. The quantity of milk for manufactured products would decrease by 0.59%, but the quantity of milk for fluid products would increase by 0.70%. Climate policy leads to a diversion of farm milk from manufactured products to fluid products. In aggregate, farm milk production would fall by 165.1 million pounds. Changes in the prices of final products are weighted averages of the changes in factor prices. The price of manufactured products would increase by 0.21% and the price of fluid products would decrease by 0.25%. As a consequence, the production of manufactured products would decrease by 89.5 million pounds and the production of fluid products would increase slightly, by 336.5 thousand gallons.

To put the changes in equilibrium prices and quantities in perspective, I calculate changes in measures of economic welfare. The change in consumer surplus (CS) measured off the demand curve for manufactured dairy products is $\Delta CS^m = -P^m Q^m EP^m(1+0.5EQ^m)$. Similarly, I calculate the change in consumer surplus for fluid dairy products. The change in producer surplus (PS) for farm milk is calculated as $\Delta PS_1 = W_1 X_1 EW_1(1+0.5EX_1)$ (Thurman, 1991; Alston, Norton, and Pardey, 1995; Just, Hueth, and Schmitz, 2004). Using the baseline equilibrium prices and quantities in Table 2, changes in economic welfare from a 30% increase in energy prices are summarized in the second half of Table 4. Under the California MMO, consumers of manufactured products would lose \$26.6 million per year, but consumers of fluid products would gain \$3.9 million. Dairy farmers would lose \$50.1 million, representing 0.85% of the baseline milk revenue. Compared to the scenario with no milk policy, simulation results indicate that for consumers of manufactured products and dairy farmers, milk pricing policies cushion the full impact of climate policy (i.e., lowering their welfare losses). On the other hand, consumers of fluid products enjoy a smaller welfare gain from climate policy when milk pricing policies exist.

I evaluate the sensitivity of numerical results to parameter values by generating empirical distributions of the changes in equilibrium prices and quantities using prior distributions of model parameters (Davis and Espinoza, 1998, 2000; Griffiths and Zhao, 2000). Gamma distributions with shape and rate parameters $\alpha = 2$ and $\beta = 2$, $\alpha = 2$ and $\beta = 1$, $\alpha = 13$ and $\beta = 2$, and $\alpha = 2$ and $\beta = 5$ are used as the prior distributions for the elasticity of milk supply, the elasticity of the composite input supply, and the own-price elasticities of demand for manufactured and fluid products, respectively. The mode of a gamma distribution is chosen to be the same as the baseline value of the corresponding model parameter, and the shape and rate parameters of a gamma distribution are chosen to reflect the variance of the model parameter in the literature. Uniform distributions with support $[-0.1, 0.1]$ are chosen as the prior distributions for η^{mf} and η^{fm}. I also use uniform distributions with support $[-0.01, 0.03]$ for $\tilde{\eta}_{12}$ and $\tilde{\eta}_{32}$ and $[-0.04, 0.4]$ for $\tilde{\eta}_{13}$, $\tilde{\eta}_{23}$, $\tilde{\eta}_{21}$, and $\tilde{\eta}_{31}$ for both final products. Uniform distributions are used to reflect the fact that the central tendencies of the model parameters are not clear from the literature. The supports of the uniform distributions are chosen such that different patterns of substitution or complementarity are allowed in the consumption and the production of fluid and manufactured dairy products.

Table 5 reports the 95% simulated confidence intervals of the empirical distributions of 1,000 iterations in parentheses. For reference, the simulated effects under the California MMO using the baseline model parameters are copied here from Table 4. The reductions in the prices of milk for manufactured and fluid products range from 0.43% to 1.22% and from 0.36% to 1.04%, respectively. The quantity of milk for manufactured products could decrease by as much as 1.83%. The quantity of milk for fluid products could either decrease by as much as 0.18% or increase by as much as 1.10%. The total production of milk could fall by as much as 1.55%. The increase in the price of manufactured products ranges from 0.11% to 0.62% and the reduction in quantity ranges by 0.69% to 4.26%. The price and quantity of fluid products could either decrease or increase.

I also simulate small changes in model parameters, one at a time. For each model parameter, I simulate a small increase and a small decrease. As shown in Tables S1 and S2, the changes in

Table 5. Response of Simulated Effects under California MMO to Model Parameters

Prices and Quantities	Notation	California MMO		ε_1	ε_3	η^m	η^f	η^{mf}	η^{fm}	$\tilde{\eta}^m_{12}$	$\tilde{\eta}^m_{13}$	$\tilde{\eta}^f_{12}$	$\tilde{\eta}^f_{13}$	$\tilde{\eta}^m_{31}$	$\tilde{\eta}^m_{32}$	$\tilde{\eta}^f_{31}$	$\tilde{\eta}^f_{32}$
Price of milk for manufactured products	W_1^m	−0.866	(−1.223, −0.427)	+	−	+	−	−	+	+	+	+	+	+	−	+	−
Price of milk for fluid products	W_1^f	−0.734	(−1.036, −0.361)	+	−	+	−	−	+	+	+	+	+	+	−	+	−
Supply price of milk	W_1	−0.853	(−1.220, −0.415)	+	−	+	−	−	+	+	+	+	+	+	−	+	−
Price of manufactured products	P^m	0.207	(0.105, 0.623)	+	+	+	−	−	+	+	+	+	+	−	+	−	+
Price of fluid products	P^m	−0.250	(−0.166, 0.137)	+	+	+	−	−	+	+	+	+	+	−	+	−	+
Price of the composite input	W_3	−0.407	(−1.087, −0.022)	−	+	+	−	−	+	−	−	−	−	−	+	−	+
Quantity of milk for manufactured products	X_1^m	−0.591	(−1.832, −0.233)	−	−	+	+	−	−	+	+	−	−	+	−	+	−
Quantity of milk for fluid products	X_1^f	0.695	(−0.176, 1.100)	−	+	−	−	+	+	−	−	+	+	−	+	−	+
Quantity of milk supply	X_1	-0.427	(−1.552, −0.138)	−	−	+	−	−	+	+	+	+	+	+	−	+	−
Quantity of manufactured products	Q^m	−1.245	(−4.262, −0.685)	−	−	+	+	−	−	−	−	−	−	+	−	+	−
Quantity of fluid products	Q^f	0.054	(−0.077, 0.096)	−	−	−	−	+	+	−	−	−	−	+	−	+	−
Quantity of energy for manufactured products	X_2^m	−10.459	(−22.914, −1.328)	−	−	+	+	−	−	−	−	−	−	+	−	+	−
Quantity of energy for fluid products	X_2^f	−9.133	(−21.288, −0.221)	+	−	+	−	−	+	+	+	+	+	+	−	+	−
Quantity of energy supply	X_2	−10.128	(−20.257, −3.157)	−	−	+	−	−	+	−	−	−	−	+	−	+	−
Quantity of the composite input for manufactured products	X_3^m	−0.812	(−2.121, −0.201)	−	−	+	+	−	−	−	−	−	−	−	+	+	−
Quantity of the composite input for fluid products	X_3^f	0.538	(−0.291, 1.017)	+	−	−	−	+	+	+	+	+	+	+	−	−	+
Quantity of the composite input supply	X_3	−0.407	(−1.372, −0.036)	−	−	+	−	−	+	−	−	−	−	−	+	−	+

Notes: Table 3 summarizes model parameters used in the simulations under the California MMO. The 95% simulated confidence intervals of the empirical distributions of 1,000 iterations are reported in parentheses. A "+" indicates that an increase in a certain model parameter would lead to an increase in the equilibrium value of a variable and a "–" indicates the opposite.

the equilibrium prices and quantities of milk and dairy products respond primarily to the elasticity of milk supply, the own-price elasticity of demand for manufactured products, and the output-constant elasticity of substitution between milk and energy in the production of manufactured products. Table 5 shows the directions of the changes in the equilibrium prices and quantities when a corresponding model parameter changes. A "+" indicates that an increase in a certain model parameter would lead to an increase in the equilibrium value of a variable and a "–" indicates the opposite.

Impact of Climate Policy under FMMO Changes

To explore how different milk pricing policies affect the energy-price-induced changes in the dairy market equilibrium, I simulate two potential changes under the new FMMO: a 40% reduction in the differential, d, between the prices of milk for manufactured and fluid products, and a 40% reduction in quota payment R.[16] A 40% reduction in d is equivalent to about a 7% increase in W_1^m in 2017 (i.e., from \$15.23/cwt to \$16.34/cwt). As discussed previously, the new FMMO is likely to generate a higher minimum price of milk for cheese due to a higher value attributed to whey and hence to narrow the gap between the prices of milk for fluid and manufactured products. Because the new stand-alone quota program will assess all Grade A milk to fund quota payment, instead of just pool milk, the revenue taken out of the new FMMO pool will be smaller. A 40% reduction in quota payment R is equivalent to a 1% increase in the quantity of assessable milk in 2017, from 38,702 million pounds to 39,101 million pounds. It is beyond the scope of this study to predict quantitatively how the new FMMO will change milk prices in California. Simulating these two hypothetical changes allows us to see the direction of influence of moving from the California system to an FMMO.

The insights from the analytical model suggest that an increase in the price of milk for manufactured products would reduce the distortion of the relative price of milk to energy. I thus expect that when d is smaller, so too are the reductions in the price of milk for manufactured products caused by higher energy prices; conversely, the reductions in the price of milk for fluid products would be larger. Comparing the simulation results under the California MMO and the scenario with a 40% reduction in d in Table 4, I confirm the analytical findings derived previously: The existence of a marketing order amplifies the reductions in the price of milk for manufactured products but dampens the reductions in the price of milk for fluid products. Because the quota payment reduces the supply price of farm milk and total milk production, through the equilibrium of farm milk market, it raises the prices of milk for both manufactured and fluid products. I thus expect energy-price-induced reductions in the prices of milk for both fluid and manufactured products to be larger when R is reduced. Comparing the simulation results under the California MMO and the scenario with a 40% reduction in R confirms the analytical findings concerning the influence of the milk quota program: Milk quota payment dampens the reductions in the prices of milk.

The two potential changes under the new FMMO influence the price of milk for manufactured products in the opposite direction. The net effect of an increase in energy price on the price of milk for manufactured products could be similar under the new FMMO to that under the California system. On the other hand, the two potential changes under the new FMMO influence the price of milk for fluid products in the same direction. When both potential policy changes are in place, a 30% increase in energy price would induce a 0.79% reduction in the price of milk for fluid products, compared to a 0.73% reduction under the California milk pricing system. Under the new FMMO, climate policy could divert more milk to fluid products and lead to a bigger reduction in the price and a bigger increase in the quantity of fluid products. As a consequence, consumers of fluid products

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[16] This exercise is to simulate only marginal changes in the policy parameters (d and R) while holding other model parameters fixed. In the simulation model, a 40% reduction in d is implemented by changing model parameter γ from 0.847 to 0.908. A 40% reduction in R is implemented by changing model parameters ϕ^m and ϕ^f from 0.874 and 0.152 to 0.865 and 0.150.

could enjoy a bigger welfare gain from climate policy under the new FMMO: from \$3.89 million under the California MMO to \$4.27 million under this hypothetical FMMO.[17]

Implications for Dairy Market Transfer and CO_2 Emissions

In addition to the effects on the dairy industry in California, climate policy in California also affects the dairy industry in the rest of the United States and the rest of the world, through trade in dairy products. The value of California dairy exports was \$1,712 million in 2017, representing 31% of the value of U.S. dairy exports (U.S. Census Bureau, 2020). When quantifying the changes in dairy industry CO_2 emissions resulting from the climate policy in California, it is important to account for changes in emissions in trade-related regions.

Climate-policy-induced market transfer of dairy production from California to trade-related regions depends on the price elasticities of demand and supply of dairy products, the market share of California's dairy products, and domestic and trade policies for dairy products across all dairy trading regions. In the Online Supplement, I assess the market transfer rate for manufactured dairy products from California.[18] Under the assumptions that the price elasticity of world demand for manufactured products is -0.5, the supply elasticity of manufactured products is 0.5, and California's market share of manufactured products is 15%, the calculated market transfer rate for manufactured products from California is 0.46. As shown above, under the California MMO, a 30% increase in energy price would reduce California's production of manufactured products by 89.5 million pounds and the production transferred to manufacturers outside California would be 41.1 million pounds, representing 0.57% of California's production in 2017. Less elastic demand and more elastic supply would lead to a higher market transfer.

Using the simulated changes in production, I can gauge the impact of California's climate policy on CO_2 emissions abatement and leakage from the dairy manufacturing industry. The quantity of emissions leakage depends on the emissions intensities of dairy manufacturers that increase production in response to the policy-induced reduction in California's production. Similar to other studies on GHG emissions leakage, I assume that the emissions intensities of manufactured dairy products are the same across all regions and equal to the average California emissions intensities.[19] To construct the CO_2 emissions intensities of manufactured products in California, I first construct the energy intensities and then use the fuel-specific CO_2 emissions factors to convert energy intensities into CO_2 emissions intensities.[20] Using CO_2 emissions intensities of 0.29 metric tons per thousand gallons for fluid products and 70 metric tons per million pounds for manufactured products, the simulation indicates that under the California MMO, a 30% increase in energy price would lead to an abatement of CO_2 emissions of 6,167 metric tons from the California dairy manufacturing industry and a CO_2 emissions leakage of 2,878 metric tons (i.e., a net abatement of CO_2 emissions of 3,288 metric tons).

Conclusion

This paper examines the impact of California's climate policy on the dairy manufacturing industry with explicit modeling of milk pricing policies. California dairy farmers produce more than 18% of all U.S. milk, and the dairy product industry has the highest value of of shipments within California's food manufacturing sector. Given that milk pricing policies affect the price of milk relative to

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[17] The implementation of an FMMO in California limits the State government's ability to mitigate the impact of climate policy on the dairy manufacturing industry. An independent MMO in California could have allowed adjustments in manufacturing cost allowances to compensate for higher energy costs (Hamilton et al., 2016).

[18] I assume that fluid dairy products are not traded beyond the state line.

[19] The CO_2 emissions intensities of the production that responds to policy-induced reductions in California's production (i.e., marginal emissions intensities) can be different from the average emissions intensities (Fowlie and Reguant, 2020).

[20] CO_2 emissions embodied in nonenergy inputs are not taken into account, given the data challenges of accounting for upstream emissions. See the Online Supplement for details.

energy, the impact of climate policy on the dairy market equilibrium is distorted. I demonstrate that milk marketing orders amplify the reduction in the price of milk for manufactured products but dampen the reduction in the price of milk for fluid products. On the other hand, the milk quota program in California dampens the reductions in the prices of milk for both fluid and manufactured products. Since the two milk pricing policies influence the price of milk for fluid products in the same direction, energy-price-induced reductions in the price of milk for fluid products are smaller in the presence of milk pricing policies.

Numerical simulations indicate that, under most scenarios, a climate policy would lead to an increase in the quantity of farm milk used for fluid products. This outcome reflects the fact that fluid products are less energy intensive and demand for fluid products is inelastic compared to manufactured products. Climate policy results in a diversion of milk from manufactured products to fluid products and increases welfare for consumers of fluid products. Under the new FMMO, the distorting effect of milk pricing policies is lessened. Consequently, consumers of fluid products could enjoy a bigger welfare gain from climate policy. With a calculated market transfer rate of 0.46 for manufactured dairy products in California, simulations indicate that a 30% increase in energy price would result in a market transfer of 0.57% of California's production and a CO_2 emissions leakage of 47% of California's abatement in 2017.

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References

Alston, J. M., and J. S. James. "The Incidence of Agricultural Policy." In B. L. Gardner and G. C. Rausser, eds., *Handbook of Agricultural Economics,* vol. 2. Amsterdam, Netherlands: Elsevier Science, 2002, 1689–1749.

Alston, J. M., G. W. Norton, and P. G. Pardey. *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. Ithaca, NY: Cornell University Press, 1995.

Balagtas, J. V. *New Perspectives on the Economics of Milk Marketing Orders: Rent Dissipation through Endogenous Quality*. Ph.D. thesis, University of California, Davis, 2004.

Balagtas, J. V., and S. Kim. "Measuring the Effects of Generic Dairy Advertising in a Multi-Market Equilibrium." *American Journal of Agricultural Economics* 89(2007):932–946. doi: 10.1111/j.1467-8276.2007.01037.x.

Bartelsman, E. J., and W. Gray. "The NBER Manufacturing Productivity Database." Technical Working Paper 205, NBER, Cambridge, MA, 1996.

Braulke, M. "The Firm in Short-Run Industry Equilibrium: Comment." *American Economic Review* 74(1984):750–753.

———. "On the Comparative Statics of a Competitive Industry." *American Economic Review* 77(1987):479–485.

California Department of Food and Agriculture. "Milk Pricing in California." 2008.

———. *California Dairy Statistics Annual: 2017 Data*. Sacramento, CA: California Department of Food and Agriculture, Division of Marketing Services, Dairy Marketing Branch, 2017a. Available online at https://web.archive.org/web/ 20190323232944/ https://www.cdfa.ca.gov/dairy/pdf/Annual/2017/2017_Statistics_Annual.pdf.

———. *Minimum Prices for Class 1, 2, 3, 4a, and 4b Market Milk F.O.B. Plant; Pool Prices for Quota, Overbase, and Blend*. Sacramento, CA: California Department of Food and Agriculture, Division of Marketing Services, Dairy Marketing Branch, 2017b. Available online at https://www.cdfa.ca.gov/dairy/ prices_main.html.

———. *Manufacturing Cost Annual: California 2016 Data*. Sacramento, CA: California Department of Food and Agriculture, Division of Marketing Services, Dairy Marketing Branch,

2018. Available online at https://www.cdfa.ca.gov/dairy/pdf/Annual/2017/ManufacturingCostAnnual2016Data.pdf.

Chavas, J.-P., and R. M. Klemme. "Aggregate Milk Supply Response and Investment Behavior on U.S. Dairy Farms." *American Journal of Agricultural Economics* 68(1986):55–66. doi: doi.org/10.2307/1241649.

Chouinard, H. H., D. E. Davis, J. T. LaFrance, and J. M. Perloff. "Milk Marketing Order Winners and Losers." *Applied Economic Perspectives and Policy* 32(2010):59–76. doi: 10.1093/aepp/ppp002.

Cox, T. L., and J.-P. Chavas. "An Interregional Analysis of Price Discrimination and Domestic Policy Reform in the U.S. Dairy Sector." *American Journal of Agricultural Economics* 83(2001):89–106. doi: 10.2307/1241649.

Davis, G. C., and M. C. Espinoza. "A Unified Approach to Sensitivity Analysis in Equilibrium Displacement Models." *American Journal of Agricultural Economics* 80(1998):868–879. doi: 10.2307/1244070.

———. "A Unified Approach to Sensitivity Analysis in Equilibrium Displacement Models: Reply." *American Journal of Agricultural Economics* 82(2000):241–243. doi: 10.1111/0002-9092.00021.

Fowlie, M. L. "Incomplete Environmental Regulation, Imperfect Competition, and Emissions Leakage." *American Economic Journal: Economic Policy* 1(2009):72–112. doi: 10.1257/pol.1.2.72.

Fowlie, M. L., and M. Reguant. "Mitigating Emissions Leakage in Incomplete Carbon Markets." Working paper 14421, NBER, Cambridge, MA, 2020.

Fullerton, D., and G. Heutel. "The General Equilibrium Incidence of Environmental Taxes." *Journal of Public Economics* 91(2007):571–591. doi: 10.1016/j.jpubeco.2006.07.004.

———. "The General Equilibrium Incidence of Environmental Mandates." *American Economic Journal: Economic Policy* 2(2010):64–89. doi: 10.1257/pol.2.3.64.

Fullerton, D., and E. Muehlegger. "Who Bears the Economic Burdens of Environmental Regulations?" *Review of Environmental Economics and Policy* 13(2019):62–82. doi: 10.1093/reep/rey023.

Ganapati, S., J. S. Shapiro, and R. Walker. "Energy Cost Pass-Through in US Manufacturing: Estimates and Implications for Carbon Taxes." *American Economic Journal: Applied Economics* 12(2020):303–342. doi: 10.1257/app.20180474.

Griffiths, W., and X. Zhao. "A Unified Approach to Sensitivity Analysis in Equilibrium Displacement Models: Comment." *American Journal of Agricultural Economics* 82(2000):236–240. doi: 10.1111/0002-9092.00020.

Hamilton, S. F., E. Ligon, A. Shafran, and S. Villas-Boas. *Production and Emissions Leakage from California's Cap-and-Trade Program in Food Processing Industries: Case Study of Tomato, Sugar, Wet Corn and Cheese Markets*. Sacramento, CA: Report to the California Air Resources Board, 2016.

Hastings, J. "Petition Seeks to End California Quota." *Dairy Business* (2019). Available online at https://www.dairybusiness.com/petition-seeks-to-end-california-quota/.

Heiner, R. "Theory of the Firm in 'Short-Run' Industry Equilibrium." *American Economic Review* 72(1982):555–562.

Helmberger, P., and Y.-H. Chen. "Economic Effects of U.S. Dairy Programs." *Journal of Agricultural and Resource Economics* 19(1994):225–238. doi: 10.22004/ag.econ.30750.

Huang, K. S. "A Complete System of U.S. Demand for Food." Technical Bulletin 1821, U.S. Department of Agriculture, Economic Research Service, Washington, DC, 1993.

Just, R. E., D. L. Hueth, and A. Schmitz. *The Welfare Economics of Public Policy: A Practical Approach to Project and Policy Evaluation*. Cheltenham, UK: Elgar, 2004.

Lade, G. E., and J. Bushnell. "Fuel Subsidy Pass-Through and Market Structure: Evidence from the Renewable Fuel Standard." *Journal of the Association of Environmental and Resource*

Economists 6(2019):563–592. doi: 10.1086/702878.

Montgomery, W. D. "Markets in Licenses and Efficient Pollution Control Programs." *Journal of Economic Theory* 5(1972):395–418. doi: 10.1016/0022-0531(72)90049-X.

Muth, R. F. "The Derived Demand Curve for a Productive Factor and the Industry Supply Curve." *Oxford Economic Papers* 16(1964):221–234. doi: 10.1093/oxfordjournals.oep.a040951.

Schmit, T. M., and H. M. Kaiser. "Decomposing the Variation in Generic Advertising Response over Time." *American Journal of Agricultural Economics* 86(2004):139–153. doi: 10.1111/j.0092-5853.2004.00568.x.

Sumner, D. A. "New California Milk Marketing Regulations Will Not Change Economic Fundamentals." *Choices* 33(2018):1–6. doi: 10.22004/ag.econ.279868.

Sumner, D. A., and C. A. Wolf. "Quotas without Supply Control: Effects of Dairy Quota Policy in California." *American Journal of Agricultural Economics* 78(1996):354–366. doi: 10.2307/1243708.

Thurman, W. N. "Applied General Equilibrium Welfare Analysis." *American Journal of Agricultural Economics* 73(1991):1508–1516. doi: 10.2307/1242413.

U.S. Census Bureau. "USA Trade Online." 2020. Available online at https://usatrade.census.gov/ [Accessed August 1, 2021].

U.S. Department of Agriculture. *Retail Milk Prices Report*. RMP-1217. Washington, DC: U.S. Department of Agriculture, Agricultural Marketing Service, Market Information Branch, 2017.

———. *Dairy Market Statistics: 2017 Annual Summary*. Washington, DC: U.S. Department of Agriculture, Agricultural Marketing Service, 2018.

Zhang, W., and J. M. Alston. "The Demand for Inputs and Technical Change in the US Dairy Manufacturing Industry." *Agricultural and Resource Economics Review* 47(2018):533–567. doi: 10.1017/age.2017.3.

Appendix A: Solution to the Equilibrium Displacement Model

The equilibrium displacement model is solved by substitution. EP^m and EP^f are first eliminated by substituting equations (3′) and (4′) into equations (1′) and (2′). The resulting expressions for EQ^m and EQ^f are then substituted into equations (5′)–(8′). Using the relationship between EW_1^f and EW_1^m in equation (9′), I can express the proportional changes in factor demand as functions of EW_1^m and the exogenous shift in energy supply δ:

$$EX_1^m = \eta_{11}^m EW_1^m + \eta_{12}^m \delta, \tag{A1}$$

$$EX_2^m = \eta_{21}^m EW_1^m + \eta_{22}^m \delta, \tag{A2}$$

$$EX_1^f = \eta_{11}^f EW_1^m + \eta_{12}^f \delta, \tag{A3}$$

$$EX_2^f = \eta_{21}^f EW_1^m + \eta_{22}^f \delta. \tag{A4}$$

ηs are equilibrium elasticities, defined as

$$\eta_{11}^m = \tilde{\eta}_{11}^m + \eta^m s_1^m + \eta^{mf} s_1^f \gamma,$$

$$\eta_{12}^m = \tilde{\eta}_{12}^m + \eta^m s_2^m + \eta^{mf} s_2^f,$$

$$\eta_{21}^m = \tilde{\eta}_{21}^m + \eta^m s_1^m + \eta^{mf} s_1^f \gamma,$$

$$\eta_{22}^m = \tilde{\eta}_{22}^m + \eta^m s_2^m + \eta^{mf} s_2^f,$$

$$\eta_{11}^f = \tilde{\eta}_{11}^f \gamma + \eta^f s_1^f \gamma + \eta^{fm} s_1^m,$$

$$\eta_{12}^f = \tilde{\eta}_{12}^f + \eta^f s_2^f + \eta^{fm} s_2^m,$$

$$\eta_{21}^f = \tilde{\eta}_{21}^f \gamma + \eta^f s_1^f \gamma + \eta^{fm} s_1^m,$$

$$\eta_{22}^f = \tilde{\eta}_{22}^f + \eta^f s_2^f + \eta^{fm} s_2^m.$$

Substitute equation (11′) into equation (13′) to eliminate EX_1. Substitute equation (10′) into the resulting equation and rearrange terms to obtain

$$\alpha_1^m EX_1^m + \alpha_1^f EX_1^f = \rho_1 EW_1^m, \tag{A5}$$

where $\alpha_1^m = \theta_1^m + \varepsilon_1(\theta_1^m - \phi^m)$, $\alpha_1^f = \theta_1^f + \varepsilon_1(\theta_1^f - \phi^f)$ and $\rho_1 = \varepsilon_1(\phi^m + \gamma\phi^f)$. Equation (A5) represents the "effective" market-clearing condition for milk with the effects of milk pricing policies incorporated in the parameters.

Substitute equations (A1) and (A3) into equation (A5) to solve for EW_1^m:

$$EW_1^m = \frac{-(\alpha_1^m \eta_{12}^m + \alpha_1^f \eta_{12}^f)}{\alpha_1^m \eta_{11}^m + \alpha_1^f \eta_{11}^f - \rho_1}\delta. \tag{A6}$$

Solutions for the remaining proportional changes in prices and quantities are obtained by substituting EW_1^m back into the previous equations:

$$EW_1^f = \frac{-\gamma(\alpha_1^m \eta_{12}^m + \alpha_1^f \eta_{12}^f)}{\alpha_1^m \eta_{11}^m + \alpha_1^f \eta_{11}^f - \rho_1}\delta, \tag{A7}$$

$$EX_1^m = \frac{\alpha_1^f(\eta_{11}^f \eta_{12}^m - \eta_{11}^m \eta_{12}^f) - \eta_{12}^m \rho_1}{\alpha_1^m \eta_{11}^m + \alpha_1^f \eta_{11}^f - \rho_1}\delta, \tag{A8}$$

$$EX_1^f = \frac{\alpha_1^m(\eta_{11}^m \eta_{12}^f - \eta_{11}^f \eta_{12}^m) - \eta_{12}^f \rho_1}{\alpha_1^m \eta_{11}^m + \alpha_1^f \eta_{11}^f - \rho_1}\delta, \tag{A9}$$

$$EX_2^m = \frac{-\eta_{21}^m(\alpha_1^m \eta_{12}^m + \alpha_1^f \eta_{12}^f) + \eta_{22}^m(\alpha_1^m \eta_{11}^m + \alpha_1^f \eta_{11}^f - \rho_1)}{\alpha_1^m \eta_{11}^m + \alpha_1^f \eta_{11}^f - \rho_1}\delta, \tag{A10}$$

$$EX_2^f = \frac{-\eta_{21}^f(\alpha_1^m \eta_{12}^m + \alpha_1^f \eta_{12}^f) + \eta_{22}^f(\alpha_1^m \eta_{11}^m + \alpha_1^f \eta_{11}^f - \rho_1)}{\alpha_1^m \eta_{11}^m + \alpha_1^f \eta_{11}^f - \rho_1}\delta. \tag{A11}$$

Solutions for EP^m and EP^f can be obtained by substituting EW_1^m into equations ($3'$) and ($4'$), and solutions for EQ^m and EQ^f can then be obtained by substituting solutions for EP^m and EP^f into equations ($1'$) and ($2'$).

Now I show that, in general, the denominator of the above solutions, $\alpha_1^m \eta_{11}^m + \alpha_1^f \eta_{11}^f - \rho_1$, is negative. The magnitudes of α_1^m and α_1^f depend on the elasticity of milk supply, the allocation of milk between manufactured and fluid products, and milk pricing policies. Substituting the definitions of θ_1^m and ϕ^m into α_1^m gives

$$\alpha_1^m = \frac{X_1^m(W_1 + \varepsilon_1 W_1 - \varepsilon_1 W_1^m)}{W_1 X_1} > 0$$

and substituting θ_1^f and ϕ^f into α_1^f gives

$$\alpha_1^f = \frac{X_1^f(W_1 + \varepsilon_1 W_1 - \varepsilon_1 W_1^f)}{W_1 X_1} > 0$$

when $\varepsilon_1 < \frac{W_1}{W_1^f - W_1}$. Thus, as long as the supply of farm milk is not too elastic, $\alpha_1^f > 0$. This condition is satisfied for all of the estimates of the elasticity of milk supply in the literature. The ηs are the equilibrium elasticities and are related to partial elasticities as shown above. Heiner (1982) proved that the short-run industry response to a change in factor price is negative semidefinite and symmetric, as long as related markets are normal. Markets are "normal" when own-price effects outweigh cross-price effects. Heiner proved this result for a single-output industry, and Braulke (1984, 1987) generalized it to multiproduct industry. Thus, $\eta_{11}^m \leq 0$ and $\eta_{11}^f \leq 0$. ρ_1 is positive by definition. Thus, $\alpha_1^m \eta_{11}^m + \alpha_1^f \eta_{11}^f - \rho_1 < 0$.

Note that, in general, the signs of the changes in the equilibrium prices and quantities are indeterminate because the signs of η_{12}^m and η_{12}^f are theoretically indeterminate. When the output market equilibrium effect is stronger than the input substitution effect, the equilibrium cross-price elasticity of input demand is negative (i.e., $\eta_{12}^m < 0$ and $\eta_{12}^f < 0$). In this case, I have $EW_1^m < 0$ and $EW_1^f < 0$.

Appendix B. The Influence of Milk Pricing Policies

This appendix derives how milk pricing policies affect the changes in the equilibrium prices of milk when the price of energy increases. I first derive the effects of marketing orders. Let us use A to denote $\alpha_1^m \eta_{12}^m + \alpha_1^f \eta_{12}^f$ and D to denote $\alpha_1^m \eta_{11}^m + \alpha_1^f \eta_{11}^f - \rho_1$. Note that A is not a function of γ. I then have

$$\text{(B1)} \qquad \frac{\partial EW_1^m}{\partial \gamma} = \frac{A\delta}{D^2}\frac{\partial D}{\partial \gamma}.$$

Using the definitions of the equilibrium elasticities and ρ_1 in Appendix A,

$$\frac{\partial D}{\partial \gamma} = \alpha_1^m \eta^{mf} s_1^f + \alpha_1^f(\tilde{\eta}_{11}^f + \eta^f s_1^f) - \varepsilon_1 \phi^f.$$

The first term in $\frac{\partial D}{\partial \gamma}$ is positive. As long as the elasticity of demand for manufactured products with respect to the price of fluid products, η^{mf}, is moderate in size, the effects of the two negative terms in $\frac{\partial D}{\partial \gamma}$ should dominate. Thus, $\frac{\partial D}{\partial \gamma} < 0$. Since when the output market equilibrium effect is stronger than the input substitution effect, $\eta_{12}^m < 0$ and $\eta_{12}^f < 0$, $A < 0$ and $\frac{\partial EW_1^m}{\partial \gamma} > 0$. Note that $\frac{\partial EW_1^f}{\partial \gamma} = EW_1^m + \gamma\frac{\partial EW_1^m}{\partial \gamma} = EW_1^m(1 + \frac{\partial EW_1^m}{\partial \gamma}\frac{\gamma}{EW_1^m}) < 0$ when the elasticity of EW_1^m with respect to γ is greater than -1 (inelastic).

Now I derive how milk quota affects changes in the equilibrium milk prices. To simplify the derivation, I discuss the influence of milk quota assuming no MMO (i.e., $\gamma = 1$). Under this simplifying assumption, equation (10) becomes $W_1 = \frac{W_1^m X_1 - R}{X_1}$ and equation (10′) becomes $EW_1 = (1 + \phi^R)EW_1^m + \phi^R EX_1$, with $\phi^R = \frac{R}{W_1 X_1} = \frac{R}{W_1^m X_1 - R}$ as the only model parameter through which milk quota affects the dairy market equilibrium. The market-clearing condition for milk, equation (A5), can then be expressed as

$$\text{(B2)} \qquad \theta_1^m(1 - \varepsilon_1\phi^R)EX_1^m + \theta_1^f(1 - \varepsilon_1\phi^R)EX_1^f = \varepsilon_1(1 + \phi^R)EW_1^m,$$

where α_1^m, α_1^f, and ρ_1 are expressed as functions of ϕ^R. Thus, $\frac{\partial \alpha_1^m}{\partial \phi^R} = -\theta_1^m \varepsilon_1$, $\frac{\partial \alpha_1^f}{\partial \phi^R} = -\theta_1^f \varepsilon_1$, and $\frac{\partial \rho_1}{\partial \phi^R} = \varepsilon_1$.

Both A and D, the numerator and the denominator of EW_1^m, are functions of ϕ^R:

$$\text{(B3)} \qquad \frac{\partial EW_1^m}{\partial \phi^R} = \frac{-\delta}{D^2}\left(\frac{\partial A}{\partial \phi^R}D - \frac{\partial D}{\partial \phi^R}A\right),$$

with $\frac{\partial A}{\partial \phi^R} = -\varepsilon_1(\theta_1^m \eta_{12}^m + \theta_1^f \eta_{12}^f)$ and $\frac{\partial D}{\partial \phi^R} = -\varepsilon_1(\theta_1^m \eta_{11}^m + \theta_1^f \eta_{11}^f + 1)$.

Substituting the expressions for A, D, $\frac{\partial A}{\partial \phi^R}$, and $\frac{\partial A}{\partial \phi^R}$ into the terms in parentheses in equation (B3) and rearranging yields $\frac{\partial EW_1^m}{\partial \phi^R} = \frac{-\delta}{D^2}\varepsilon_1(\varepsilon_1 + 1)(\theta_1^m \eta_{12}^m + \theta_1^f \eta_{12}^f)$. Since when the output market equilibrium effect is stronger than the input substitution effect, $\eta_{12}^m < 0$ and $\eta_{12}^f < 0$, $\theta_1^m \eta_{12}^m + \theta_1^f \eta_{12}^f < 0$ and $\frac{\partial EW_1^m}{\partial \phi^R} > 0$. $\frac{\partial EW_1^f}{\partial \phi^R} = \gamma\frac{\partial EW_1^m}{\partial \phi^R} > 0$.

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Online Supplement: California's Climate Policy and the Dairy Manufacturing Industry: How Does a Federal Milk Marketing Order Matter?

Wei Zhang

Residual Demand and Market Transfer for Manufactured Dairy Products in California

The demand for California's manufactured dairy products (Q^m) is the world demand minus the supply from the rest of the world. The price elasticity of this residual demand is

$$\eta^m = \frac{1}{s_C}\eta_D + (1 - \frac{1}{s_C})\varepsilon_S, \tag{S1}$$

where s_C is the market share of California's dairy products, η_D is the price elasticity of demand in the world market and ε_S is the elasticity of supply of the rest of dairy trading countries and regions.

Data from the Foreign Agricultural Service (FAS) of the USDA show that California's shares in the 2017 world dairy market were 3%, 6%, and 7% for butter, cheese, and nonfat dry milk, respectively (U.S. Department of Agriculture, 2017). Note that trade restrictions and barriers insulate some countries, such as India and Ukraine, from the world dairy market. This increases the effective market shares of California's dairy products. Most soft and frozen dairy products stay within the United States. In this case, the relevant market shares are the market shares of California's products in the U.S. market. Data reported in U.S. Department of Agriculture (2018) show that California produced 14%, 10%, and 14% of the 2017 U.S. production of sour cream, yogurt, and ice cream, respectively. However, less than 10% of California's farm milk used for manufactured products goes to soft and frozen products (California Department of Food and Agriculture, 2017).

I assume $\eta_D = -0.5$ and $\varepsilon_S = 0.5$. Using a market share of 15%, the calculated price elasticity of residual demand for California's manufactured dairy products is -6.17. I also consider 10% and 20% market shares and slightly more elastic demand and supply. In the baseline simulation, I use -6 as the elasticity of residual demand for manufactured products. Sensitivity analyses with residual demand elasticities of -10 and -4 are reported in Table S1.

The decrease in California's production of manufactured dairy products due to climate policy is different from the increase in out-of-state production. The market transfer rate measures the increase in out-of-state-production in response to the reduction in California's production.

$$\text{market transfer rate} = 1 - \frac{\eta_D}{\eta_D + (s_C - 1)\varepsilon_S}. \tag{S2}$$

Under the assumptions that $\eta_D = -0.5$, $\varepsilon_S = 0.5$, and $s_C = 0.15$, the calculated market transfer rate for the dairy manufacturing industry in California is 0.46. The market transfer rate would be higher if the demand were less elastic or the supply were more elastic.

Emissions Intensities of Manufactured Dairy Products in California

To construct the CO_2 emissions intensities of dairy products in California, I first construct the energy intensities of production and then use fuel-specific CO_2 emissions factors to convert energy intensities into CO_2 emissions intensities. CO_2 emissions embodied in non-energy inputs are not taken into account. California Department of Food and Agriculture (2018) reports the 2016 electricity and natural gas and fuel oil expenditures for butter, cheddar cheese, and NFDM production in California. The prices of natural gas and electricity in California in 2016 were obtained from the State Energy Data System of the Energy Information Administration (EIA). The calculated energy intensities are 560, 964, and 3,508 million British thermal units (Btu) per million pounds for butter, cheddar cheese, and NFDM, respectively.[1] Using the CO_2 emissions factors for natural gas and electricity produced in California from the EIA, the calculated CO_2 emissions intensities are 34, 55, and 194 metric tons per million pounds for butter, cheddar cheese, and NFDM, respectively.[2] Production-weighted average CO_2 emissions intensity for these three products is 73 metric tons per million pounds. Data are not available to assess the CO_2 emissions intensities of fluid, soft, and frozen dairy products produced in California. I assume that their CO_2 emissions intensities are similar to that of butter. In my assessment of the abatement and leakage of CO_2 emissions, I use for fluid products a CO_2 emissions intensity of 0.29 metric tons per thousand gallons and for manufactured products a CO_2 emissions intensity of 70 metric tons per million pounds.

Sensitivity of Numerical Simulations

I evaluate how the simulated changes in equilibrium prices and quantities depend on model parameters. Results are obtained under the California MMO. Table S1 shows how the changes respond to supply and demand elasticities, and Table S2 shows how the changes respond to output-constant elasticities of substitution between factors. The changes in the equilibrium prices and quantities of milk and dairy products respond primarily to the elasticity of supply of milk, the own-price elasticity of demand for manufactured products, and the elasticity of substitution between milk and energy in the production of manufactured products.

References

California Department of Food and Agriculture. *California Dairy Statistics Annual: 2017 Data*. Sacramento, CA: California Department of Food and Agriculture, Division of Marketing Services, Dairy Marketing Branch, 2017. Available online at https://web.archive.org/web/20190323232944/ https://www.cdfa.ca.gov/dairy/pdf/Annual/2017/2017_Statistics_Annual.pdf.

———. *Manufacturing Cost Annual: California 2016 Data*. Sacramento, CA: California Department of Food and Agriculture, Division of Marketing Services, Dairy Marketing Branch, 2018. Available online at https://www.cdfa.ca.gov/dairy/pdf/Annual/2017/ManufacturingCostAnnual2016Data.pdf.

U.S. Department of Agriculture. "Dairy: World Markets and Trade 2017." 2017.

———. *Dairy Market Statistics: 2017 Annual Summary*. Washington, DC: U.S. Department of Agriculture, Agricultural Marketing Service, 2018.

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[1] See https://www.eia.gov/state/seds/, last accessed August 20, 2020.

[2] See https://www.eia.gov/environment/emissions/co2_vol_mass.php and https://www.eia.gov/electricity/state/archive/2016/california/, last accessed August 20, 2020.

Table S1. Response of Simulated Effects to Model Parameters: Supply and Demand Elasticities

Prices and Quantities	Notation	California MMO	$\varepsilon_1 =$ 0.1	$\varepsilon_1 =$ 2	$\varepsilon_3 =$ 0.5	$\varepsilon_3 =$ 4	$\eta^m =$ −4	$\eta^m =$ −10	$\eta^f =$ −1	$\eta^f =$ −0.1	$\eta^{mf} =$ −0.1	$\eta^{mf} =$ 0.1	$\eta^{fm} =$ −0.1	$\eta^{fm} =$ 0.1
Price of milk for manufactured products	W_1^m	−0.866	−1.020	−0.555	−0.805	−0.968	−0.762	−0.959	−0.870	−0.866	−0.861	−0.870	−0.866	−0.867
Price of milk for fluid products	W_1^f	−0.734	−0.864	−0.470	−0.681	−0.819	−0.645	−0.812	−0.737	−0.733	−0.729	−0.737	−0.733	−0.734
Supply price of milk	W_1	−0.853	−1.006	−0.544	−0.791	−0.955	−0.749	−0.946	−0.853	−0.853	−0.848	−0.857	−0.853	−0.853
Price of manufactured products	P^m	0.207	0.149	0.323	0.197	0.222	0.293	0.130	0.212	0.206	0.211	0.204	0.206	0.207
Price of fluid products	P^f	−0.250	−0.237	−0.276	−0.310	−0.152	−0.178	−0.313	−0.238	−0.251	−0.246	−0.252	−0.251	−0.249
Price of the composite input	W_3	−0.407	−0.275	−0.674	−0.561	−0.153	−0.348	−0.459	−0.383	−0.410	−0.404	−0.409	−0.410	−0.405
Quantity of milk for manufactured products	X_1^m	−0.591	−0.220	−1.343	−0.555	−0.651	−0.529	−0.647	−0.619	−0.588	−0.588	−0.593	−0.588	−0.594
Quantity of milk for fluid products	X_1^f	0.695	0.715	0.655	0.689	0.704	0.678	0.710	0.886	0.670	0.694	0.696	0.670	0.712
Quantity of milk supply	X_1	−0.427	−0.101	−1.088	−0.396	−0.477	−0.374	−0.473	−0.426	−0.427	−0.424	−0.428	−0.427	−0.427
Quantity of manufactured products	Q^m	−1.245	−0.900	−1.945	−1.190	−1.335	−1.177	−1.306	−1.275	−1.241	−1.242	−1.248	−1.241	−1.248
Quantity of fluid products	Q^f	0.054	0.050	0.062	0.066	0.035	0.042	0.065	0.243	0.029	0.053	0.055	0.030	0.070
Quantity of energy for manufactured products	X_2^m	−10.459	−10.132	−11.123	−10.408	−10.544	−10.364	−10.543	−10.488	−10.455	−10.454	−10.463	−10.456	−10.462
Quantity of energy for fluid products	X_2^f	−9.133	−9.150	−9.100	−9.127	−9.144	−9.122	−9.143	−8.943	−9.158	−9.133	−9.134	−9.158	−9.117
Quantity of energy supply	X_2	−10.128	−9.886	−10.618	−10.087	−10.194	−10.054	−10.193	−10.102	−10.131	−10.124	−10.130	−10.131	−10.125
Quantity of the composite input for manufactured products	X_3^m	−0.812	−0.578	−1.286	−0.672	−1.042	−0.727	−0.887	−0.853	−0.806	−0.808	−0.815	−0.806	−0.815
Quantity of the composite input for fluid products	X_3^f	0.538	0.432	0.753	0.632	0.385	0.536	0.540	0.715	0.515	0.538	0.538	0.515	0.553
Quantity of the composite input supply	X_3	−0.407	−0.275	−0.674	−0.281	−0.614	−0.348	−0.459	−0.383	−0.410	−0.404	−0.409	−0.410	−0.405

Notes: Table 3 summarizes model parameters used in the simulations under the California MMO.

Table S2. Response of Simulated Effects to Model Parameters: Elasticities of Substitution

Prices and Quantities	Notation	California MMO	$\tilde{\eta}^m_{12} =$ −0.01	$\tilde{\eta}^m_{12} =$ 0.03	$\tilde{\eta}^m_{13} =$ −0.04	$\tilde{\eta}^m_{13} =$ 0.40	$\tilde{\eta}^f_{12} =$ −0.01	$\tilde{\eta}^f_{12} =$ 0.03	$\tilde{\eta}^f_{13} =$ −0.04	$\tilde{\eta}^f_{13} =$ 0.40
Price of milk for manufactured products	W_1^m	−0.866	−1.177	−0.764	−0.886	−0.826	−0.907	−0.853	−0.868	−0.862
Price of milk for fluid products	W_1^f	−0.734	−0.997	−0.647	−0.751	−0.699	−0.768	−0.722	−0.735	−0.730
Supply price of milk	W_1	−0.853	−1.164	−0.751	−0.873	−0.812	−0.916	−0.832	−0.856	−0.846
Price of manufactured products	P^m	0.207	0.090	0.245	0.199	0.222	0.191	0.212	0.206	0.208
Price of fluid products	P^f	−0.250	−0.224	−0.258	−0.248	−0.253	−0.246	−0.251	−0.250	−0.250
Price of the composite input	W_3	−0.407	−0.140	−0.495	−0.390	−0.442	−0.372	−0.419	−0.405	−0.411
Quantity of milk for manufactured products	X_1^m	−0.591	−0.775	−0.531	−0.603	−0.567	−0.492	−0.624	−0.587	−0.602
Quantity of milk for fluid products	X_1^f	0.695	0.735	0.682	0.697	0.690	−0.223	1.000	0.656	0.797
Quantity of milk supply	X_1	−0.427	−0.582	−0.375	−0.436	−0.406	−0.458	−0.416	−0.428	−0.423
Quantity of manufactured products	Q^m	−1.245	−0.547	−1.475	−1.201	−1.337	−1.153	−1.276	−1.241	−1.255
Quantity of fluid products	Q^f	0.054	0.047	0.057	0.054	0.055	0.053	0.054	0.054	0.054
Quantity of energy for manufactured products	X_2^m	−10.459	−9.796	−10.677	−10.417	−10.546	−10.372	−10.488	−10.456	−10.469
Quantity of energy for fluid products	X_2^f	−9.133	−9.167	−9.122	−9.135	−9.129	−9.138	−9.132	−9.134	−9.133
Quantity of energy supply	X_2	−10.128	−9.639	−10.289	−10.097	−10.192	−10.063	−10.149	−10.125	−10.135
Quantity of the composite input for manufactured products	X_3^m	−0.812	−0.338	−0.968	−0.782	−0.874	−0.749	−0.832	−0.809	−0.819
Quantity of the composite input for fluid products	X_3^f	0.538	0.324	0.609	0.524	0.566	0.510	0.547	0.537	0.541
Quantity of the composite input supply	X_3	−0.407	−0.140	−0.495	−0.390	−0.442	−0.372	−0.419	−0.405	−0.411

Notes: Table 3 summarizes model parameters used in the simulations under the California MMO.

Table S3. Response of Simulated Effects to Model Parameters: Elasticities of Substitution (continued)

Prices and Quantities	**Notation**	California MMO	$\tilde{\eta}^m_{31} = -0.04$	$\tilde{\eta}^m_{31} = 0.40$	$\tilde{\eta}^m_{32} = -0.01$	$\tilde{\eta}^m_{32} = 0.03$	$\tilde{\eta}^f_{31} = -0.04$	$\tilde{\eta}^f_{31} = 0.40$	$\tilde{\eta}^f_{32} = -0.01$	$\tilde{\eta}^f_{32} = 0.03$
Price of milk for manufactured products	W_1^m	−0.866	−0.905	−0.865	−0.724	−0.913	−0.876	−0.866	−0.806	−0.886
Price of milk for fluid products	W_1^f	−0.734	−0.766	−0.733	−0.613	−0.773	−0.742	−0.733	−0.683	−0.751
Supply price of milk	W_1	−0.853	−0.892	−0.852	−0.711	−0.900	−0.863	−0.853	−0.793	−0.873
Price of manufactured products	P^m	0.207	0.213	0.207	0.185	0.214	0.208	0.207	0.198	0.210
Price of fluid products	P^f	−0.250	−0.213	−0.251	−0.388	−0.205	−0.240	−0.250	−0.309	−0.230
Price of the composite input	W_3	−0.407	−0.311	−0.410	−0.763	−0.290	−0.382	−0.408	−0.558	−0.357
Quantity of milk for manufactured products	X_1^m	−0.591	−0.614	−0.590	−0.508	−0.619	−0.597	−0.591	−0.556	−0.603
Quantity of milk for fluid products	X_1^f	0.695	0.699	0.695	0.682	0.699	0.696	0.695	0.689	0.697
Quantity of milk supply	X_1	−0.427	−0.446	−0.426	−0.355	−0.450	−0.432	−0.426	−0.396	−0.437
Quantity of manufactured products	Q^m	−1.245	−1.279	−1.244	−1.119	−1.287	−1.254	−1.245	−1.192	−1.263
Quantity of fluid products	Q^f	0.054	0.047	0.054	0.081	0.045	0.052	0.054	0.066	0.050
Quantity of energy for manufactured products	X_2^m	−10.459	−10.491	−10.458	−10.340	−10.498	−10.468	−10.459	−10.409	−10.476
Quantity of energy for fluid products	X_2^f	−9.133	−9.138	−9.133	−9.118	−9.138	−9.134	−9.133	−9.127	−9.136
Quantity of energy supply	X_2	−10.128	−10.153	−10.127	−10.035	−10.158	−10.134	−10.127	−10.088	−10.141
Quantity of the composite input for manufactured products	X_3^m	−0.812	−0.649	−0.818	−1.412	−0.615	−0.834	−0.811	−0.674	−0.857
Quantity of the composite input for fluid products	X_3^f	0.538	0.480	0.540	0.753	0.467	0.674	0.532	−0.287	0.811
Quantity of the composite input supply	X_3	−0.407	−0.311	−0.410	−0.763	−0.290	−0.382	−0.408	−0.558	−0.357

Notes: Table 3 summarizes model parameters used in the simulations under the California MMO.