Effects of a Local Air Quality Regulation on Dairy Farms in the San Joaquin Valley

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Abstract California dairy farms have experienced hard times in the past few years. In addition to changes in market conditions in both input and output markets, the burden of environmental and other regulations has been mentioned as a culprit. This research examines the effects of a local air quality regulation on dairy farms in the San Joaquin Valley in California, in terms of both their production practices and costs of operation. Different from previous analysis of the effects of environmental regulations on agricultural production, I identify the realized operational changes associated with abiding by the regulation. Estimated adoption rates of different pollution-mitigation practices reveal that the air quality regulation led to the adoption of labor-intensive production practices. Further, using farm-level cost data on a panel of dairy farms, I estimate the effects of the regulation on the costs of milk production. Estimation results indicate that the air quality regulation has not affected the total costs of milk production. The regulation reduced feed costs during some periods, perhaps because some pollution-mitigation practices can reduce feed fermentation. The regulation led to statistically significant increases in the costs of hired labor: for example, in 2011, the regulation increased hired labor costs by $0.19 per hundredweight of milk, which is equivalent to a 14% increase in hired labor costs for dairy farms facing the regulation.

Effects of a Local Air Quality Regulation on Dairy Farms in the San Joaquin Valley

The San Joaquin Valley in California is one of only two areas in the country that are designated by the Environmental Protection Agency (EPA) as "extreme" for 8-hour ozone nonattainment of the National Ambient Air Quality Standards (Environmental Protection Agency, 2012a). The San Joaquin Valley is also in nonattainment for fine particulate matter, "PM2.5" (Environmental Protection Agency, 2012b).[1] Geographic factors—topography and wind patterns—and vehicular emissions are among the many causes of the severe air quality problems in the San Joaquin Valley. Agricultural pollution, especially emissions from large dairy operations, also plays an important role (EPA, 2010). In 2011, the San Joaquin Valley accommodated over 1,200 dairies, each of which on average had more than 1,200 cows. In total, dairy farms in the San Joaquin Valley produced 35,799 million pounds of milk, about 88% of the state's total milk production (CDFA, 2011a). Cash receipts from milk and cream were about 6.7 billion in 2011, accounting for 22% of the gross value of agricultural production of the San Joaquin Valley (CDFA, 2012).

The San Joaquin Valley Air Pollution Control District (SJVAPCD, or "San Joaquin Valley Air District", henceforth) has adopted several State Implementation Plans for ozone and PM2.5.[2] Rule 4570 was adopted in June 2006, as an important part of the District's 2004 Ozone Implementation Plan, to reduce emissions of Volatile Organic Compounds (VOCs) from large confined animal facilities (CAFs).[3] VOCs contribute to ground-level ozone formation through complex reactions with nitrogen oxides (Blanchard, 2000). An amended version of Rule 4570 (Phase II) was passed in October 2010, requiring medium-sized dairy CAFs—dairy farms with more than 500 but less than 1,000 milking cows—to start complying with the Rule along with large dairy CAFs.[4] San Joaquin

[1] PM2.5 refers to particles with diameter 2.5 micrometers and smaller (Environmental Protection Agency, 2012b).

[2] States and local air quality management agencies prepare State Implementation Plans and submit them to EPA for approval to meet specific requirements of the Clean Air Act, including the requirement to attain and maintain the National Ambient Air Quality Standards (EPA, 2013). The San Joaquin Valley Air District adopted the following State Implementation Plans for ozone and PM2.5: 2004 1-hour Ozone, 2007 8-hour Ozone, 2008 PM2.5, and 2012 PM2.5 (ARB, 2013).

[3] Large CAFs are defined as operations with the minimum number of 1,000 milking cows, 3,500 beef cattle, 650,000 chickens, 100,000 turkeys, or 3,000 swine. California does not have large CAFs of other animal types, such as ducks or sheep.

[4] Operations below the threshold of 500 milking cows are exempt from the Rule, but are required to keep quarterly record of animal inventories.

Valley Air District estimated that Rule 4570 would lead to a compliance cost of $18,324,074 per year for dairy CAFs in aggregate, about 9.6% of their net profit in 2006 (SJVAPCD, 2009). For Phase II, the estimated compliance cost increased to $61,312,210 per year for dairy CAFs because of the change in the regulatory threshold and the more stringent pollution-mitigation practices (SJVAPCD, 2010).

This paper examines the effects of Rule 4570 on medium and large dairy CAFs in the San Joaquin Valley, in terms of both their production practices and costs of operation. California dairy farms have experienced hard times in the past few years. In addition to changes in market conditions in both input and output markets, the burden of environmental and other regulations has been mentioned as a culprit (Ling, 2007). Given this economic context and potential impacts on future environmental legislation on agricultural production, it is important to analyze how previous environmental regulations have affected agricultural operations.

By examining the effects of Rule 4570 on dairy operations, this paper contributes to the economic literature on environmental regulation of agricultural production in several ways. First, using data on observed compliance choices, I identify the realized changes in operational practices associated with abiding by the regulation. Studies exist on the voluntary adoption of best management practices (Wu and Babcock, 1998; Wu et al., 2004; Valentin, Bernardo, and Kastens, 2004), but a majority of them focus on soil, nutrients, and pest management practices. Very few studies have examined livestock management (Gillespie, Kim, and Paudel, 2007). Moreover, decision-making under regulations is different from voluntary behavior. This paper estimates the adoption rates of different pollution-mitigation practices. Results reveal that Rule 4570 has led to the adoption of labor-intensive production practices. Capital-intensive mitigation technologies are not widely adopted and the physical structure of dairy operations are not affected by the Rule.

Second, this research provides the first farm-level econometric analysis of the effects of an environmental regulation on the economic performance of agricultural operations. Previous studies have used simulation models to examine the effects of environmental regulations on farm practices and the induced economic consequences (Johnson, Adams, and Perry, 1991; Key and Kaplan, 2007). Econometric studies have focused on the effects of regulations on the spatial structure of the livestock industry (Isik, 2004; Herath, Weersink, and Carpentier, 2005; Sneeringer and Hogle, 2008). Different from previous analysis, using farm-level cost data on a panel of dairy farms, I estimate the effects of the regulation on the costs of milk production by applying a difference-in-differences approach. Estimation results indicate that Rule 4570 has not affected the total costs of milk production. The regulation reduced feed costs during some periods, perhaps because some pollution-mitigation practices reduce feed fermentation. The Rule led to statistically significant increases in the costs of hired labor: for example, in 2011, the regulation increased hired labor costs by $0.19 per hundredweight of milk, which is equivalent to a 13% increase in hired labor costs for dairy farms facing the regulation.

The rest of the paper is organized as follows. Section 1 provides a detailed description of Rule 4570, with a focus on the mitigation measures related to dairy CAFs. In section 2, I calculate the adoption rates of different VOC measures and discuss the effects of the Rule on the production practices of dairy farms. In section 3, I develop a economic model for understanding the effects of environmental regulation on the operation of dairy farms and derive the conditions under which the Rule would affect the costs of milk production. Section 4 describes the cost data obtained from the California Department of Food and Agriculture (CDFA) for econometric analysis. I introduce the identification strategy of the econometric analysis in section 5. Section 6 presents the estimation results, and Section 7 provides some robustness checks. Section 8 concludes the paper.

1 Regulatory Background

CAFs generate emissions of VOCs, ammonia, and methane. The compounds that have been identified as important components of VOC emissions from dairies are alcohols and volatile fatty acids (Zhang, 2010). In 2005, CAFs emitted 57.6 tons of VOCs per day, accounting for 14% of the total anthropogenic VOC emissions in the San Joaquin Valley. It was estimated that the contribution of VOC emissions from CAFs to ozone concentrations ranged from 1.6% to 2.8% of the total ground-level ozone concentration at San Joaquin Valley monitoring sites (SJVAPCD, 2009). Even though computer modelling by the San Joaquin Valley Air District indicated that reductions in nitrogen oxides are more important to ozone attainment of the San Joaquin Valley than reductions in VOCs, Rule 4570 was adopted on the basis that stationary sources of nitrogen oxides had already been well controlled, and reductions in VOCs are necessary to supplement the reductions in nitrogen oxides to reduce ozone concentration. The San Joaquin Valley Air District estimated that Rule

4570 would lead to a VOC reduction of 20.7 tons per day. For dairy CAFs, the reduction rate was estimated to be about 36%, i.e. from 36.9 tons of VOCs per day to 23.6 tons of VOCs per day (SJVAPCD, 2009).

It is challenging to implement regulations on CAFs. First, CAFs are highly heterogeneous. Numerous factors could affect the design of CAFs, such as animal type, regional climate conditions, and the preferences of the operators. It is impractical and uneconomic to impose the same regulatory standards on all CAFs. Second, most emissions of air pollutants from CAFs cannot be reasonably channelled through stacks or other openings. It is difficult to use end-of-pipe devices to scrub these emissions. Third, agricultural facilities tend to be expansive, with multiple pollution sources on one facility. Because of these characteristics of CAFs, Rule 4570 relies mainly on management practices, rather than control devices, to prevent emissions from CAFs.

Rule 4570 groups emission sources of CAFs into "operation areas."[5] Rather than capture emissions at the point of release, Rule 4570 prescribes management practices that minimize the formation of VOCs within each operation area. Some examples of the management practices that could lead to reductions in VOCs from CAFs are feed manipulation, frequent scraping of animal housing, and covering of silage piles. Menu-based regulations give farmers the flexibility to adopt the least-cost control measures. Even though some VOC control devices are included in the menu of mitigation options, such as anaerobic digesters and biofilters, Rule 4570 has not induced any adoption of these options (SJVAPCD, 2010). The Rule also provides CAFs the flexibility to develop their own mitigation measures, provided that they can demonstrate that such measures can achieve equal or greater reductions in VOCs compared with the options in the menu. Operators are likely to choose options from the menu because the menu does provide flexibility, and prior approval by the District, ARB and EPA would need to be granted for own-designed alternative mitigation practices.

Rule 4570 was adopted in June 2006.[6] Owners or operators of large CAFs were required to submit applications for permits to operate or construct dairies by December 15, 2006, and to comply with the Rule on and after 365 days from the permit issuance date.[7] All farms covered

[5]Operation areas defined in Rule 4570 for dairy facilities include feed, silage, milking parlor, freestall barn, corrals, solid manure/separated solids, liquid manure, and land application.

[6]The rule was set aside on May 21, 2009 in response to a court order resulting from a lawsuit brought against the District, and was readopted on June 19, 2009.

[7]The processing of a Rule 4570 application can be completed in under a month if all the information has been

by the Rule were thus expected to be in full compliance in early 2008. However, the Rule may have started to affect farms as soon as applications for permits were submitted, as it takes time to achieve full compliance. In 2009, the San Joaquin Valley had approximately 7,000 CAFs, 558 of which were subject to the control requirements of Rule 4570, including 478 dairy farms, 35 turkey farms, 32 chicken farms, 12 beef feedlots, and one swine farm (SJVAPCD, 2009).

An amended version of Rule 4570 was passed in October 2010, introducing Phase II of the Rule. The amendments affected mainly dairies.[8] The regulatory threshold changed from 1,000 milking cows to 500 milking cows, i.e., from "large" dairy CAFs to "medium" dairy CAFs. It was estimated that another 419 medium dairy CAFs would be subject to the Rule (SJVAPCD, 2009). Medium dairy CAFs were required to implement all of the mitigation measures listed for large dairy CAFs, except for the solid-manure handling measures, which were not applicable to medium dairy CAFs. Additional mitigation measures were introduced for Phase II of the Rule, primarily for silage. Recent studies have found silage to be a significant source of emissions (Alanis et al., 2010; Zhang, 2010). Moreover, some of the mitigation measures—feed and housing measures—became mandatory, and CAFs were required to perform some optional measures more frequently. Owners or operators of CAFs subject to Phase II of Rule 4570 were required to submit applications for permits to operate or construct dairies by April 21, 2011. Figure 1 presents a timeline of Rule 4570.

The San Joaquin Valley Air District provided detailed analyses of the compliance costs of both the original Rule 4570 and the amendments of it (SJVAPCD, 2009, 2010). In these analyses, staff of the District selected the mitigation practices that are most likely to be chosen (assumed to be least costly to implement) by producers and evaluated the costs of compliance associated with implementing these mitigation practices. Table 1 summarizes the number of mitigation measures prescribed and the number of mitigation measures required in Phase II of the Rule for each operation area at dairy CAFs under the Rule. Table 1 also provides descriptions of the measures that were analyzed in either the 2006 or the 2010 analysis of the compliance costs of the Rule, and the estimates of the costs of adopting these measures. The 2010 analysis provided estimates of the costs of compliance for a greater number of mitigation practices and some of the estimates are quite different from the earlier estimates. This is mainly because more information was available,

included in the application (Gill, 2013). CDFA (2007) reports that all dairy CAFs covered by the Rule began to be in full compliance by April 2008.

[8] Some poultry facilities were also affected.

from CAFs and scientific studies. The last column of Table 1 is the estimated adoption rate of each mitigation measure by 2010 as reported in the 2010 analysis of the compliance costs of the amendments of the Rule. The adoption rates were estimated using the permit database of the San Joaquin Valley Air District.

For most mitigation measures, the costs estimated by the District include only labor costs and fuel or electricity costs. Annualized capital costs are included in the estimated costs of four measures—store grain in a weather proof structure, cover silage piles, install shade structures for corrals with light-permeable roofing material, and use solid separators. Both analyses of the compliance costs also mentioned that feeding according to Natural Resource Council Guidelines may cause the costs of feed to change. Rule 4570 may also lead to additional record keeping and maintenance costs. CAFs covered by the Rule are required to keep detailed records for up to five years of all the mitigation measures adopted.

2 Effects of Rule 4570 on Farm Practices

One of the challenges faced by *ex post* analysis of the effect of environmental regulations on agricultural production stems from the difficulty in identifying the realized operational changes associated with abiding by the regulations. Most prescribed activities by environmental regulations for agriculture are "best management practices" rather than use of pollution-control devices such as scrubbers or filters. Because these practices are often similar to practices that have been in use on some operations, it is difficult to ascribe costs to the regulation (Sneeringer and Key, 2011). This section provides empirical evidence on the adoption of different VOC mitigation practices by dairy CAFs facing Rule 4570.

Information on the production practices of dairies in the San Joaquin Valley before the introduction of Rule 4570 is sparse and can only be gleaned from publications of survey results by dairy scientists, such as Meyer, Garnett, and Guthrie (1997) and Meyer et al. (2011). This limited information about prior practices makes it impossible to estimate the effect of the original Rule 4570 on production practices. Dairies subject to Rule 4570 were required to submit applications for permits. In these applications, dairies identified the mitigation measures that they would use to comply with the Rule. The San Joaquin Valley Air District has since maintained a database of the permits, information from which was used to estimate the adoption rates of VOC mitigation measures in the analysis of the compliance costs of the amendments of Rule 4570 in 2010. Some of the estimated adoption rates are shown in Table 1. I obtained information from the District's permit database to estimate the adoption rates of VOC mitigation measures as of 2013.

The permit database consists of 972 records of 933 dairies that are subject to Rule 4570.[9] The database also includes herd information for a subset of dairies. Table 2 summarizes the aggregate adoption rates of some mitigation measures among dairies in the database, and the adoption rates of these mitigation measures for large and medium dairy CAFs, respectively.

Comparing the adoption rates by 2013 in Table 2 and by 2010 in Table 1, one notices that Phase II of Rule 4570 has significantly changed the production practices of dairy farms. The adoption rates of mandatory mitigation measures are close to 100%. For example, even though by 2010 only 24% of the dairies flushed, scraped, or vacuumed freestall flush lanes at least three times a day, 99% of the dairies had adopted this practice by 2013. Moreover, given that the number of required mitigation measures for each operation area is greater than the number of mandatory measures, Phase II of Rule 4570 significantly increased the adoption rates of some of the optional measures. For example, the adoption rate of "Remove uneaten wet feed from bunks within 24 hours after a rain event" increased from 13% to 45%, the adoption rate of "Cover the surface of silage piles" increased from 41% to 93%, and the adoption rate of "Remove manure not dry from individual cow freestall beds" increased from 27% to 97%.

Comparing the adoption rates of different optional mitigation measures in Table 2 further reveals the compliance decisions of dairies under Rule 4570. First, Phase II of Rule 4570 led to increased adoption of labor-intensive VOC mitigation measures. Most of these mitigation measures are about cleaning up feed residue or manure to reduce fermentation, such as "Remove uneaten wet feed from bunks within 24 hours after a rain event" and "Remove manure that is not dry from individual cow freestall beds." Second, capital-intensive mitigation technologies are not widely adopted. For example, the adoption rate of solid separators increased from 38% to 86%, and solid separators are less capital intensive than the other mitigation measures for the "liquid manure" operation area—phototropic lagoons and anaerobic treatment lagoons. The adoption rates of phototropic lagoons and anaerobic treatment lagoons are 0.6% and 1.8%, respectively. Third, dairies tend to

[9] 36 dairies updated their VOC mitigation practices, and 3 dairies updated twice.

adopt mitigation practices that do not change the physical structure of the operation area. For example, few dairies decided to comply by using non-manure based bedding material for freestalls or absorbent materials such as lime in corrals. Fourth, medium and large dairy CAFs have made similar decisions to comply with the Rule. The rates of adoption for most of the VOC mitigation measures in Table 2 are comparable between the two groups of dairy farms.

3 Environmental Regulation and the Operation of Dairy Farms

Air pollution from dairy farms is very different in nature from stereotypical industrial pollution. First, a dairy operation involves multiple production activities, such as silage piling, feeding, milking, and manure collecting, and pollutants can be released from more than one activity. Second, pollutants from dairies are not generated by using a particular input. For example, both VOCs and greenhouse gases are groups of pollutants. Some of the VOCs emitted by dairies are from feed and silage fermentation and others are from manure, and greenhouse gases are mainly from enteric fermentation and digestion of manure.

Given the nature of air pollution from dairy operations, environmental regulations, such as Rule 4570, are often based on best management practices of production activities. In this section, I provide a simple model for understanding the economic trade-offs faced by dairy farms between production of milk and mitigation of pollution. The framework can be used to analyze management-practice based environmental regulations of emissions from dairy operations, such as VOCs, greenhouse gases, and other pollutants.

Milk production can be analyzed using a cost-minimizing framework where the operator of a dairy farm chooses the quantities of labor input for different production activities given quantities of output and fixed inputs, such as capital and dairy cows. Other variable inputs are assumed to be used in fixed proportions with labor. The number of production activities employed by a dairy farm may differ because of production characteristics: dairies that do not feed silage do not manage silage piles to produce milk. For illustrative purposes, I divide the production activities of a dairy into two groups: pollution-mitigation activities, such as feeding according to Natural Resource Council Guidelines or flushing milking parlor, and other activities. I use x_1 to denote the quantity of labor used for pollution-mitigation activities and x_2 to denote the quantity of labor used for other production activities. The operator of the dairy chooses x_1 and x_2 to minimize the cost of production. Formally, the operator's problem is to

$$
\begin{aligned}
\min_{x_1,x_2} \quad & w(x_1+x_2) \\
\text{s.t.} \quad & f(x_1,x_2;K) \geq Q,
\end{aligned} \tag{1}
$$

where w denotes wage rate, K denotes the fixed factors in production, f is the milk production function, and Q is the quantity of milk produced. The optimal solution $\{x_1^*, x_2^*\}$ is achieved when the marginal products of labor are equalized across the two production activities, i.e. $\frac{\partial f(x_1^*,x_2^*)}{\partial x_1} = \frac{\partial f(x_1^*,x_2^*)}{\partial x_2}$.

Management-practice based environmental regulations, such as Rule 4570, require farms to perform certain production activities more frequently, and most of these activities, as analyzed in the previous section, are labor intensive. This type of regulation can thus be modelled as a constraint on labor input for pollution-mitigation activities.[10] The cost-minimization problem of the dairy can now be specified as

$$
\begin{aligned}
\min_{x_1,x_2} \quad & w(x_1+x_2) \\
\text{s.t.} \quad & f(x_1,x_2;K) \geq Q, \quad : \lambda_1 \\
& x_1 \geq L. \quad : \lambda_2
\end{aligned} \tag{2}
$$

[10] Instead, the regulation can be modeled as a constraint on emissions from the dairy. Given an emission abatement function $g(x_1)$, baseline emissions G^0, and the constraint on emissions G, the optimization problem can be specified as follows:

$$
\begin{aligned}
\min_{x_1,x_2} \quad & w(x_1+x_2) \\
\text{s.t.} \quad & f(x_1,x_2;K) \geq Q, \\
& g(x_1) \geq G^0 - G.
\end{aligned}
$$

Even though regulators may have a goal of emission reduction in mind when designing pollution-mitigation practices, given that agricultural emissions are difficult to measure, environmental regulations on agricultural pollution are seldom specified in this fashion.

The first-order conditions for an optimal solution are

$$w - \lambda_1 \frac{\partial f}{\partial x_1} - \lambda_2 = 0,$$
$$w - \lambda_1 \frac{\partial f}{\partial x_2} = 0,$$
$$\lambda_1 (f(x_1, x_2; K) - Q) = 0,$$
$$\lambda_2 (x_1 - L) = 0.$$

λ_1 and λ_2 are Lagrange multipliers for the minimum constraints on output and labor use in pollution-mitigation activities. To distinguish the solution of this regulatory-constrained optimization problem from $\{x_1^*, x_2^*\}$, I use the upper-bar notation. The optimal solution $\{\bar{x}_1, \bar{x}_2\}$ is achieved when $\bar{\lambda}_1 \frac{\partial f(\bar{x}_1, \bar{x}_2)}{\partial x_1} + \bar{\lambda}_2 = \bar{\lambda}_1 \frac{\partial f(\bar{x}_1, \bar{x}_2)}{\partial x_2}$. That is, the shadow values of labor are equalized across the two production activities.

The minimum cost of production is $\bar{C} = w(\bar{x}_1 + \bar{x}_2)$. Of particular importance is how the minimum cost function responds to changes in the regulation, $\frac{\partial \bar{C}}{\partial L}$. Using the envelope theorem, $\frac{\partial \bar{C}}{\partial L} = \bar{\lambda}_2$, and from the first-order conditions,

$$(3) \quad \bar{\lambda}_2 = w\left(1 - \frac{\partial f(\bar{x}_1, \bar{x}_2)/\partial x_1}{\partial f(\bar{x}_1, \bar{x}_2)/\partial x_2}\right) \geq 0.$$

The effects of the regulation on the minimum cost of production depend on the amount of labor input required by the regulation, L. If $0 \leq L \leq x_1^*$, i.e., labor input required by the regulation for pollution-mitigation activities is less than or equal to the optimal labor input engaged in the mitigation of pollution without the regulation, $\{x_1^*, x_2^*\}$ is still the optimal solution. Recall that at $\{x_1^*, x_2^*\}$, $\frac{\partial f(x_1^*, x_2^*)}{\partial x_1} = \frac{\partial f(x_1^*, x_2^*)}{\partial x_2}$ and hence from equation (3), $\bar{\lambda}_2 = 0$. The shadow cost of the constraint on labor input used for mitigation of pollution is zero in this case. If $L > x_1^*$, additional labor input is needed for pollution-mitigation activities so that the constraint on labor input is satisfied. This reallocation of labor input also affects milk production. In this case, there is a shadow cost of the constraint on labor use for mitigation of pollution, and the magnitude of the shadow cost depends on the "marginal rate of technical substitution" between labor used in the two production activities at $\{\bar{x}_1, \bar{x}_2\}$, $\frac{\partial f(\bar{x}_1, \bar{x}_2)/\partial x_1}{\partial f(\bar{x}_1, \bar{x}_2)/\partial x_2}$, and the wage rate, w. A special case is when $\partial f(\bar{x}_1, \bar{x}_2)/\partial x_1 = 0$, i.e., at $\{\bar{x}_1, \bar{x}_2\}$ adjustment of labor input for pollution-mitigation activities does not affect milk production, the shadow cost of the constraint on labor use for mitigation of pollution equals the wage rate.

Analysis of the costs of regulatory compliance often does not account for the effects of the regulation on production or input substitution, and therefore overestimates the costs of compliance. In the rest of the paper, I use observational data to estimate the effects of Rule 4570 on the costs of milk production.

4 Discussion of Data

I use farm-level cost data on an unbalanced panel of dairy farms from the CDFA for econometric analysis of the effects of Rule 4570 on the costs of milk production. The Cost of Production Unit of the Dairy Marketing Branch at the CDFA has been conducting financial reviews of individual dairy farms since 1955. Auditors collect and calculate costs of milk production from the financial records of Grade A dairy farms throughout California. Information collected is used by the California milk marketing order, and is used by participating dairy farms to compare their operational expenses with one another.[11]

About 10% of California dairy farms are surveyed in each quarter by the Cost of Production Unit of the CDFA. Dairy farms in California are located in diverse regions. The sample of farms is constructed based on four unique areas of the state—North Coast, North Valley, South Valley, and Southern California—to be representative of dairy farms in the State. Table 3 summarizes characteristics of dairy production in each region in years 2001 and 2011. Dairies in the North Coast averaged 341 cows in 2011. Most organic dairy producers in the state are located in the North Coast, where they can take advantage of available pasture. The North Valley is the most diverse in terms of herd size, herd type, and weather. In 2011, the herd size of the North Valley averaged 881 cows. The South Valley covers four counties—Fresno, Tulare, Kings, and Kern—and is the largest area in terms of milk production, producing 54.2% of the state's total milk production in 2011 (CDFA, 2012). The climate in this area provides many farmers the opportunity to crop the land for corn silage. The average herd size in the South Valley was 1,607 cows in 2011. Finally, the average herd size in Southern California was 1,049 cows in 2011 (CDFA, 2011a). The majority

[11]The CDFA has the legal authority to collect data on cost of milk production from farms in the California milk marketing order. Dairy producers who find the survey results useful may volunteer to participate (CDFA, 2007).

of the dairies located in Southern California rely on feed ingredients from outside the area.

Quarterly data on production costs were obtained for the years 2006 to 2012.[12] This dataset includes only the costs of activities related to milk and dry cows, but not to calves or heifers, or other farming activities. The total costs of production are reported by five groups: feed costs, costs of hired labor, costs of herd replacement, operating costs, and marketing costs. On average, hired labor accounted for more than 95% of the total costs of labor for dairies in California (CDFA, 2011a). The data on feed costs can be further partitioned into four subcategories: costs of dry roughage, costs of wet feed and wet roughage, costs of concentrates, minerals, and supplements, and pasture costs. On average, pasture accounted for only 1% of feed costs for dairies in California. Only one dairy farm in the sample under Rule 4570 used any pasture, and it was only a small amount. Data on operating costs can also be divided into subcategories, such as utilities, fuel and oil, outside services, repairs and maintenance, and so on. Based on the analyses conducted by the San Joaquin Valley Air District on the compliance costs of Rule 4570 and the estimates of the adoption rates of VOC mitigation measures in section 2, I expected Rule 4570 to affect feed costs, costs of hired labor, and operating costs, but not costs of herd replacement or marketing costs. I also investigate the effects of Rule 4570 on the subcategories of feed costs and operating costs. Appendix A provides definitions of all the variables used in this analysis.

In addition to cost information, the CDFA also collects data related to milk production. Milk production data include the total number of cows, the number of milking cows, the quantity of milk shipped, the quantity of milk fat shipped, and the quantity of solids-not-fat (SNF) shipped. Additionally, I have information on a few categorical variables, including the breed of the herd (Holstein, Jersey, or crossbred), the number of times cows are milked per day (two or three times), and whether the dairy is organic.

Table 4 provides some summary statistics. Panel A describes the sample of dairy farms used in this study. I have information on production costs for a total of 4,297 farm-quarters, including 20 farm-quarters on organic farms. I do not include the observations of organic farms in the analysis because of the operational differences between organic and conventional farms. The number of

[12] Most of the farm-level cost data collected by the CDFA are released under random identification number on the website: http://www.cdfa.ca.gov/dairy/cost_of_production_feedback.html. I obtained the unique identification number for each dairy from the CDFA to construct the panel of dairy farms for the analysis. Some other confidential information, such as herd size, was also obtained from the CDFA.

dairy farms surveyed decreased from 189 in 2006 to 139 in 2012.[13] Meanwhile, the average number of milking cows in the herd increased from 914 to 1,157, and milk yield, measured as the average quantity of milk sold per milk cow per month, increased from 19.7 hundredweight (cwt) to 20.7 cwt. SNF content increased slightly during the study period. Comparing Table 4 and Table 3, one can tell that the sample is representative of the general trends in dairy farming in California: the number of dairy farms has been decreasing, while herd size and the productivity of milking cows have been increasing.

Panel B of Table 4 summarizes the costs of production incurred by the dairy farms in the sample. All costs are reported in 2005 dollars for a cwt of milk.[14] The average total cost of production peaked in 2008 at $16.7 per cwt of milk. High feed and operating costs, which accounted for 58% and 17% of average total cost in 2008, drove this peak. Average feed costs peaked in 2012 at $10.6 per cwt of milk. Average costs of hired labor and marketing remained stable over the sample period.

Panel C of Table 4 reports summary statistics for the three subcategories of feed costs, and some of the subcategories of operating costs. The costs of all three subcategories of feed increased during the sample period. The average cost of dry roughage peaked in 2008 at $2.60 per cwt of milk, the average cost of wet feed and wet roughage increased from $1.22 per cwt of milk in 2006 to $2.05 per cwt of milk in 2012, and the average cost of concentrates, minerals, and supplements peaked in 2012 at $5.72 per cwt of milk. The subcategories of the operating costs accounted for very small shares of the total costs of production. The average cost of utilities remained stable at $0.33 per cwt of milk, the average cost of fuel and oil was relatively high in 2008, 2011, and 2012, and the average cost of maintenance and the average miscellaneous costs increased slightly in 2008.

Figures 2 to 6 plot the average costs of production and their elements. The data are grouped based on whether the farms are under Rule 4570. Quarterly data on costs are averaged across dairy farms within each group. Panel (a) compares large dairy CAFs in the San Joaquin Valley to farms that are not affected by Rule 4570, and panel (b) compares medium dairy CAFs in the San Joaquin Valley to farms that are not affected by the Rule. Recall that farms in the San Joaquin Valley with fewer than 500 milking cows and farms in other regions of the state are not affected by the Rule.

[13] About 10% of California dairy farms are surveyed in each quarter by the CDFA.

[14] I use the Quarterly Gross Domestic Product Implicit Price Deflator (Federal Reserve Bank of St. Louis, 2012) to deflate all the cost data.

The solid line plots the average costs of farms that are affected by the Rule.

During the sample period, the averages of the total costs for different groups follow each other closely. In Figure 2, the average total costs of large dairy CAFs were lower than that of the control farms in the sample, and the average total costs of medium dairy CAFs were also lower than that of the control farms, except in a few quarters. The pattern for the average costs of feed across different groups in Figure 3 is similar to that for total costs. As shown in Figure 4, the average cost of hired labor of large dairy CAFs under the Rule has been stable with some seasonal variation, while the average cost of hired labor of medium dairy CAFs under the Rule decreased slightly during the sample period. However, farms that were not affected by Rule 4570 experienced increases in the cost of hired labor during the second half of 2007, and in 2011 returned to about the same cost in 2006. In Figure 5, the average operating cost of large dairy CAFs in the San Joaquin Valley decreased slightly in the sample period and has been lower than that of the control farms since 2008, and the average operating cost of medium dairy CAFs in the San Joaquin Valley was stable, with seasonal variation. Similar to the average cost of hired labor, the average operating cost of farms not affected by Rule 4570 peaked in 2008. As shown in Figure 6, large and medium dairy CAFs in the San Joaquin Valley had lower marketing costs per cwt of milk than the control farms, but the patterns for the average costs of milk marketing are very similar across different groups.

5 Empirical Strategy

The goal of this analysis is to estimate the effects of Rule 4570 on the costs of milk production for dairies in the San Joaquin Valley. The basic identification strategy is a difference-in-differences (DD) method. With the DD approach, the effects of Rule 4570 are identified by comparing changes in the costs of dairies under the Rule after it took effect, with the corresponding contemporaneous changes in the costs of dairies not covered by the Rule. Two potential comparison groups exist in the dataset given the nature of the regulation. Dairies outside the San Joaquin Valley Air District are not subject to Rule 4570, and dairies within the District below the threshold of Rule 4570 are not subject to the Rule either.

The basic DD model is specified in equation (4), where y_{it} denotes the cost of milk production for dairy i in quarter t. D_{it}^{a} indicates the original Rule 4570, which equals one for dairies in the San Joaquin Valley with more than 1,000 milking cows after the first quarter of 2007 and through the second quarter of 2011, and D_{it}^{b} indicates Phase II of Rule 4570, which equals one for dairies in the San Joaquin Valley with more than 500 milking cows after the second quarter of 2011. δ^{a} and δ^{b} are the parameters of primary interest. This model also includes a set of dairy fixed effects, denoted by α_i, which control for individual unobservables that cause some dairies on average to have lower costs. These fixed effects prevent the estimated effects of the Rule from being biased downward by the fact that dairies affected by the Rule (large dairies in the San Joaquin Valley) have lower costs of production both before and after the introduction of the Rule, than do control dairies. Also included in the model is a full set of region-specific time fixed effects, λ_{rt}, controlling for unobserved quarterly shocks that are common within each production region to both dairy farms that are subject to the regulation and those that are not. Recall that the dataset encompasses four production regions: North Coast, North Valley, South Valley, and Southern California. ε_{it} is an unobserved disturbance term.

$$(4) \quad y_{it} = \delta^{a} D_{it}^{a} + \delta^{b} D_{it}^{b} + \alpha_i + \lambda_{rt} + \varepsilon_{it} \qquad i = 1, ..., N; \qquad t = 1, .., T.$$

One of the assumptions required for consistent estimation of δ^{a} and δ^{b} is that farm-specific unobserved factors affecting production costs are constant over time. This assumption may not hold, for example, if the production costs of dairy farms under the Rule have an underlying trend that differs from the trend of control farms. To separate long-run trends driven by unobservables that may confound the effects of the Rule, I augment the basic DD model with region-regulation-specific time trends. In equation (5), S_{rt} denotes a linear time trend that is specific to production region r. Moreover, since some of the dairy farms in the North Valley or the South Valley are under Rule 4570 and others are not, farms under Rule 4570 are allowed to have a time trend that is different from that for farms in the same region that are not under the Rule. To improve the precision of the estimates, I also augment equation (4) with farm-specific explanatory variables. Vector X_{it} includes the number of milking cows and dry cows in the herd, milk yield measured by the quantity of milk shipped per milk cow per month, and the fat and SNF tests of the milk.

$$(5) \quad y_{it} = \delta^a D_{it}^a + \delta^b D_{it}^b + \alpha_i + \lambda_{rt} + S_{rt}\theta + X_{it}\beta + \varepsilon_{it} \qquad i = 1, ..., N; \qquad t = 1, .., T,$$

One challenge in estimating the effects of Rule 4570 on dairy farms is that farms started to comply with Rule 4570 at different points of time. Moreover, the effects of the Rule are likely to change over time as farmers become familiar with the VOC mitigation practices adopted. In another specification, equation (6) I include a set of regulatory dummies D_{it}^s with $s \in \{1, 2, ...6\}$ indicating years 2007–2012. That is, I let $D_{it}^s = 1$ if dairy farm i in quarter t of year s is under Rule 4570.

$$(6) \quad y_{it} = \sum_s \delta^s D_{it}^s + \alpha_i + \lambda_t + S_{rt}\theta + X_{it}\beta + \varepsilon_{it} \qquad i = 1, ..., N; \qquad t = 1, .., T,$$

6 Results

Table 5 reports the estimates of the effects of Rule 4570 and its amendments on the costs of milk production from the basic DD model in equation (4). Standard errors are included in parentheses. All the standard errors reported in this analysis are estimated using a robust variance estimator that is clustered by farm. The first column of Table 5 report the estimates of the effects of Rule 4570 on the total costs of milk production. The original Rule is estimated to have reduced the total costs of milk production and Phase II is estimated to have increased the total costs of milk production. Neither of the estimates is statistically significant. As mentioned in the previous section, the estimates obtained using the basic DD specification can be inconsistent if farm-specific unobservables change over time.

Table 6 reports the estimates from the augmented model in equation (5). The top two rows of the Table report the estimated effects of Rule 4570. Neither the original Rule nor Phase II is estimated to have significantly affected the total costs of milk production. Similar to the estimates obtained from the basic DD specification, the original Rule is estimated to have reduced the costs of milk production by \$0.20 per cwt of milk and Phase II is estimated to have increased the costs of milk production by \$0.13 per cwt of milk. The average of the total costs of milk production was \$14.7 per cwt of milk in 2011 for dairy CAFs regulated by Rule 4570, so the estimated effect of the

Rule is about 1% of the total costs.

Columns 2 to 5 of Table 6 report the estimated effects of Rule 4570 on different categories of the costs of milk production, including feed, hired labor, operating, and milk marketing. The estimates have the same signs for each category between the original Rule and Phase II. The estimated effects of the original Rule on the different categories of the costs of milk production are small in magnitude and statistically insignificant. Phase II of Rule 4570 is estimated to have reduced feed costs, but the estimate is statistically insignificant. Phase II is also estimated to have had a positive effect on the costs of hired labor: the implementation of the amendments of Rule 4570 can be associated with a $0.19 per cwt of milk increase in hired labor costs, and the estimate is statistically significant at the 1 percent level. The average cost of hired labor was $1.37 per cwt of milk in 2011, so the effect of Phase II is equivalent to a 14% increase in hired labor costs for dairy CAFs regulated by Rule 4570.

Table 7 reports the estimates of the effects of Rule 4570 from the specification of the model in equation (6), where the effects of the Rule are allowed to vary across years. The implementation of Rule 4570 can be associated with some reductions in feed costs in 2007, 2008, 2011 and 2012: Rule 4570 significantly reduced feed costs in 2008 by $0.42 per cwt of milk, which is equivalent to a 4% reduction in feed costs. One hypothesis for the finding that Rule 4570 may have negatively affected feed costs is that the VOC mitigation measures prescribed by Rule 4570 to reduce feed fermentation reduced feed consumption and hence costs, especially during the time when feed was generally more expensive. The implementation of Phase II of Rule 4570 can be associated with significant increases in hired labor costs. The estimates imply that Rule 4570 increased the costs of hired labor by $0.19 and $0.29 per cwt of milk in 2011 and 2012 respectively, and the estimates are statistically significant at the 1 percent level.

To further investigate the effects of Rule 4570 on the management practices of dairy farms, I estimate equation (5) using subcategories of feed costs and operating costs as the dependent variables. Table 8 reports the corresponding estimates for feed costs. The estimation results indicate that Rule 4570 can be associated with some decreases in the costs of concentrates, minerals, and supplements, but the estimated effect is about 1% of feed costs. The breakdown results of the effects of Rule 4570 on operating costs are shown in Table 9. Rule 4570 has not affected operating costs: most of the estimates are small in magnitude and statistically insignificant.

7 Robustness Checks

To interpret the estimates as causal effects of Rule 4570 on the costs of milk production of dairy CAFs, the critical assumption is the conditional unconfoundedness, which requires that conditional on observed covariates, the distribution of the costs of milk production is the same for control dairies and dairies subject to Rule 4570. That is, the costs of milk production at control dairies are assumed to be representative of the costs that would have been observed at similar dairies that are subject to Rule 4570, had the Rule not been introduced. Potential violations of this assumption can arise with the above DD analysis. If there is only limited overlap in the distributions of observed covariates across the treatment and control groups, the counterfactual outcomes will be incorrectly imputed and estimates of the effects of Rule 4570 will be biased. In the interest of mitigating these potential biases, I conduct a few robustness checks.

I estimate the effects of Rule 4570 on only medium dairy CAFs, using as a control group either medium dairies outside the San Joaquin Valley or small dairies in the San Joaquin Valley. The point of this exercise is that the two different control groups are likely to have different biases. The cost trajectories of medium dairies outside the San Joaquin Valley may differ from the counterfactual trajectories of medium dairy CAFs in the San Joaquin Valley because they are operating in different regions and have different operational characteristics. The cost trajectories of small dairies in the San Joaquin Valley can also differ from the counterfactual trajectories of medium dairy CAFs regulated by Rule 4570 because of different scale effects.

The estimation results are similar to those reported in Table 6 using the entire sample. Estimation results of equation (5) with medium dairies outside the San Joaquin Valley as a control group for medium dairy CAFs regulated by Rule 4570 are shown in Table 10. The effect of Phase II on the total costs of milk production for medium dairy CAFs in the San Joaquin Valley is small and statistically insignificant. Phase II of the Rule is estimated to increase the costs of hired labor for medium dairy CAFs in the San Joaquin Valley by \$0.13 per cwt of milk and the estimate is statistically significant at the 1 percent level. Estimation results of equation (5) using small dairies in the San Joaquin Valley as a control group are shown in Table 11. The estimates are similar to those in Table 10. Phase II of the Rule is estimated to have increased the costs of hired labor for medium dairy CAFs in the San Joaquin Valley by \$0.21 per cwt of milk and the estimate is statistically significant at the 1 percent level.

The results shown to this point were estimated using an unbalanced panel of dairy farms. Nonrandom selection into and out of the sample could introduce selection bias. Even though the sample is constructed by the CDFA to be representative of California milk production, dairy farms can volunteer to participate in cost audits. One might be concerned that dairies with high milk production costs would have more incentives to participate in cost audits, so that they can compare costs with other dairy farms to seek ways of reducing costs of production. This would result in inflated estimates of the effects of Rule 4570. For a robustness check, I report estimation results of the effects of Rule 4570 using a balanced panel of dairy farms.

Table 12 reports the estimated effects of Rule 4570 on the total costs and different categories of costs of milk production from the model in equation (5). Cost data for 83 dairy farms from 2006 to 2012 were used in the estimation. Comparing estimates reported in Tables 6 and 12, the negative effects of Rule 4570 on feed costs become statistically significant. Phase II can be associated with an average reduction in feed costs of \$0.56 per cwt of milk, and the estimate is statistically significant at the 1 percent level. The estimated effect of Phase II on the costs of hired labor is very close to the estimate in Table 6: Phase II of Rule 4570 increased hired labor costs for dairy CAFs in the San Joaquin Valley by \$0.20 per cwt of milk.

8 Conclusion

This paper examines the effects of Rule 4570—a local air quality regulation—on large and medium dairy farms in the San Joaquin Valley in terms of their management practices and costs of production. Estimates of the adoption rates of VOC mitigation measures indicate that the Rule has led to adoptions of certain labor-intensive production practices by dairy farms. On the contrary, capital-intensive mitigation technologies are not widely adopted, and few dairies decided to comply by changing the physical structure of their operations.

Using farm-level data, I estimate the effects of Rule 4570 on the costs of milk production. Estimation results indicate that neither the original Rule nor Phase II of it has significantly affected the costs of milk production. The Rule reduced feed costs during some periods, perhaps because some VOC mitigation practices can reduce feed fermentation. Phase II of Rule 4570 led to statistically significant increases in the costs of hired labor: for example, in 2011, Phase II increased hired labor costs by \$0.19 per hundredweight of milk, which is equivalent to a 14% increase in hired labor costs for dairy farms facing the Rule.

Analysis of the costs of regulatory compliance often does not account for the effects of the regulation on production or input substitution, and therefore overestimates the costs of compliance. Estimates provided by the San Joaquin Valley Air District indicate that the Rule would lead to a compliance cost at about 9.6% of the net profit for dairy CAFs in 2006. Estimates obtained in this paper using observational data indicate that Phase II of the Rule may have increased the costs of dairy operations, but the effects are about 1% of the milk production cost, significantly lower than the engineering estimates provided by the San Joaquin Valley Air District.

Table 1: Summary of Mitigation Measures for Dairy CAFs in Rule 4570

Numbers of Measures		Descriptions of Measures	Estimated Costs		Adoption rate
# Listed	# Required		***2006 Analysis*** ($/cow/year)	***2010 Analysis*** ($/cow/year)	***2010 Analysis*** ***(%)***
7	5	***Feed***			
		a)* Feed according to Natural Resource Council Guidelines	NS	12	14
		b)* Store grain in a weather-proof structure	NS	40.21[a]	50
		c) Remove uneaten wet feed from bunks within 24 hours after a rain event	5.3	0.38	13
2	1	***Silage***			
		a) Cover the surface of silage piles	10	3.65[a]	41
1	1	***Milking Parlor***			
		a)* Flush or hose milking parlor immediately prior to, after, or during each milking	NS	NS	100
5	3	***Freestall barn***			
		a) Remove manure that is not dry from individual cow freestall beds at least once every seven days for large CAFs and once every fourteen days for medium CAFs	5.3	1.78	27
		b)* Flush, scrape, or vacuum freestall flush lanes immediately prior to, after, or during each milking or at least three times a day	NA	0.18	24
9	7	***Corral***			
		a)* Clean manure from corrals at least four times per year	42.4	5.16	6
		b)* Scrape, vacuum, or flush concrete lanes in corrals at least once every day for mature cows	NA	0.1	60
		c)* Inspect water pipes and troughs and repair leaks	NA	0.18	64
		e) Install shade structures with light-permeable roofing material	NA	10.55[a]	39
		f) Manage corrals such that the depth of manure does not exceed 12 inches	NA	0.51	NA
2	1	***Solid Manure Handling***			
		a) Cover dry manure pile within 72 hours of removal from housing	3.65	NS	100
4	1	***Liquid Manure Handling***			
		b) Remove solids from the waste with a solid separator	NS	17.22[a]	38
4	1	***Land Application***			
		a) Land-incorporate manure within 72 hours	NS	NS	100

Notes: Dairy CAFs can design their own mitigation measures for all source categories. Mitigation measures with a "*" are mandatory in Phase II of Rule 4570. "NS" indicates that the mitigation measure was estimated to be already employed by most affected dairy CAFs, and "NA" indicates no estimates were provided. [a] The estimated costs include annualized capital costs.

Table 2: Adoption Rates of VOC Mitigation Measures by 2013

	Adoption Rate (%)		
	Large CAFs	Medium CAFs	Total
Feed			
1) Feed steam-flaked, dry rolled, cracked or ground corn or other cereal grains	52.4	64.9	58.5
2) Remove uneaten wet feed from bunks within 24 hours after a rain event	48.4	40.1	44.7
3) For total mixed rations that contain at least 30% by weight of silage, feed animals total mixed rations that contain at least 45% of moisture	1.6	4.6	3.7
Silage			
4) Cover the surface of silage piles	90.6	93.4	92.8
Milking Parlor			
5)* Flush or hose milking parlor immediately prior to, after, or during each milking	100.0	99.7	99.2
Freestall Barn			
6)* Flush, scrape, or vacuum freestall flush lanes immediately prior to, after, or during each milking or at least three times a day	98.1	98.7	98.5
7) Use non-manured-based and non-separated solids based bedding for at least 90% of the bedding material for freestalls	0.9	3.1	2.9
8) Remove manure that is not dry from individual cow freestall beds at least once every seven days for large CAFs and once every fourteen days for medium CAFs	99.1	96.4	96.7
Corral			
9)* Scrape, vacuum, or flush concrete lanes in corrals at least once every day for mature	99.2	100.0	99.7
10) Install shade structures for corrals with light-permeable roofing material	0.8	1.3	2.4
11) Manage corrals such that the depth of manure does not exceed 12 inches	84.8	86	85.6
12) Use lime or a similar absorbent material in the corrals	0.0	1.0	0.9
Liquid Manure			
13) Remove solids from the waste with a solid separator	89.1	83.1	89.0
14) Use a phototropic lagoon	0.3	0.8	0.6
15) Use an anaerobic treatment lagoon	1.0	0.8	1.8
16) Allow liquid manure to stand in fields no more than 24 hours after irrigation	96.8	94.8	94.6
Number of Dairies	128	302	933

Notes: Mitigation measures with a "*" are mandatory in Phase II of Rule 4570.

Table 3: Characteristics of Dairy Production in Regions of California

Region	Number of Dairies	Number of Cows	Milk Production (cwt/year)	Average Herd Size	Milk Production per Dairy (cwt/year)	Milk Yield (cwt/cow/year)
2001						
North Coast	234	62,939	12,719,600	269	54,357	202
North Valley	1,022	658,174	118,838,200	644	116,280	181
South Valley	603	658,174	144,521,700	1,091	239,671	220
Southern California	295	266,672	56,617,600	904	191,924	212
Total/Average	2,154	1,645,959	332,697,100	764	154,455	202
2011						
North Coast	170	57,954	9,668,600	341	56,874	167
North Valley	765	674,108	153,129,600	881	200,169	227
South Valley	600	964,484	221,684,600	1,607	369,474	230
Southern California	133	139,566	29,795,800	1,049	224,029	213
Total/Average	1,668	1,836,112	414,278,600	1,101	248,368	226

Notes: Quantities of milk production and milk production per dairy are reported in hundredweight per year, and milk yield is in hundredweight per cow per year.

Table 4: Summary Statistics

A: Dairy Farms

Year	Number of Observations	Number of Farms	Number of Milk Cows	Number of Dry Cows	Milk Yield (cwt/milk cow/month)	Fat Test (%)	SNF Test (%)
2006	709	189	914	144	19.70	3.80	8.84
			(816)	(141)	(3.42)	(0.35)	(0.20)
2007	658	179	997	160	20.10	3.78	8.84
			(865)	(148)	(3.33)	(0.36)	(0.19)
2008	632	168	1,072	169	20.21	3.79	8.85
			(956)	(154)	(3.53)	(0.37)	(0.20)
2009	593	154	1,081	173	19.87	3.77	8.86
			(942)	(156)	(3.66)	(0.41)	(0.25)
2010	580	151	1,124	177	20.19	3.75	8.88
			(967)	(160)	(3.68)	(0.43)	(0.22)
2011	576	147	1,154	181	20.46	3.81	8.89
			(984)	(162)	(3.85)	(0.43)	(0.22)
2012	529	139	1,157	182	20.73	3.83	8.90
			(1041)	(176)	(3.89)	(0.44)	(0.24)
Total/Average	4277	161	1,064	168	20.16	3.79	8.87
			(938)	(156)	(3.62)	(0.40)	(0.22)

Table 4 Summary Statistics (Continued)

B: Costs of Production

	Annual Average Cost					Cost Share			
Year	Total	Feed	Hired Labor	Operating	Marketing	Feed	Hired Labor	Operating	Marketing
			($/cwt)					(%)	
2006	13.73	7.06	1.55	2.68	0.52	51.4	11.3	19.5	3.8
	(2.18)	(1.25)	(0.49)	(0.71)	(0.11)				
2007	14.52	7.83	1.53	2.69	0.51	53.9	10.5	18.5	3.5
	(2.46)	(1.63)	(0.48)	(0.69)	(0.11)				
2008	16.68	9.64	1.60	2.83	0.53	57.8	9.6	17.0	3.2
	(3.19)	(2.17)	(0.55)	(0.79)	(0.17)				
2009	15.12	8.52	1.61	2.74	0.50	56.3	10.6	18.1	3.3
	(3.36)	(2.05)	(0.60)	(0.89)	(0.13)				
2010	13.58	7.51	1.56	2.72	0.49	55.3	11.5	20.0	3.6
	(2.71)	(1.53)	(0.58)	(0.85)	(0.12)				
2011	15.30	9.48	1.51	2.7	0.49	62.0	9.9	17.6	3.2
	(3.01)	(1.96)	(0.58)	(0.85)	(0.13)				
2012	16.29	10.61	1.48	2.63	0.48	65.1	9.1	16.1	2.9
	(3.50)	(2.47)	(0.57)	(0.89)	(0.13)				
Average	14.99	8.59	1.55	2.72	0.50	57.3	10.3	18.1	3.3
	(3.12)	(2.22)	(0.55)	(0.81)	(0.13)				

Table 4 Summary Statistics (Continued)

C: Subcategories of Costs of Production

Year	Dry Feed	Wet Feed	Concentrates & Additives	Utilities	Fuel & Oil	Maintenance	Miscellaneous
							($/cwt)
2006	1.95	1.22	3.76	0.33	0.17	0.31	0.07
	(0.85)	(0.55)	(0.73)	(0.16)	(0.09)	(0.20)	(0.04)
2007	2.12	1.34	4.21	0.31	0.17	0.32	0.09
	(0.88)	(0.53)	(1.04)	(0.15)	(0.09)	(0.20)	(0.05)
2008	2.60	1.64	5.14	0.33	0.21	0.36	0.12
	(1.20)	(0.77)	(1.27)	(0.16)	(0.10)	(0.25)	(0.06)
2009	2.27	1.62	4.34	0.33	0.14	0.32	0.12
	(1.07)	(0.81)	(1.29)	(0.19)	(0.07)	(0.22)	(0.07)
2010	1.87	1.31	4.16	0.33	0.16	0.32	0.12
	(0.90)	(0.74)	(1.02)	(0.19)	(0.07)	(0.19)	(0.08)
2011	2.32	1.71	5.19	0.33	0.22	0.35	0.07
	(1.19)	(0.75)	(1.30)	(0.19)	(0.11)	(0.23)	(0.07)
2012	2.47	2.05	5.72	0.33	0.23	0.33	0.08
	(1.19)	(0.92)	(1.81)	(0.22)	(0.13)	(0.26)	(0.08)
Average	2.22	1.54	4.60	0.33	0.18	0.33	0.09
	(1.07)	(0.77)	(1.39)	(0.18)	(0.10)	(0.22)	(0.07)

Notes: Data used in the construction of this table are farm-level quarterly data obtained from the CDFA. This cost dataset includes only the costs of activities related to milk and dry cows, but not to calves or heifers, or other farming activities. The observations of organic farms are not included.

Table 5: Estimation Results of Specification (4): Total Costs and Elements

	Total	Feed	Hired Labor	Operating	Marketing
Rule 4570	-0.240	-0.070	-0.030	0.031	-0.006
	(0.171)	(0.082)	(0.028)	(0.043)	(0.008)
Rule 4570: Phase II	-0.167	-0.127	-0.028	0.116	-0.022*
	(0.242)	(0.157)	(0.061)	(0.082)	(0.012)
Farm FEs	Yes	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes	Yes
Constant	14.093***	7.956***	1.540***	2.681***	0.504***
	(0.115)	(0.070)	(0.025)	(0.033)	(0.006)
R-squared (within farm)	0.496	0.702	0.117	0.164	0.106
Observations	4277	4277	4277	4277	4277
Farms	220	220	220	220	220

* $p<0.10$, ** $p<0.05$, *** $p<0.01$ All costs are in 2005 dollars per cwt of milk.

LCAFs indicate large confined animal facilities and MCAFs indicate medium confined animal facilities.

Table 6: Estimation Results of Specification (5): Total Costs and Elements

	Total	Feed	Hired Labor	Operating	Marketing
Rule 4570	-0.204	-0.091	0.011	0.024	0.003
	(0.129)	(0.069)	(0.023)	(0.038)	(0.007)
Rule 4570: Phase II	0.130	-0.153	0.192***	0.090	0.029*
	(0.221)	(0.165)	(0.055)	(0.080)	(0.017)
Number of Milk Cows (1,000)	-1.248***	-0.446***	-0.248***	-0.497***	-0.002
	(0.341)	(0.142)	(0.070)	(0.122)	(0.015)
Number of Dry Cows (1,000)	5.317***	2.819***	0.933***	1.273**	-0.018
	(1.638)	(0.818)	(0.279)	(0.517)	(0.023)
Milk Yield (cwt/milk cow/month)	-0.622***	-0.262***	-0.062***	-0.098***	0.004
	(0.051)	(0.035)	(0.008)	(0.010)	(0.002)
Fat Test (%)	1.112***	0.670***	0.148**	0.337**	0.025**
	(0.361)	(0.207)	(0.064)	(0.139)	(0.011)
SNF test (%)	-0.405	-0.087	-0.015	-0.238**	-0.020
	(0.373)	(0.248)	(0.095)	(0.117)	(0.014)
Trend: North Coast	0.197***	0.213***	0.010	0.018*	-0.005**
	(0.050)	(0.043)	(0.014)	(0.011)	(0.003)
Trend: North Valley (LCAFs)	-0.023*	-0.030**	-0.002	-0.017**	-0.000
	(0.014)	(0.015)	(0.004)	(0.007)	(0.002)
Trend: North Valley (MCAFs)	-0.035***	-0.027**	-0.006*	-0.009	-0.000
	(0.012)	(0.012)	(0.003)	(0.008)	(0.001)
Trend: South Valley (LCAFs)	-0.001	0.002	-0.004	0.015*	0.000
	(0.012)	(0.011)	(0.007)	(0.008)	(0.000)
Trend: South Valley (MCAFs)	-0.017*	-0.004	-0.008	0.006	-0.000
	(0.009)	(0.009)	(0.005)	(0.005)	(0.000)
Trend: Southern California	0.116***	0.164***	-0.008***	-0.011***	0.001***
	(0.017)	(0.010)	(0.002)	(0.004)	(0.000)
Trend: North Valley (other)	-0.037	-0.040**	0.009	-0.022**	0.004
	(0.022)	(0.019)	(0.007)	(0.011)	(0.002)
Trend: South Valley (other)	-0.008	-0.019	0.005	0.016	0.002**
	(0.019)	(0.014)	(0.008)	(0.011)	(0.001)
Farm FEs	Yes	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes	Yes
Constant	27.125***	12.178***	2.408***	5.535***	0.485***
	(3.249)	(2.138)	(0.840)	(0.956)	(0.136)
R-squared (within farm)	0.674	0.755	0.223	0.283	0.124
Observations	4277	4277	4277	4277	4277
Farms	220	220	220	220	220

* p <0.10, ** p<0.05, *** p<0.01 All costs are in 2005 dollars per cwt of milk.
LCAFs indicate large confined animal facilities and MCAFs indicate medium confined animal facilities.

Table 7: Estimation Results of Specification (6): Total Costs and Elements

	Total	Feed	Hired Labor	Operating	Marketing
Rule 4570: 2007	-0.212*	-0.059	0.022	-0.032	-0.001
	(0.127)	(0.077)	(0.028)	(0.053)	(0.009)
Rule 4570: 2008	-0.628***	-0.422***	-0.026	0.044	-0.001
	(0.178)	(0.116)	(0.037)	(0.051)	(0.011)
Rule 4570: 2009	-0.150	0.012	-0.014	0.016	0.007
	(0.221)	(0.120)	(0.036)	(0.057)	(0.011)
Rule 4570: 2010	0.204	0.130	0.067**	0.067	0.010
	(0.155)	(0.100)	(0.028)	(0.048)	(0.007)
Rule 4570: 2011	0.116	-0.154	0.189***	0.036	0.022
	(0.237)	(0.188)	(0.054)	(0.091)	(0.017)
Rule 4570: 2012	0.370	-0.121	0.289***	0.174*	0.050**
	(0.289)	(0.222)	(0.081)	(0.105)	(0.023)
Number of Milk Cows (1,000)	-1.251***	-0.447***	-0.248***	-0.495***	-0.002
	(0.341)	(0.140)	(0.070)	(0.122)	(0.015)
Number of Dry Cows (1,000)	5.364***	2.829***	0.941***	1.281**	-0.017
	(1.651)	(0.830)	(0.279)	(0.516)	(0.022)
Milk Yield (cwt/milk cow/month)	-0.625***	-0.264***	-0.062***	-0.098***	0.004
	(0.051)	(0.035)	(0.008)	(0.010)	(0.002)
Fat Test (%)	1.085***	0.653***	0.144**	0.340**	0.025**
	(0.360)	(0.208)	(0.064)	(0.139)	(0.011)
SNF test (%)	-0.434	-0.113	-0.015	-0.237**	-0.020
	(0.368)	(0.244)	(0.095)	(0.117)	(0.014)
Trend: North Coast	0.197***	0.213***	0.010	0.018*	-0.005**
	(0.051)	(0.043)	(0.014)	(0.011)	(0.003)
Trend: North Valley (LCAFs)	-0.032**	-0.035**	-0.003	-0.018**	-0.000
	(0.015)	(0.015)	(0.004)	(0.007)	(0.002)
Trend: North Valley (MCAFs)	-0.036***	-0.027**	-0.006*	-0.009	-0.000
	(0.012)	(0.012)	(0.003)	(0.008)	(0.001)
Trend: South Valley (LCAFs)	-0.009	-0.002	-0.004	0.014*	0.000
	(0.012)	(0.011)	(0.007)	(0.008)	(0.000)
Trend: South Valley (MCAFs)	-0.017*	-0.004	-0.008	0.006	-0.000
	(0.009)	(0.009)	(0.005)	(0.005)	(0.000)
Trend: Southern California	0.116***	0.164***	-0.008***	-0.011***	0.001***
	(0.018)	(0.010)	(0.002)	(0.004)	(0.000)
Trend: North Valley (other)	-0.031	-0.040**	0.012	-0.020*	0.004*
	(0.023)	(0.020)	(0.008)	(0.011)	(0.003)
Trend: South Valley (other)	-0.000	-0.017	0.008	0.018	0.002**
	(0.020)	(0.015)	(0.008)	(0.011)	(0.001)
Farm FEs	Yes	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes	Yes
Constant	26.198***	10.809***	2.520***	5.658***	0.499***
	(3.210)	(2.103)	(0.844)	(0.978)	(0.134)
R-squared (within farm)	0.677	0.757	0.227	0.284	0.125
Observations	4277	4277	4277	4277	4277
Farms	220	220	220	220	220

* p<0.10, ** p<0.05, *** p<0.01 All costs are in 2005 dollars per cwt of milk.

LCAFs indicate large confined animal facilities and MCAFs indicate medium confined animal facilities.

Table 8: Estimation Results of Specification (5): Feed Costs and Elements

	Feed Costs:			
	Total	Dry Feed	Wet Feed	Concentrates & Additives
Rule 4570	-0.091	-0.033	0.034	-0.134*
	(0.069)	(0.068)	(0.051)	(0.074)
Rule 4570: Phase II	-0.153	-0.012	-0.081	-0.061
	(0.165)	(0.153)	(0.136)	(0.165)
Number of Milk Cows (1,000)	-0.446***	-0.351***	-0.228***	0.107
	(0.142)	(0.115)	(0.078)	(0.092)
Number of Dry Cows (1,000)	2.819***	2.025***	1.064***	0.035
	(0.818)	(0.621)	(0.362)	(0.252)
Milk Yield (cwt/milk cow/month)	-0.262***	-0.129***	-0.047***	-0.142***
	(0.035)	(0.020)	(0.011)	(0.026)
Fat Test (%)	0.670***	0.300*	0.250**	0.009
	(0.207)	(0.171)	(0.119)	(0.154)
SNF test (%)	-0.087	-0.214	-0.672***	0.828***
	(0.248)	(0.241)	(0.172)	(0.210)
Trend: North Coast	0.213***	0.018	0.023***	0.117***
	(0.043)	(0.026)	(0.008)	(0.044)
Trend: North Valley (LCAFs)	-0.030**	-0.027**	0.020***	-0.018
	(0.015)	(0.011)	(0.006)	(0.023)
Trend: North Valley (MCAFs)	-0.027**	-0.010	0.020***	-0.039*
	(0.012)	(0.011)	(0.005)	(0.023)
Trend: South Valley (LCAFs)	0.002	0.009	-0.003	-0.008
	(0.011)	(0.011)	(0.011)	(0.010)
Trend: South Valley (MCAFs)	-0.004	0.009	-0.003	-0.011
	(0.009)	(0.008)	(0.009)	(0.007)
Trend: Southern California	0.164***	0.043***	0.036***	0.087***
	(0.010)	(0.009)	(0.011)	(0.009)
Trend: North Valley (other)	-0.040**	-0.018	0.023**	-0.044*
	(0.019)	(0.015)	(0.009)	(0.026)
Trend: South Valley (other)	-0.019	0.021	-0.001	-0.041***
	(0.014)	(0.023)	(0.019)	(0.016)
Farm FEs	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes
Constant	12.178***	5.590***	7.642***	0.212
	(2.138)	(2.077)	(1.519)	(2.045)
R-squared (within farm)	0.755	0.428	0.376	0.544
Observations	4277	4277	4277	4277
Farms	220	220	220	220

* p<0.10, ** p<0.05, *** p<0.01 All costs are in 2005 dollars per cwt of milk.
LCAFs indicate large confined animal facilities and MCAFs indicate medium confined animal facilities.

Table 9: Estimation Results of Specification (5): Operating Costs and Elements

	Operating Costs:				
	Total	Utilities	Fuel & Oil	Maintenance	Miscellaneous
Rule 4570	0.024	0.003	0.007	-0.003	-0.005
	(0.038)	(0.007)	(0.006)	(0.014)	(0.005)
Rule 4570: Phase II	0.090	-0.003	-0.013	-0.002	0.010
	(0.080)	(0.018)	(0.011)	(0.033)	(0.013)
Number of Milk Cows (1,000)	-0.497***	-0.045**	-0.040***	-0.015	0.001
	(0.122)	(0.020)	(0.012)	(0.021)	(0.005)
Number of Dry Cows (1,000)	1.273**	0.145**	0.096**	0.157	0.000
	(0.517)	(0.071)	(0.045)	(0.111)	(0.027)
Milk Yield (cwt/milk cow/month)	-0.098***	-0.020***	-0.011***	-0.013***	-0.002**
	(0.010)	(0.002)	(0.001)	(0.004)	(0.001)
Fat Test (%)	0.337**	0.024	0.001	0.090**	0.024**
	(0.139)	(0.019)	(0.013)	(0.041)	(0.011)
SNF test (%)	-0.238**	0.007	-0.016	0.035	-0.016
	(0.117)	(0.021)	(0.015)	(0.046)	(0.014)
Trend: North Coast	0.018*	0.008***	0.008***	-0.002	0.000
	(0.011)	(0.003)	(0.002)	(0.004)	(0.001)
Trend: North Valley (LCAFs)	-0.017**	-0.002	-0.000	-0.003	-0.001
	(0.007)	(0.002)	(0.001)	(0.002)	(0.001)
Trend: North Valley (MCAFs)	-0.009	-0.003	-0.001	-0.001	-0.001
	(0.008)	(0.002)	(0.001)	(0.002)	(0.001)
Trend: South Valley (LCAFs)	0.015*	-0.000	0.002	-0.003	0.000
	(0.008)	(0.002)	(0.001)	(0.002)	(0.000)
Trend: South Valley (MCAFs)	0.006	-0.000	0.001	-0.004**	0.001**
	(0.005)	(0.002)	(0.001)	(0.002)	(0.000)
Trend: Southern California	-0.011***	-0.001*	0.003***	-0.001	-0.000
	(0.004)	(0.001)	(0.000)	(0.003)	(0.000)
Trend: North Valley (other)	-0.022**	-0.004*	-0.003**	-0.003	-0.000
	(0.011)	(0.003)	(0.001)	(0.003)	(0.001)
Trend: South Valley (other)	0.016	-0.001	0.001	-0.000	0.002**
	(0.011)	(0.002)	(0.002)	(0.004)	(0.001)
Farm FEs	Yes	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes	Yes
Constant	5.535***	0.565***	0.546***	-0.057	0.151
	(0.956)	(0.201)	(0.141)	(0.490)	(0.156)
R-squared (within farm)	0.283	0.269	0.384	0.076	0.299
Observations	4277	4264	4277	4277	4277
Farms	220	220	220	220	220

* p<0.10, ** p<0.05, *** p<0.01 All costs are in 2005 dollars per cwt of milk.
LCAFs indicate large confined animal facilities and MCAFs indicate medium confined animal facilities.

Table 10: Estimation Results of Specification (5) with Medium Dairies: Total Costs and Elements

	Total	Feed	Hired Labor	Operating	Marketing
Rule 4570: Phase II	0.039	0.336	0.133***	-0.301	0.081**
	(0.573)	(0.467)	(0.050)	(0.226)	(0.036)
Number of Milk Cows (1,000)	-7.742***	-1.704	-1.557***	-2.918***	-0.079
	(1.566)	(1.469)	(0.327)	(0.625)	(0.103)
Number of Dry Cows (1,000)	3.490*	5.115***	0.806	0.275	-0.029
	(1.906)	(1.604)	(0.545)	(1.178)	(0.167)
Milk Yield (cwt/milk cow/month)	-0.758***	-0.329***	-0.067***	-0.106***	0.013*
	(0.099)	(0.090)	(0.009)	(0.018)	(0.007)
Fat Test (%)	0.541	0.402	0.221**	0.198	0.008
	(0.696)	(0.428)	(0.108)	(0.228)	(0.023)
SNF test (%)	0.472	0.558	-0.072	-0.030	-0.024
	(1.102)	(0.697)	(0.211)	(0.481)	(0.048)
Trend: North Coast	0.277***	0.237***	-0.036***	0.031*	0.026***
	(0.066)	(0.048)	(0.007)	(0.016)	(0.003)
Trend: North Valley (MCAFs)	0.148***	0.143***	-0.008**	0.035***	-0.003
	(0.025)	(0.029)	(0.004)	(0.010)	(0.003)
Trend: South Valley (MCAFs)	0.124***	0.143***	-0.012**	0.010	-0.003**
	(0.023)	(0.019)	(0.005)	(0.011)	(0.001)
Trend: Southern California	0.177***	0.196***	-0.005	-0.002	-0.000
	(0.014)	(0.013)	(0.004)	(0.006)	(0.001)
Trend: North Valley (other)	0.132***	0.151***	-0.011**	0.000	0.001
	(0.040)	(0.019)	(0.005)	(0.013)	(0.002)
Farm FEs	Yes	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes	Yes
Constant	27.422**	7.581	3.809*	6.131	0.475
	(12.618)	(7.081)	(2.069)	(4.660)	(0.405)
R-squared (within farm)	0.772	0.781	0.412	0.392	0.166
Observations	1080	1080	1080	1080	1080
Farms	67	67	67	67	67

* $p<0.10$, ** $p<0.05$, *** $p<0.01$ All costs are in 2005 dollars per cwt of milk.

LCAFs indicate large confined animal facilities and MCAFs indicate medium confined animal facilities.

Table 11: Estimation Results of Specification (5) with Medium and Small Dairies in the SJV: Total Costs and Elements

	Total	Feed	Hired Labor	Operating	Marketing
Rule 4570: Phase II	0.193	-0.150	0.210***	0.136	0.031
	(0.246)	(0.183)	(0.063)	(0.089)	(0.019)
Number of Milk Cows (1,000)	-9.407***	-3.331***	-1.928***	-3.173***	-0.089
	(1.581)	(0.791)	(0.420)	(0.640)	(0.060)
Number of Dry Cows (1,000)	15.106***	9.481***	2.170***	3.680***	-0.025
	(2.219)	(1.029)	(0.477)	(1.153)	(0.094)
Milk Yield (cwt/milk cow/month)	-0.653***	-0.288***	-0.055***	-0.107***	0.009**
	(0.080)	(0.055)	(0.010)	(0.015)	(0.004)
Fat Test (%)	1.354***	0.581**	0.274***	0.286	0.017
	(0.447)	(0.258)	(0.093)	(0.203)	(0.016)
SNF test (%)	-0.416	-0.245	0.013	-0.223*	-0.005
	(0.293)	(0.180)	(0.137)	(0.123)	(0.019)
Trend: North Valley (MCAFs)	0.132***	0.161***	-0.013***	0.015**	-0.001
	(0.018)	(0.018)	(0.004)	(0.006)	(0.002)
Trend: South Valley (MCAFs)	0.118***	0.161***	-0.014***	-0.006	-0.002*
	(0.012)	(0.009)	(0.005)	(0.007)	(0.001)
Trend: North Valley (other)	0.136***	0.147***	0.005	0.007	0.003**
	(0.011)	(0.009)	(0.005)	(0.005)	(0.002)
Trend: South Valley (other)	0.122***	0.144***	-0.002	0.002	0.001*
	(0.016)	(0.008)	(0.004)	(0.008)	(0.000)
Farm FEs	Yes	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes	Yes
Constant	28.445***	13.554***	2.386*	6.795***	0.343*
	(3.563)	(1.932)	(1.258)	(1.338)	(0.185)
R-squared (within farm)	0.739	0.776	0.283	0.348	0.119
Observations	1807	1807	1807	1807	1807
Farms	98	98	98	98	98

* p<0.10, ** p<0.05, *** p<0.01 All costs are in 2005 dollars per cwt of milk.

LCAFs indicate large confined animal facilities and MCAFs indicate medium confined animal facilities.

Table 12: Estimation Results of Specification (5) with a Balanced Panel: Total Costs and Elements

	Total	Feed	Hired Labor	Operating	Marketing
Rule 4570	-0.305*	-0.179**	0.019	0.028	0.011*
	(0.164)	(0.087)	(0.029)	(0.044)	(0.006)
Rule 4570: Phase II	-0.369	-0.557***	0.203**	0.037	0.023
	(0.251)	(0.180)	(0.080)	(0.098)	(0.021)
Number of Milk Cows (1,000)	-0.684***	-0.141	-0.171**	-0.332***	0.007
	(0.200)	(0.093)	(0.085)	(0.099)	(0.016)
Number of Dry Cows (1,000)	1.534**	1.427***	0.247	-0.017	0.031
	(0.627)	(0.428)	(0.153)	(0.230)	(0.022)
Milk Yield (cwt/milk cow/month)	-0.534***	-0.192***	-0.044***	-0.080***	0.003
	(0.066)	(0.040)	(0.009)	(0.010)	(0.003)
Fat Test (%)	0.407	0.340*	0.098	0.111	0.023
	(0.307)	(0.177)	(0.090)	(0.136)	(0.022)
SNF test (%)	-0.503	-0.225	-0.077	-0.297	-0.015
	(0.526)	(0.290)	(0.190)	(0.196)	(0.019)
Trend: North Coast	0.099***	0.136***	-0.005	-0.001	0.002
	(0.026)	(0.015)	(0.021)	(0.012)	(0.002)
Trend: North Valley (LCAFs)	-0.028	-0.039**	-0.001	-0.007	0.000
	(0.020)	(0.019)	(0.005)	(0.007)	(0.002)
Trend: North Valley (MCAFs)	-0.022	-0.020	-0.002	0.002	-0.001
	(0.015)	(0.013)	(0.004)	(0.007)	(0.002)
Trend: South Valley (LCAFs)	0.002	0.020	-0.009	0.007	0.001**
	(0.012)	(0.014)	(0.008)	(0.010)	(0.000)
Trend: South Valley (MCAFs)	-0.014	0.004	-0.012*	-0.000	0.001**
	(0.010)	(0.013)	(0.006)	(0.005)	(0.000)
Trend: Southern California	0.125***	0.167***	-0.011***	-0.011**	0.001**
	(0.019)	(0.012)	(0.002)	(0.005)	(0.000)
Trend: North Valley (other)	-0.038	-0.056**	0.015	-0.004	0.004
	(0.030)	(0.025)	(0.010)	(0.012)	(0.003)
Trend: South Valley (other)	0.000	-0.006	0.004	0.007	0.002**
	(0.016)	(0.017)	(0.009)	(0.014)	(0.001)
Farm FEs	Yes	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes	Yes
Constant	27.537***	11.297***	2.937*	6.738***	0.439*
	(5.639)	(3.211)	(1.712)	(1.911)	(0.221)
R-squared (within farm)	0.754	0.853	0.200	0.293	0.111
Observations	2324	2324	2324	2324	2324
Farms	83	83	83	83	83

* p<0.10, ** p<0.05, *** p<0.01 All costs are in 2005 dollars per cwt of milk.

LCAFs indicate large confined animal facilities and MCAFs indicate medium confined animal facilities.

Figure 1: A Timeline of Rule 4570

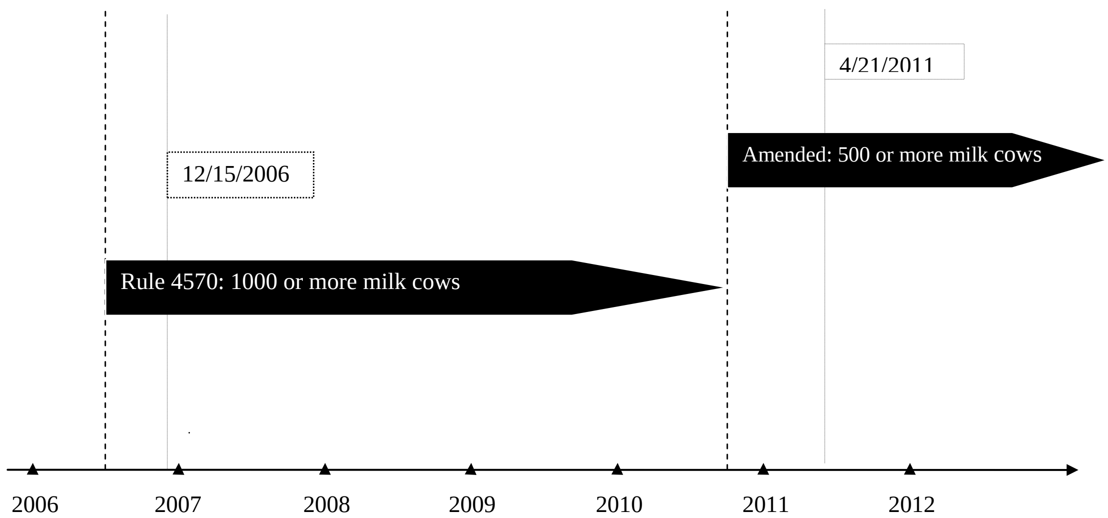
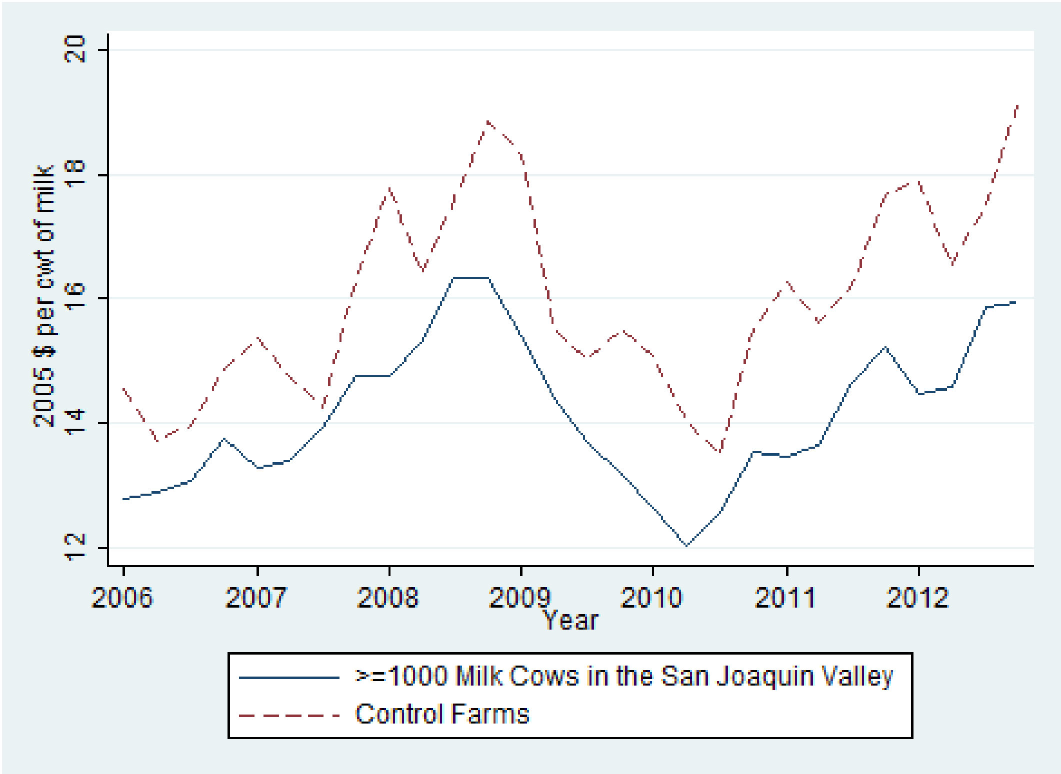
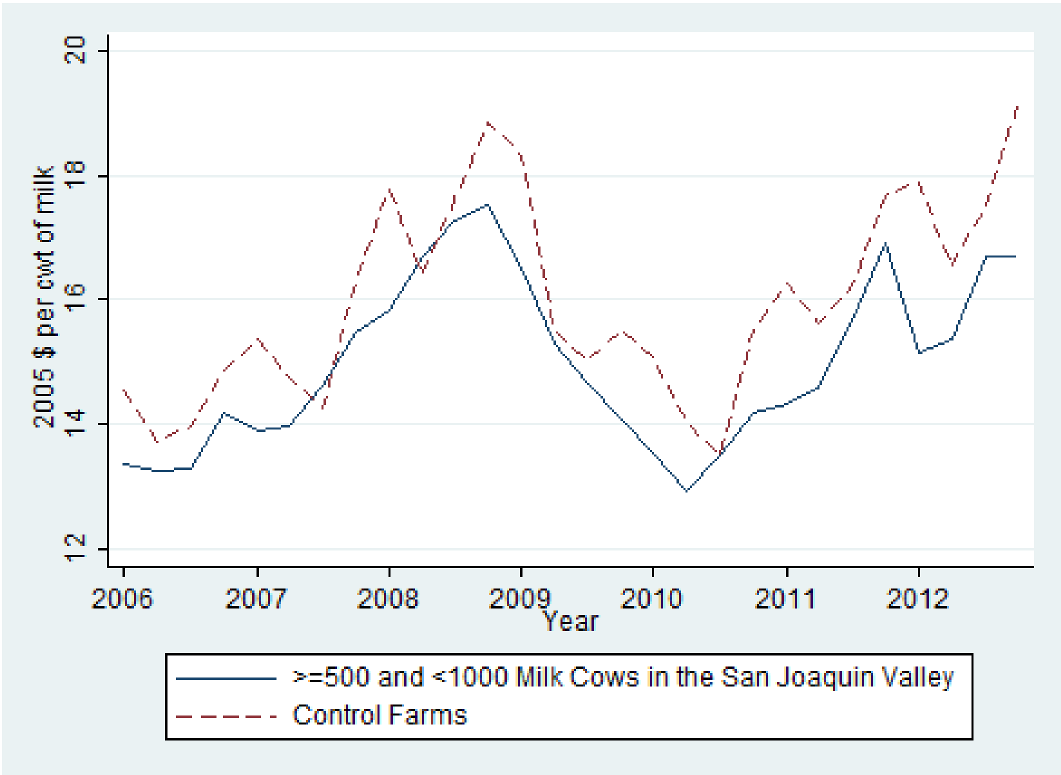


Figure 2: Total Costs

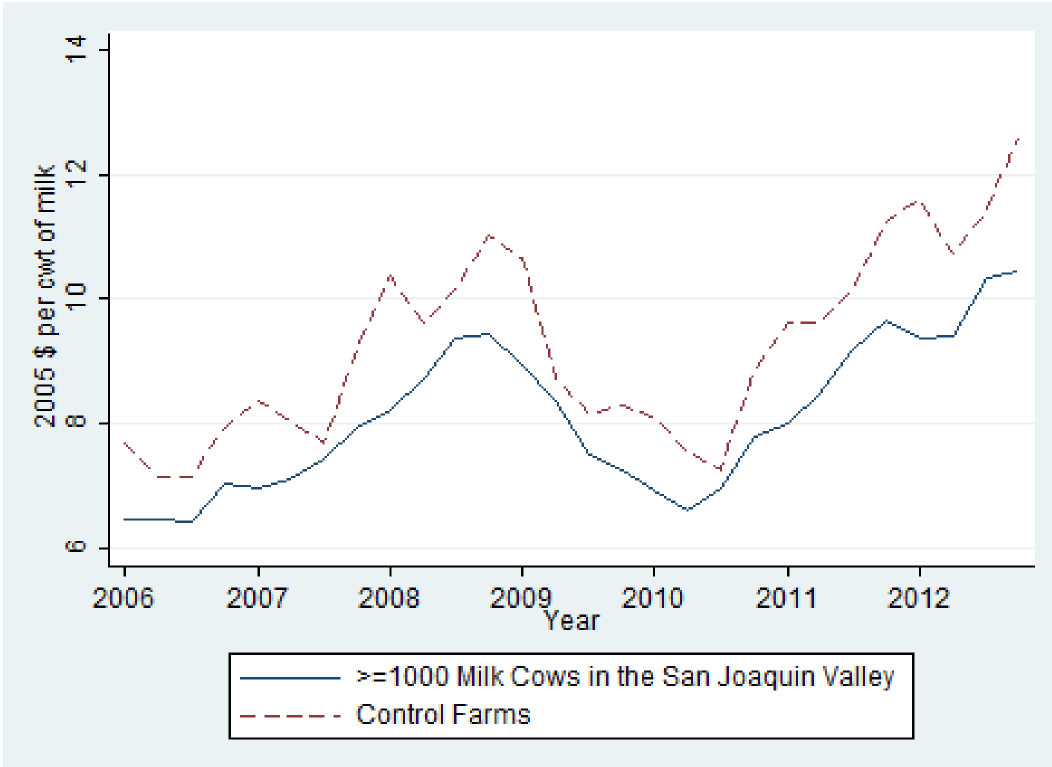


(a) Large dairy CAFs in the San Joaquin Valley versus control farms

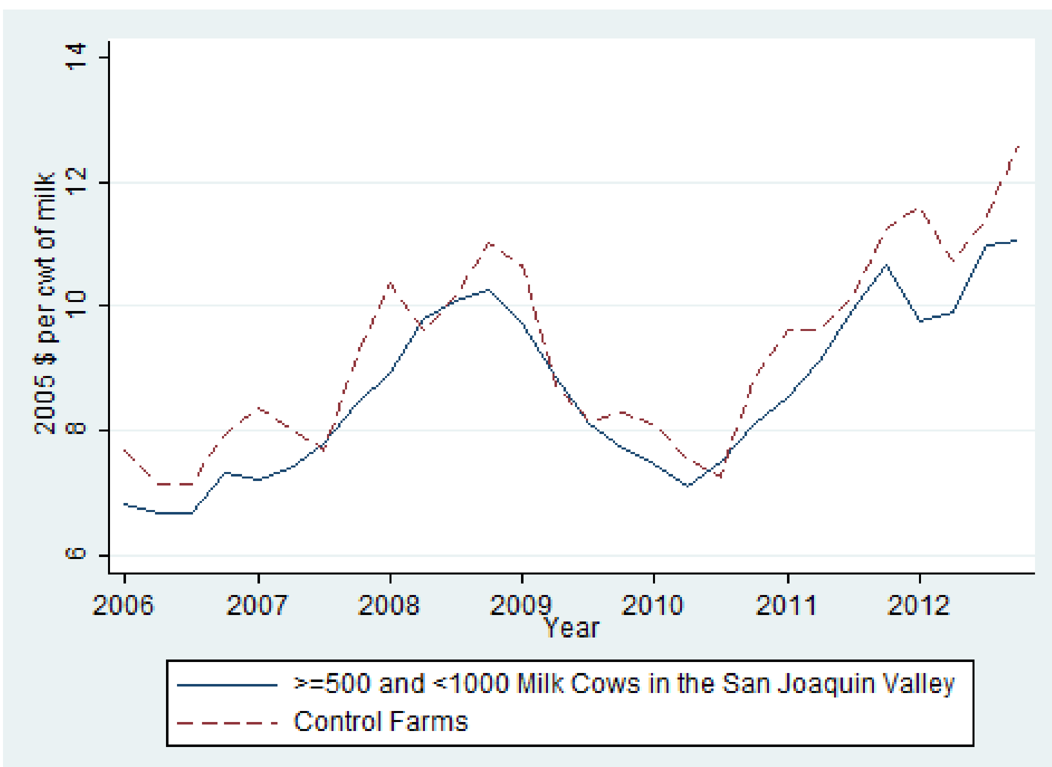


(b) Medium dairy CAFs in the San Joaquin Valley versus control farms

Figure 3: Feed Costs

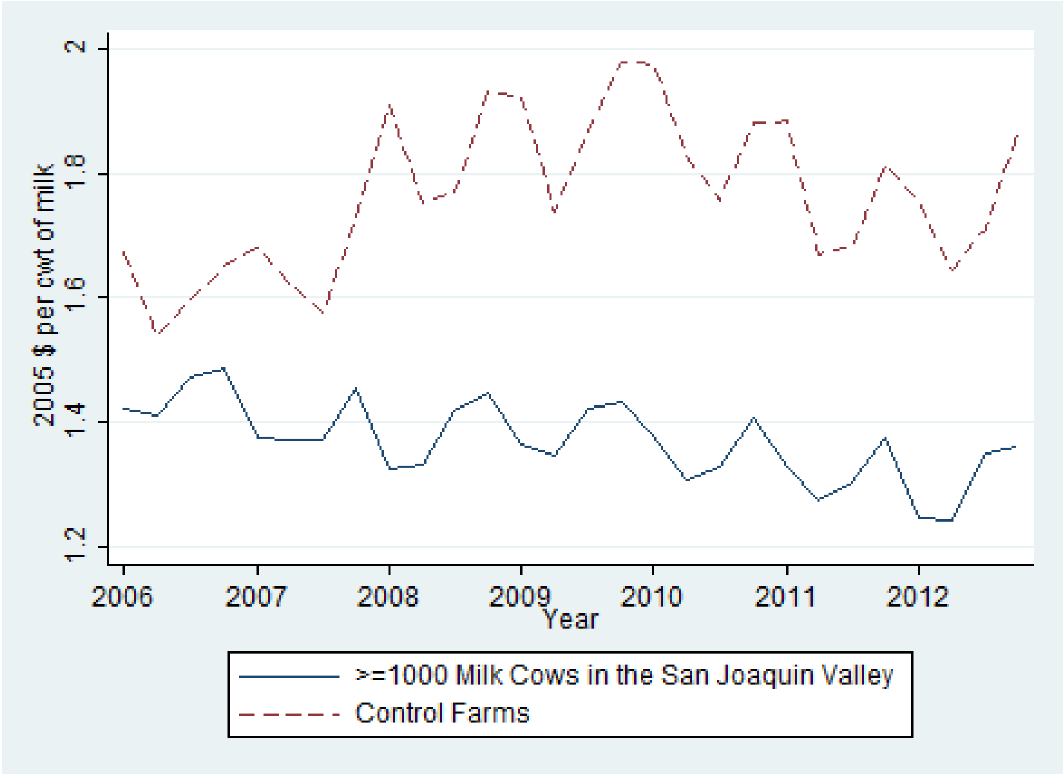


(a) Large dairy CAFs in the San Joaquin Valley versus control farms

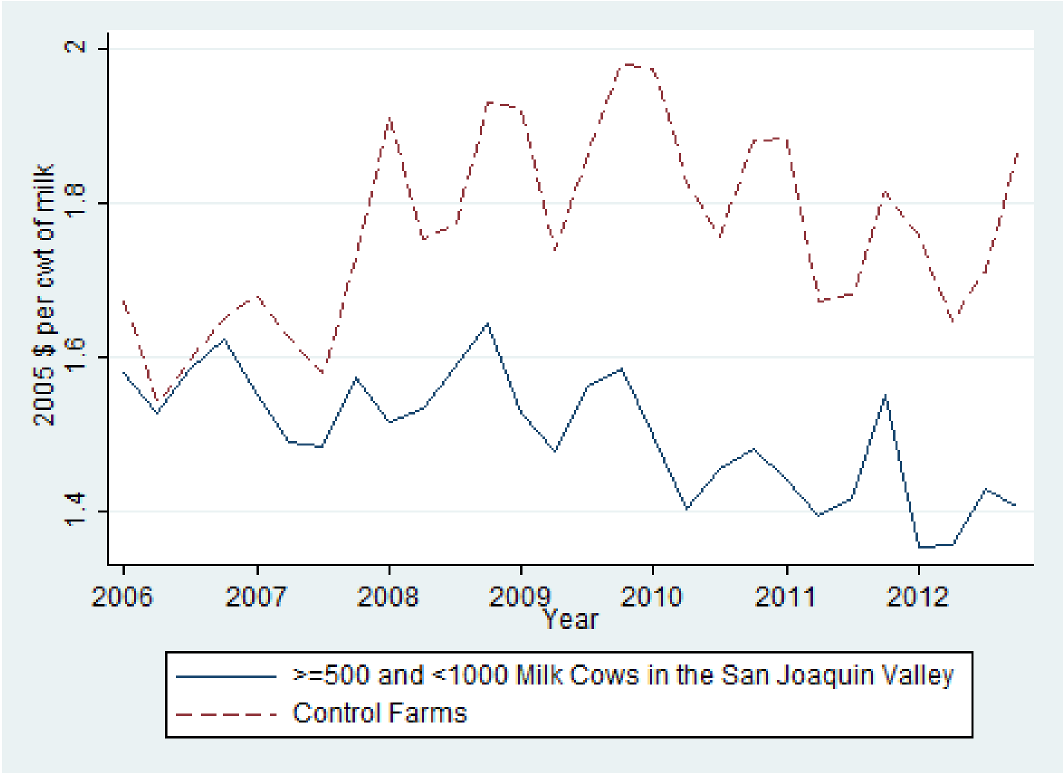


(b) Medium dairy CAFs in the San Joaquin Valley versus control farms

Figure 4: Hired Labor Costs

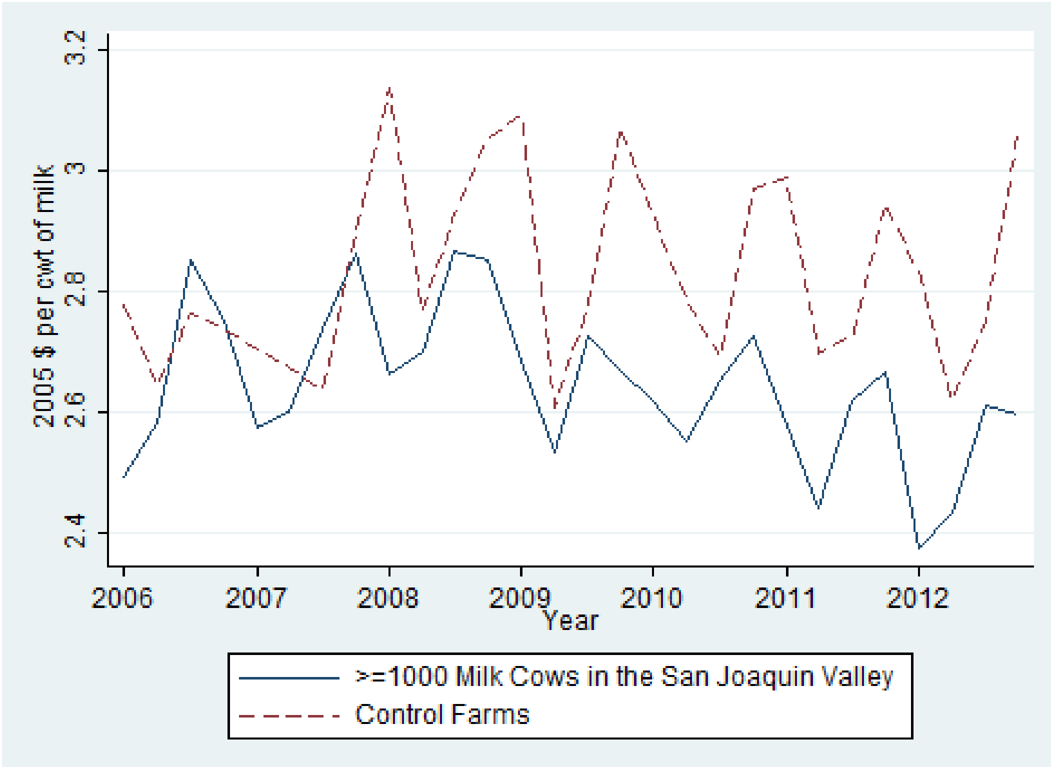


(a) Large dairy CAFs in the San Joaquin Valley versus control farms

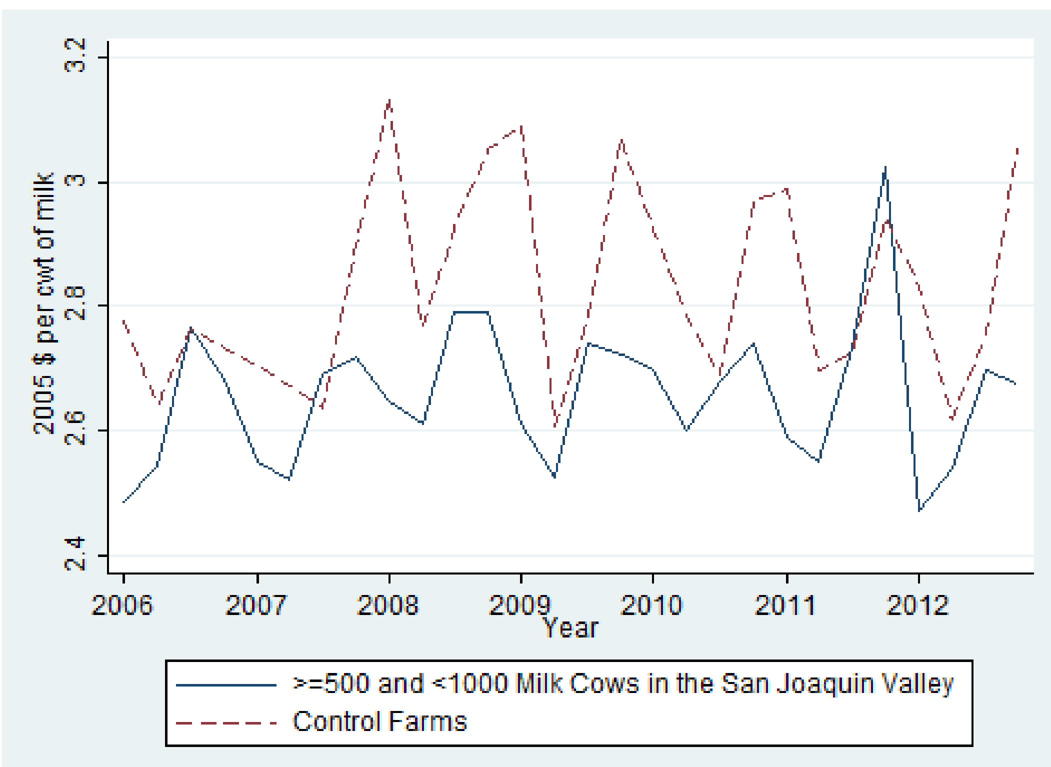


(b) Medium dairy CAFs in the San Joaquin Valley versus control farms

Figure 5: Operating Costs

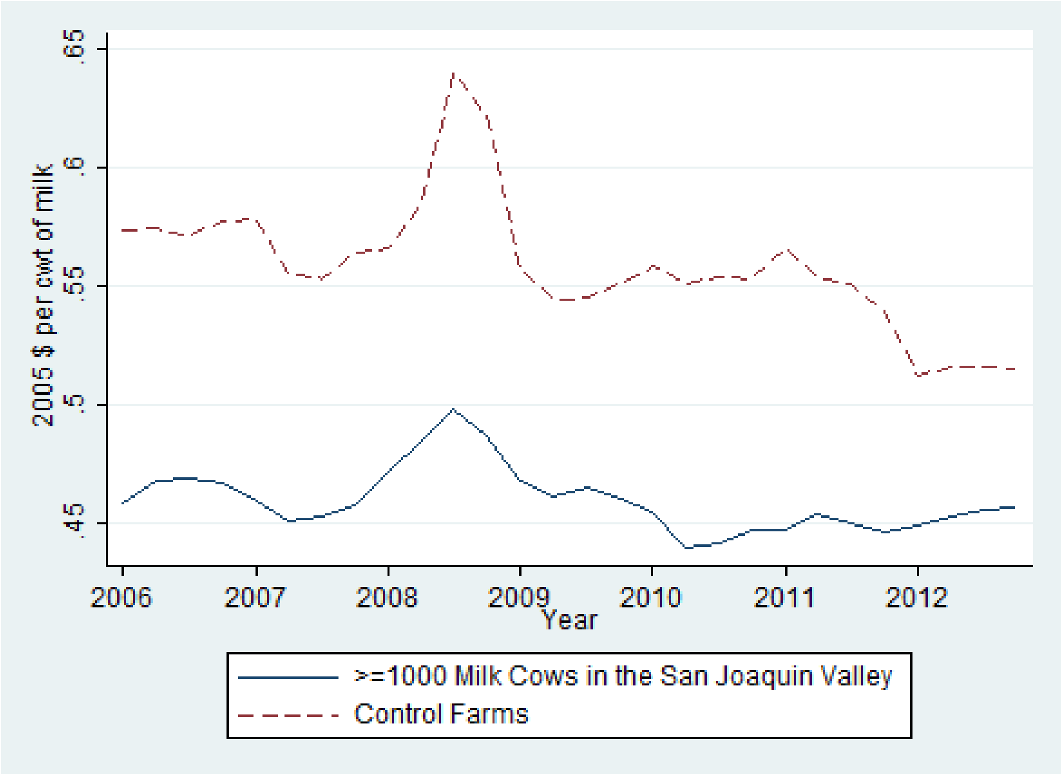


(a) Large dairy CAFs in the San Joaquin Valley versus control farms

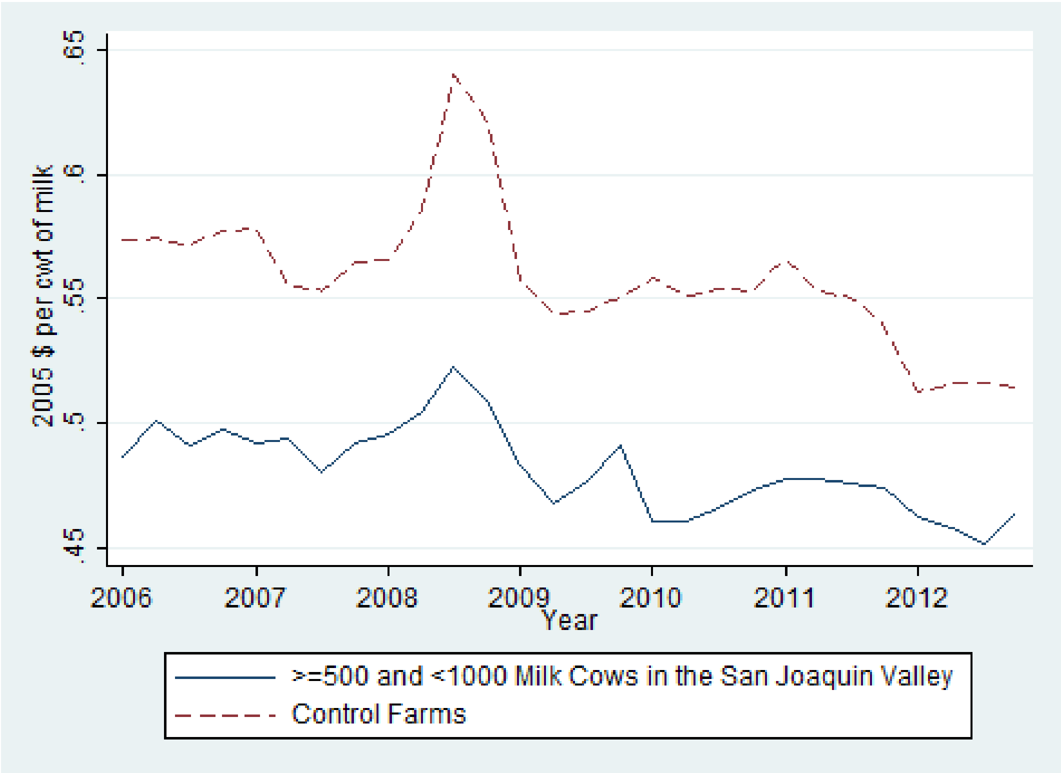


(b) Medium dairy CAFs in the San Joaquin Valley versus control farms

Figure 6: Milk Marketing Costs



(a) Large dairy CAFs in the San Joaquin Valley versus control farms



(b) Medium dairy CAFs in the San Joaquin Valley versus control farms

Appendix A. Definitions of Variables

This appendix describes the variables used in the analysis of this paper. CDFA (2011b) provides more details.

Total costs of dairy production consist of feed costs, costs of hired labor, costs of herd replacement, operating costs, and costs of milk marketing. All costs are reported per cwt of milk.

Feed Costs is the total of the following items:

a) Costs of Dry Roughage: dry roughage includes all forages low in moisture content and high in fiber, such as alfalfa hay, oat hay, and almond hulls.

b) Costs of Wet Feed and Wet Roughage: wet feed and wet roughage include forages high in moisture content. Wet feed includes brewers' malt, wet whey, wet citrus, and cull vegetables, and wet roughage includes haylage, earlage, corn silage, and green chop.

c) Costs of Concentrates, Minerals, and Supplements: concentrates are products relatively high in energy and low in fiber, including grains, milled by-products, and protein products, such as rolled corn. Minerals and supplements include micro and macro minerals, vitamins, and feed additives that improve feed efficiency

Hired Labor Costs includes gross wages earned by hired milkers, pushers, feeders, and outside workers plus employer taxes and perquisites, such as housing, utilities, and health insurance.

Operating Costs include costs of utilities, supplies, veterinary and medicine, outside services, repairs and maintenance, miscellaneous costs, bedding and manure hauling, fuel and oil, interest, lease expense, depreciation, taxes, and insurance. I study the effects of Rule 4570 on the following subcategories of operating costs:

a) Costs of Utilities: utilities include electricity, natural gas, garbage, telephone, water, and so on.

b) Costs of Fuel and Oil.

c) Costs of Repairs and Maintenance: all repairs and maintenance of equipment and structures used by the dairy enterprise, such as milking parlor, freestalls, corrals, feedwagons, and so on.

d) Miscellaneous Costs: any other operating costs not covered above, such as county or state permits, branding fees, subscriptions, producer association fees, etc.

Milk Marketing Costs includes hauling charges, mandatory assessments, and miscellaneous deductions.

The following production data are also used in the analysis.

a) **Number of Milking Cows** is the number of lactating cows in the herd.

b) **Number of Dry Cows** is the number of dry cows in the herd.

c) **Milk Yield** is the quantity of milk shipped for the month (measured in cwt), divided by the number of milking cows.

d) **Fat Test(%)** is the quantity of milk fat shipped for the month, divided by the quantity of milk shipped for the month, and then multiplied by 100.

e) **SNF Test(%)** is the quantity of solids-not-fat shipped for the month, divided by the quantity of milk shipped for the month, and then multiplied by 100.

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