Costs of a Practice-Based Air Quality Regulation: Dairy Farms in the San Joaquin Valley

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The San Joaquin Valley in California is one of only two areas in the country that are classified by the Environmental Protection Agency (EPA) as "extreme" for the 8-hour ozone National Ambient Air Quality Standard.[1] Geographic factors—topography and wind patterns—and vehicular emissions are among the many causes of the severe air quality issues in the San Joaquin Valley. Agricultural pollution, especially emissions from large dairy operations, also plays an important role (EPA, 2010). The San Joaquin Valley had over 1,200 dairy farms in 2011, each of which on average housed more than 1,200 cows. In total, dairy farms in the San Joaquin Valley produced 36.4 billion pounds of milk, accounting for 19% of the milk production of the United States.

The San Joaquin Valley Air Pollution Control District (SJVAPCD, or "San Joaquin Valley Air District", henceforth) adopted air quality Rule 4570 in June 2006 to reduce the emissions of Volatile Organic Compounds (VOCs) from large confined animal facilities (CAFs). VOCs contribute to ground-level ozone formation through complex reactions with nitrogen oxides (Blanchard, 2000). Dairy farms with 1,000 or more milking cows are defined as large CAFs under Rule 4570.[2] Rule 4570 prescribes management practices that reduce the formation of VOCs during the production of CAFs. An amended version of Rule 4570 (Phase II) was passed in October 2010, requiring medium dairy CAFs—dairy farms with 500 or more but less than 1,000 milking cows—to start complying with the Rule along with large dairy CAFs.[3]

Before Rule 4570 was implemented, the San Joaquin Valley Air District estimated that the Rule would lead to a compliance cost of $18.3 million per year for dairy CAFs, about 9.6% of their net profit in 2006 (SJVAPCD, 2009). With Phase II, the estimated compliance cost increased to $61.3 million per year for dairy CAFs because of the change in the regulatory threshold and the introduction of more stringent pollution-mitigation practices (SJVAPCD, 2010). *Ex ante* analyses of the costs of regulatory compliance often do not take into account the effects of the regulation on production decisions. Estimates of the costs are calculated as if only a certain device or practice is added to the current production process. However, re-

[1] Under the 2008 8-hour ozone National Ambient Air Quality Standard, EPA classified nonattainment areas as extreme, severe, serious, moderate, or marginal.

[2] In addition, large CAFs are defined as operations with the minimum number of 3,500 beef cattle, 650,000 chickens, 100,000 turkeys, or 3,000 swine. California does not have any large CAFs of other types of animals, such as ducks or sheep.

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

optimization given the regulatory constraints potentially involves adjustments of all inputs and outputs and all production activities. *Ex ante* analyses thus can overestimate the costs of compliance.

This paper provides *ex post* estimates of the costs of Rule 4570 for dairy CAFs in the San Joaquin Valley. Despite the importance of the dairy industry in California, dairy farms have experienced hard times in recent years. In addition to changes in market conditions in both input and output markets, the burden of environmental regulations has been mentioned as a culprit (Ellerby, 2010). It is important to estimate the magnitude of the cost that environmental regulations, such as Rule 4570, have imposed. Moreover, even though agriculture has been exempted from environmental regulations in most cases, this situation is changing. Examining previous environmental regulations pertaining to agriculture provides lessons for the future design of environmental regulations of agricultural production.

By examining the effects of Rule 4570 on dairy operations, this paper contributes to the literature in several ways. First, this research provides the first analysis of the costs of a practice-based environmental regulation. The inability to measure emissions at the source has made agricultural pollution difficult to regulate. Economists have recommended using proxies, such as input use or conservation practices, for regulation (Kling, 2011). Rule 4570 is a typical practice-based environmental regulation: it prescribes a menu of management practices that could reduce the formation of on-farm VOCs and farms are required to select a minimum number of pollution-mitigation practices to comply with the Rule. Few studies have examined the performance of this relatively new regulatory approach (Coglianese and Lazer, 2003; Bennear, 2007) and none has focused on the costs.

Second, this paper adds to our knowledge about the compliance decisions facing practice-based environmental regulations. Studies on farms' voluntary adoption of best management practices exist (Wu and Babcock, 1998; Wu et al., 2004; Valentin, Bernardo, and Kastens, 2004), and a majority of them have focused on soil, nutrients, and pest management practices. Very few studies have examined the decisions of livestock operations on management practices (Gillespie, Kim, and Paudel, 2007). Moreover, decision-making under a regulation is different from voluntary behavior. Using administrative data from the San Joaquin Valley Air District on observed compliance choices, I discuss the realized changes in operational practices associated with abiding by Rule 4570. Results indicate that dairy farms have adopted labor-intensive production practices to comply with Rule 4570. Capital-intensive mitigation technologies are not widely used, and few dairy farms have changed the physical structure of their operations to comply with the Rule.

Third, this research is also 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 of environmental regulations of agriculture exist mainly at the aggregate level, focusing on the effects of regulations on the spatial structure of the livestock industry (Isik, 2004; Herath, Weersink, and Carpentier, 2005; Sneeringer and Hogle, 2008). A recent publication (Sneeringer and Key, 2011) examined the effects of environmental regulations on the size of hog operations using farm-level data.

Using farm-level cost data collected by the California Department of Food and Agriculture (CDFA) on a panel of dairy farms, I estimate the costs of Rule 4570 with a difference-in-differences (DD) method. With the DD approach, the effects of Rule 4570 on the costs of milk production are identified by comparing changes in the costs for dairy farms under the Rule after it took effect with the corresponding contemporaneous changes in the costs for dairy farms not regulated by the Rule. My estimation results indicate that Rule 4570 has not significantly affected the total costs of milk production. Estimates from different specifications indicate that the regulation may have reduced feed costs, perhaps because some pollution-mitigation practices can reduce feed fermentation. The Rule has increased the costs of hired labor by about \$0.15 per hundredweight of milk, which is equivalent to a 11% increase in the costs of hired labor for dairy farms facing the regulation.

The rest of the paper is organized as follows. Section 1 provides a detailed description of Rule 4570. In section 2, I calculate the adoption rates of different pollution-mitigation practices and discuss the effects of the Rule on the management practices of dairy farms. Section 3 describes the farm-level cost data that I obtained from the CDFA to use in my econometric analysis. I introduce the identification strategy of the econometric analysis in section 4. Section 5 presents the estimation results, and Section 6 provides some robustness checks. Section 7 concludes the paper.

1 Regulatory Background

I introduce Rule 4570 in this section, emphasizing the design and the history of the regulation, which are important for the choice of empirical methods. I then discuss the *ex ante* estimates, provided by the San Joaquin Valley Air District, of the costs of compliance with Rule 4570.

1.1 Design of Rule 4570

It is challenging to design environmental regulations for agricultural operations. Emissions from farms can rarely be channeled through stacks or other openings. It is difficult to

measure emissions or to prescribe end-of-pipe devices to scrub these emissions. Moreover, agricultural operations are highly heterogeneous. Numerous factors could affect the design of farms, such as animal species, regional climate conditions, and the preferences of the operators. It is impractical and uneconomic to impose the same regulatory standards on all farms. Practice-based approach has become a major regulatory instrument for agricultural operations.

Rule 4570 is a typical practice-based regulation: it first groups emission sources of CAFs into "operation areas", and then prescribes a menu of management practices that minimize the formation of VOCs within each operation area.[4] Some examples of the management practices that could lead to reductions in VOCs from dairy CAFs are feed manipulation, frequent scraping of animal housing, and covering of silage piles. Some VOC control devices are also included in the menu of mitigation options, such as anaerobic digesters and biofilters (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, and prior approval by the District, ARB and EPA would need to be granted for own-designed alternative mitigation practices.

Flexibility of practice-based approaches can vary, ranging from the command-and-control approach mandating practices, to the more flexible performance standard where farmers are free to select the optimal mix of practices, to a fully flexible approach where credits for practices are freely tradable (Rabotyagov, Valcu, and Kling, 2014). Rule 4570, as it was initially introduced, was a performance standard. Farmers were required to select a minimum number of pollution-mitigation practices for each operation area, but were free to choose the optimal mix of practices. Phase II is less flexible as more mitigation practices became mandatory.

1.2 A brief history of Rule 4570

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 (SJVAPCD, 2009). The most important components of VOC emissions from dairy farms are alcohols and volatile fatty acids (Zhang, 2010). Even though computer modelling by the San Joaquin Valley Air District indicated that reductions in nitrogen oxides are more important to the ozone attainment for 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

[4]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.

necessary to supplement the reductions in nitrogen oxides to reduce ozone concentration.

The San Joaquin Valley Air District adopted Rule 4570 in June 2006.[5] Owners or operators of large CAFs were required to submit applications for permits to operate or construct CAFs by December 15, 2006, and to comply with the Rule on and after 365 days from the permit issuance date.[6] All farms covered 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.

The San Joaquin Valley had approximately 7,000 CAFs in 2009, 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). The San Joaquin Valley Air District estimated that Rule 4570 would lead to a 36% reduction in VOC emissions from regulated CAFs. The emissions from dairy CAFs were estimated to be reduced from 36.9 tons per day to 23.6 tons per day (SJVAPCD, 2009), accounting for 64% of the estimated reduction in emissions from implementing the Rule.

An amended version of Rule 4570 was passed in October 2010, introducing Phase II of the Rule. The amendments affected mainly dairy farms.[7] The regulatory threshold for dairy farms changed from 1,000 milking cows to 500 milking cows, i.e., from "large" dairy CAFs to "medium" dairy CAFs. It was estimated that more than 300 medium dairy CAFs would be subject to Phase II along with large dairy CAFs (CDFA, 2010). 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, primarily for silage. Recent studies have found silage to be a significant source of VOC emissions (Alanis et al., 2010; Zhang, 2010). Moreover, some of the mitigation measures related to feed and housing became mandatory, and CAFs were required to perform some optional measures more frequently. Owners or operators of CAFs subject to Phase II were required to submit applications for permits to operate or construct dairy farms by April 21, 2011. Figure 1 presents a timeline of Rule 4570.

[5]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.

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

[7]About 20 poultry facilities were affected by Phase II (CDFA, 2010).

1.3 *Ex ante* analyses of costs of compliance

The San Joaquin Valley Air District analyzed in detail the costs of complying with the original Rule 4570 and its amendments (SJVAPCD, 2009, 2010). In these analyses, staff of the District selected the mitigation practices that were most likely to be chosen (assumed to be least costly to implement) by producers and evaluated the costs associated with implementing these mitigation practices. I summarize the information reported in these analyses in Table 1.

The first two columns of Table 1 summarizes the number of mitigation measures prescribed by Rule 4570 and the number of mitigation measures required in Phase II for each operation area at regulated dairy CAFs. Table 1 also provides short descriptions of the VOC mitigation measures that were analyzed in either the 2006 or the 2010 analysis of costs of compliance. Columns 4 and 5 of Table 1 report the estimated costs of implementing these mitigation practices. The 2010 analysis provided estimates 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 from the regulated CAFs and scientific studies was available to the District on the adoption rates and the costs of implementing these mitigation measures. The last column of Table 1 is the estimated adoption rate of each mitigation measure among regulated dairies before the implementation of Phase II, as reported in the 2010 analysis of the costs of compliance. 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 the labor cost and the fuel or electricity cost associated with performing these practices. That is, they use an average wage rate and the assumed number of hours of labor needed to perform the practice to calculate the labor cost, and an average price of fuel or electricity and the assumed quantity of fuel or electricity needed to perform the practice to calculate the fuel or electricity cost. Annualized capital costs are included in the estimated costs of four measures—"Store grain in a weather proof structure", "Cover the surface of silage piles", "Install shade structures for corrals with light-permeable roofing material", and "Remove solids from the waste with a solid separator". Both analyses of the costs of compliance also mentioned that feed costs may change because of the feed manipulation practices prescribed by the Rule. 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* analyses of the effects of environmental regulations on agricultural production stems from the difficulty in identifying the realized operational changes associated with abiding by the regulations. Most pollution-mitigation actions prescribed by environmental regulations for agriculture are "best management practices" rather than adoption of pollution-control devices such as scrubbers or filters. Because these practices are often similar to the practices that have previously been in use on some operations, it is difficult to ascribe costs to the regulation (Sneeringer and Key, 2011). In this section, I provide empirical evidence on the adoption of different VOC mitigation practices by dairy CAFs facing Rule 4570.

The production practices of dairy farms in the San Joaquin Valley before the introduction of Rule 4570 are not documented. Only survey results can be gleaned from publications of dairy scientists, such as Meyer, Garnett, and Guthrie (1997) and Meyer et al. (2011). This limited information about prior practices makes it impossible to assess the effect of the original Rule 4570 on production practices.

Dairy farms subject to Rule 4570 were required to submit applications for permits. In these applications, dairies identified the practices from the menu of mitigation measures prescribed by the Rule that they would use to comply. The San Joaquin Valley Air District has since maintained a database of the permits. Before the introduction of Phase II, Staff of the District used the database to estimate the adoption rates of VOC mitigation measures among regulated dairy farms, and then calculated the costs of compliance using these adoption rates. Some of the estimated adoption rates are reported in Table 1. I obtained information from the permit database to estimate the adoption rates of VOC mitigation measures as of 2013, after Phase II.

The permit database consists of 972 records of 933 dairy farms that are subject to Phase II.[8] The database also includes herd information for a subset of dairy farms. Table 2 summarizes the aggregate adoption rates of some mitigation measures among dairy farms 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 regulated farms flushed, scraped, or vacuumed freestall flush lanes at least three times a day, 99% of them had adopted this practice by 2013. Moreover,

[8] 36 dairy farms updated their VOC mitigation practices, and three farms updated twice.

given that the number of required mitigation measures for each operation area is greater than the number of mandatory measures, Phase II has 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 provides further insights on the decision-making of dairy farms in complying with Phase II. First, dairy farms chose to adopt labor-intensive VOC mitigation measures to comply with Phase II. 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 1% and 2%, respectively. Third, dairy farms chose to adopt mitigation practices that do not change the physical structure of the operation area. For example, few farms decided to comply by changing the bedding materials of freestalls or the roofing materials of corrals. Fourth, medium and large dairy CAFs have made similar decisions to comply with Phase II. The adoption rates are comparable between the two groups of dairy farms for most VOC mitigation measures listed in Table 2.

3 Discussion of Data

I use farm-level cost data to estimate 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 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.[9]

[9]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).

3.1 The sample of dairy farms

Dairy farms in California are located in diverse areas. The sample of farms is constructed based on four unique production regions of the State—North Coast, North Valley, South Valley, and Southern California—to be representative of dairy farms in the State. Four counties in the North Valley and four counties in the South Valley constitute the San Joaquin Valley Air Pollution Control District. Table 3 summarizes the characteristics of dairy production in each region in years 2001 and 2011. Dairy farms 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 of the dairy farms located in Southern California rely on feed ingredients from outside the area.

About 10% of California dairy farms are surveyed in each quarter by the Cost of Production Unit of the CDFA. I obtained quarterly data from the CDFA for the years 2006 to 2012.[10] The data set includes only the costs of activities related to milking and dry cows, but not to calves or heifers, or other farming activities. The total costs of production are reported by five categories: 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 dairy farms 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 and additives, and pasture costs. Concentrates are products relatively high in energy and low in fiber, such as rolled corn. On average, pasture accounted for only 1% of feed costs for dairy farms in California. Only one regulated dairy farm in the sample 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. Appendix A provides definitions of all the variables used in this analysis.

[10]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.

Based on the analyses conducted by the San Joaquin Valley Air District on the costs of compliance, and the empirical evidence provided in section 2 on the adoption rates of different VOC mitigation measures, I expect Rule 4570 to affect feed costs, costs of hired labor, and operating costs, but not costs of herd replacement or marketing costs. To further understand the decision-making of dairy farms, I also investigate the effects of Rule 4570 on the subcategories of feed costs and operating costs.

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. Price data included in the data set are mailbox price of milk, price of alfalfa , and price of concentrates and additives. Hourly wages of hired labor are also reported. 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.

3.2 Summary statistics of the sample

Table 4 summarizes some of the production information of the dairy farms in the sample. I obtained data 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 dairy farms surveyed decreased from 189 in 2006 to 139 in 2012.[11] 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 milking cow per month, increased from 19.70 to 20.73 hundredweight (cwt). SNF content increased slightly during the study period. Comparing Table 5 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.

The last three columns of Table 4 summarize the prices of major inputs in milk production. The prices are reported in 2005 dollars.[12] The prices of feed peaked in 2012: the average price of alfalfa was $229.16 per ton, and the average price of concentrates and additives was $304.15 per ton. The prices of feed were also relatively high during 2008 and 2011. The average wage rate remained stable during the sample period. The highest wage rate was in 2008 at $13.32 per hour and the lowest wage rate was in 2011 at $12.80 per hour.

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

[12] I use the Quarterly Gross Domestic Product Implicit Price Deflator (Federal Reserve Bank of St. Louis, 2012) to deflate the nominal data on prices and costs.

Table 5 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. I compare the total costs, feed costs, costs of hired labor, and operating costs for three groups of dairy farms: large CAFs, medium CAFs, and other farms. "Large CAFs" refers to the dairy farms in the San Joaquin Valley subject to both the original Rule 4570 and Phase II and "medium CAFs" refers to the dairy farms in the San Joaquin Valley subject to Phase II. "Other farms" refers to the dairy farms that are in the San Joaquin Valley with fewer than 500 milking cows and the dairy farms outside the San Joaquin Valley. The full panel of farm-level data is unbalanced. Data in a given quarter for a farm can be missing for different reasons, for example, the farm was not surveyed in the quarter, the farm exited the industry, or there was simply an error in the data. 46% of large and medium dairy CAFs and 28% of other dairy farms reported information in all periods. Section 7 discusses sample selection issues.

Panel A of Table 5 compares the total costs of production and feed costs between the three groups of dairy farms. The averages of the total costs of production and feed costs were lower for medium and large dairy CAFs than for other farms, and the changes in costs for different groups followed each other closely during the sample period. The averages of the total costs of production peaked in 2008 at \$15.70, \$16.98, and \$17.54 per cwt of milk for large CAFs, medium CAFs, and other farms, respectively. The averages of feed costs peaked in 2012 at \$9.93, \$10.60, and \$11.40 per cwt of milk for large CAFs, medium CAFs, and other farms, respectively.

Panel B of Table 5 compares the costs of hired labor and operating costs between the three groups of dairy farms. The averages of the costs of hired labor and operating costs remained relatively stable during the sample period. The averages of the costs of hired labor decreased slightly for both large and medium CAFs, from \$1.44 to \$1.30 per cwt of milk and from \$1.58 to \$1.43 per cwt of milk, respectively. The average of the costs of hired labor peaked in 2009 at \$1.89 per cwt of milk for other dairy farms. The averages of operating costs peaked in 2008 at \$2.77 and \$2.95 per cwt of milk for large CAFs and other farms respectively, and peaked in 2011 at \$2.76 per cwt of milk for medium CAFs.

4 Empirical Strategy

The goal of the empirical analysis is to estimate the effects of Rule 4570 on the costs of milk production for dairy farms 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 for dairy farms under the Rule after it took effect with the corresponding contemporaneous changes in the costs for dairy farms not

regulated by the Rule. Given the nature of the regulation, two potential comparison groups exist within the data set. Dairy farms outside the San Joaquin Valley Air District and dairy farms within the District below the threshold of Rule 4570 are not subject to the Rule.

The basic DD model is specified in equation (1), 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 dairy farms in the San Joaquin Valley with 1,000 or more milking cows after the first quarter of 2007 and through the second quarter of 2011, and D_{it}^{b} indicates Phase II, which equals one for dairy farms in the San Joaquin Valley with 500 or more 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 farms on average to have lower costs. These fixed effects prevent the estimated effects of the Rule from being biased downward by the fact that dairy farms affected by the Rule (large farms in the San Joaquin Valley) have lower costs of production, both before and after the introduction of the Rule, than do control farms. 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.[13] ε_{it} is an unobserved disturbance term.

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

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 (Auffhammer and Kellogg, 2011). In equation (2), 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 regulated by Rule 4570 and others are not, farms regulated by 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 (1) with farm-specific time-varying explanatory variables. Vector X_{it} includes the number of milking cows, the number of dry cows, milk yield measured by the quantity of milk shipped per milking cow per month, the fat and SNF tests of milk, the price of alfalfa, the price of concentrates and additives, and

[13] Recall that the data set encompasses four production regions: North Coast, North Valley, South Valley, and Southern California.

wage rate.

$$(2) \quad y_{it} = \delta^a D^a_{it} + \delta^b D^b_{it} + \alpha_i + \lambda_{rt} + \theta \cdot S_{rt} + \beta \cdot X_{it} + \varepsilon_{it} \qquad i = 1, ..., N; \qquad t = 1, .., T,$$

Recall that dairy farms were required to start complying with Rule 4570 a year after the permits of operation have been granted. This implies that dairy farms started to comply with the Rule at different points in time. Moreover, the Rule may have started affecting dairy farms before it was passed as farms were anticipating the Rule, and the effects of the Rule are likely to have changed over time as farmers become familiar with the VOC mitigation practices adopted. In another specification, I allow the effects of Rule 4570 to change over time. I include in equation (3) a set of dummies variables D^s_{it} with $s \in \{-m, -(m-1), ..., 0, 1, 2, ..., \}$ indicating that dairy farm i in quarter t started to comply with the Rule s quarters earlier. If s is negative, Rule 4570 was introduced $-s$ quarters later.

$$(3) \quad y_{it} = \sum_{s \geq -m} \delta^s D^s_{it} + \alpha_i + \lambda_t + \theta \cdot S_{rt} + \beta \cdot X_{it} + \varepsilon_{it} \qquad i = 1, ..., N; \qquad t = 1, .., T,$$

5 Results

In this section, I discuss the estimated effects of Rule 4570 and Phase II on dairy CAFs in the San Joaquin Valley. I first present estimates the from basic DD model and then estimates from other model specifications.

5.1 Residual plots and estimates from the basic DD model

Figure 2 depicts the time path of the total costs of milk production after removing the noise. Each panel plots the residuals of a regression of the total costs on farm fixed effects, α_i, and region-specific time fixed effects, λ_{rt}. The residuals are grouped based on whether the farms are regulated by Rule 4570. Recall that farms in the San Joaquin Valley with fewer than 1,000 milking cows and farms in other regions of the state were not affected by the original Rule 4570, and 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 Phase II. Residuals are averaged across farms within each time period and group. Residual plots of feed costs, costs of hired labor, and operating costs are included in Appendix B.

These plots of residuals provide insights into the estimates from the basic DD approach. Panel A compares large dairy CAFs in the San Joaquin Valley to their "control farms", those not affected by Rule 4570 or Phase II. The solid line plots the average costs

of farms that are affected by Rule 4570. The vertical lines indicate the introduction of Rule 4570 and Phase II. The two sets of residuals track each other fairly closely during the sample period: they are no further apart than \$0.5 per cwt of milk, relative to the average of the total costs at about \$15 per cwt of milk. The introduction of neither Rule 4570 nor Phase II seems to have substantially affected the total costs of production for large CAFs in the San Joaquin Valley. Panel B compares medium dairy CAFs in the San Joaquin Valley to their "control farms", those not affected by Phase II. From panel B of Figure 2, it appears that Phase II cannot be associated with increases in the total costs of production for medium CAFs in the San Joaquin Valley either. However, it is possible that these time paths of residual total costs were affected by long-run trends.

Table 6 reports the estimates of the effects of Rule 4570 and Phase II on the costs of milk production from the basic DD model in equation (1). Standard errors are included in parentheses. These standard errors are estimated using a robust variance estimator that is clustered by farm. The first column of Table 6 reports the estimates of the effects of Rule 4570 on the total costs of milk production. Both Rule 4570 and Phase II are estimated to have reduced the total costs of milk production, but neither of the estimates is statistically significant. As mentioned in the previous section, estimates obtained using the basic DD specification can be inconsistent if farm-specific unobservables change over time.

5.2 Estimates from the augmented DD models

Table 7 reports the estimates from the augmented model in equation (2).[14] The top two rows of Table 7 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 \$0.11 per cwt of milk and Phase II is estimated to have increased the costs of milk production by \$0.07 per cwt of milk. Given that the average of the total costs of milk production was \$14.70 per cwt of milk in 2011 for regulated dairy CAFs, the estimated effect of Phase II is less than 0.5% of the total costs.

Columns 2 to 4 of Table 7 report the estimated effects of Rule 4570 on different categories of the costs of milk production, including feed costs, costs of hired labor, and operating costs. The estimated effects of the original Rule on 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 by \$0.13 per cwt of milk, but the estimate is statistically insignificant. Phase II is estimated to have increased the costs of hired labor:

[14] In another specification, I included quadratic time trends. Estimation results are very close to those reported in Table 7.

the implementation of Phase II can be associated with a \$0.15 per cwt of milk increase in the costs of hired labor, and the estimate is statistically significant at the 1 percent level. The average cost of hired labor was \$1.37 per cwt of milk for regulated dairy farms in 2011, so the effect of Phase II is equivalent to an 11% increase in the costs of hired labor. Phase II of Rule 4570 is also estimated to have increased operating costs by \$0.11 per cwt of milk, but the estimate is statistically insignificant.

Table 8 reports the estimates of the effects of Phase II on medium dairy CAFs in the San Joaquin Valley from the specification in equation (3), where I allow anticipatory effects and the effects of the Rule to vary across time. Phase II was passed in October 2010. In empirical estimation, I chose $m = 4$, which allows Phase II to affect the costs of milk production for medium dairy CAFs a year before it was passed. Phase II may have moderately increased the total costs of milk production, but most of the estimates are small and some of them are statistically insignificant. Phase II is estimated to have negative effects on feed costs, but most of the estimates are also statistically insignificant. Phase II have increased the costs of hired labor for medium dairy CAFs: the estimated effects were between \$0.14 and \$0.40 per cwt of milk during the two-year period after Phase II was passed, and the estimates were increasing over time. Note that 2012 was the first full year in which Phase II was in place. Phase II have also increased the operating costs for medium dairy CAFs: the implementation of Phase II in 2012 can be associated with an increase in operating costs at the magnitude of between \$0.28 and \$0.56 per cwt of milk, and the estimates are statistically significant.

5.3 SUR estimation

I obtained the estimates in Table 7 from four separate regressions. Error terms in different cost equations may potentially be correlated. I also estimated the cost functions as a system using seemingly unrelated regressions (SUR). SUR allows the contemporaneous errors associated with the dependent variables to be correlated and estimates the full variance-covariance matrix of the coefficients. Estimation results are reported in Table 9. The estimates of the coefficients are identical to those reported in Table 7. Efficiency is gained by estimating the system of equations jointly: standard errors are smaller than those reported in Table 7. As a consequence, the estimated effect of Phase II on operating costs is statistically significant at the 10 percent level.

To further investigate the effects of Rule 4570 on the management practices of dairy farms, I estimate equation (2) using SUR with subcategories of feed costs and operating costs as the dependent variables. Table 10 reports the corresponding estimates for feed

costs. The estimation results indicate that Phase II can be associated with some decreases in different subcategories of feed costs, but none of the estimates is statistically significant. The breakdown results of the effects of Rule 4570 on operating costs are shown in Table 11. Rule 4570 does not appear to have significantly affected a particular subcategory of operating costs: most of the estimates are small in magnitude and statistically insignificant.

6 Robustness Checks

To interpret the estimates as causal effects of Rule 4570 on the costs of milk production for 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 the control dairy farms and the farms subject to Rule 4570. 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. And, the results shown to this point were estimated using data on an unbalanced panel of dairy farms. Nonrandom selection into and out of the sample could introduce selection bias. In the interest of mitigating these potential biases, I conduct a few robustness checks.

6.1 Conditional unconfoundedness

The assumption of conditional unconfoundedness requires that the costs of milk production at control dairy farms to be representative of the costs that would have been observed at similar farms regulated by Rule 4570, had the Rule not been introduced. For a robustness check, I estimate the effects of Rule 4570 on only medium dairy CAFs, using as a control group either medium dairy farms outside the San Joaquin Valley or dairy farms in the San Joaquin Valley below the regulatory threshold of Phase II. The point of this exercise is that the two different control groups are likely to have different biases (Fowlie, Holland, and Mansur, 2012). The cost trajectories of medium dairy farms 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 dairy farms 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 9 using the entire sample.

Estimation results with medium dairy farms outside the San Joaquin Valley as a control group are shown in Table 12.[15] The effect of Phase II on the total costs of milk production for medium dairy CAFs in the San Joaquin Valley is positive, but statistically insignificant. Phase II is estimated to have increased the costs of hired labor for medium dairy CAFs in the San Joaquin Valley by $0.20 per cwt of milk and the estimate is statistically significant at the 1 percent level. Estimation results using small dairy farms in the San Joaquin Valley as a control group are shown in Table 13. Phase II is estimated to have increased the costs of hired labor for medium dairy CAFs in the San Joaquin Valley by $0.15 per cwt of milk and the estimate is statistically significant at the 1 percent level. Phase II is also estimated to have increased the operating costs for medium dairy CAFs: the estimated effect is about $0.17 per cwt of milk and is statistically significant at the 1 percent level.

6.2 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 dairy farms with high compliance 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 the costs of production. This would result in inflated estimates of the effects of Rule 4570. On the other hand, if the Rule led some dairy farms to exit the industry, estimates obtained using an unbalanced panel could underestimate the effects of Rule 4570 on the costs of milk production. For a robustness check, I report estimation results of the effects of Rule 4570 using a balanced panel of dairy farms.

Table 14 reports the estimated effects of Rule 4570 on the total costs and different categories of costs of milk production from the model in equation (2). Cost data for 82 dairy farms from 2006 to 2012 were used in the estimation. Comparing estimates reported in Tables 7 and 14, the negative effects of Phase II on feed costs become statistically significant. Phase II can be associated with an average reduction in feed costs of $0.28 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 7: Phase II has increased the costs of hired labor for dairy CAFs in the San Joaquin Valley by $0.18 per cwt of milk.

[15] Time trends were estimated to be statistically insignificant. Given the small sample size, I did not include time trends in the reported estimation.

7 Conclusion

This paper examines the effects of Rule 4570—a practice-based 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 dairy farms adopted labor-intensive production practices to comply with Rule 4570. On the contrary, capital-intensive mitigation technologies are not widely used, and few farms decided to comply by changing the physical structure of their operations. It is not surprising that the Rule has not significantly affected the costs of milk production.

Using farm-level data, I estimate the effects of Rule 4570 on the costs of milk production. Estimation results show that neither the original Rule nor Phase II has significantly affected the total costs of milk production. The Rule may have reduced feed costs, perhaps because some VOC mitigation practices have reduced feed fermentation or changed the diet of cows. Phase II of Rule 4570 has statistically significantly increased the costs of hired labor. The increase is about \$0.15 per hundredweight of milk, which is equivalent to a 11% increase in hired labor costs for regulated dairy farms. The Rule may also have lead to moderate increases in operating costs.

Analyses of the costs of regulatory compliance often do not take into account the effects of the regulations on production or input substitution and overestimate the costs of compliance. Estimates provided by the San Joaquin Valley Air District before the adoption of Phase II indicate that Phase II would lead to a compliance cost of \$61.3 million per year for regulated dairy CAFs. Estimates obtained in this paper using observational data do not provide any evidence that Rule 4570 has significantly increased the total costs of milk production.

I would like to emphasize that Rule 4570 may have affected other production aspects of dairy farms in the San Joaquin Valley. First, given that the Rule requires additional permit applications and record keeping, it has increased the costs of entry for dairy farms. Second, Rule 4570 may have slightly increased capital costs. Some pollution mitigation practices, such as covering silage piles, require capital investments. Third, Rule 4570 may affect the long-run growth of the dairy industry in the San Joaquin Valley. Sneeringer and Key (2011) have shown that size-based environmental regulations may lead farm operations to enter the industry at a size below the regulatory threshold, so that they can avoid compliance costs. If this is the case, the long-run growth of the dairy industry could be affected by Rule 4570. Fourth, even though the econometric analysis in this paper does not indicate that the Rule has increased the costs of production on average, Rule 4570 could have been the last straw that led some dairy farms to exit the industry.

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 National Research Council Guidelines	NS	12.0	14
		b)* Store grain in a weather-proof structure	NS	40.2[a]	50
		c) Remove uneaten wet feed from bunks within 24 hours after a rain event	5.3	0.4	13
		d) Begin feeding or disposing of rations within two hours of grinding	NA	NS	100
2	1	***Silage***			
		a) Cover the surface of silage piles	10	3.6[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	1.8	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	0.2	24
9	7	***Corral***			
		a)* Clean manure from corrals at least four times per year	42.4	5.2	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	0.2	64
		d) Harrow, rake or scrape corrals to maintain dry surface	NA	0.5	41
		e) Install shade structures with light-permeable roofing material	NA	10.6[a]	39
		f) Manage corrals such that the depth of manure does not exceed 12 inches	NA	0.5	NA
2	1	***Solid manure handling***			
		a) Cover dry manure pile within 72 hours of removal from housing	3.7	NS	100
4	1	***Liquid manure handling***			
		b) Remove solids from the waste with a solid separator	NS	17.2[a]	38
4	1	***Land application***			
		a) Land-incorporate manure within 72 hours	NS	NS	100
		b) Allow liquid manure to stand in fields no more than 24 hours after irrigation	NA	NS	100

Notes: Dairy CAFs can design their own mitigation measures for all operation areas. 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	65	59
2) Remove uneaten wet feed from bunks within 24 hours after a rain event	48	40	45
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	2	5	4
Silage			
4) Cover the surface of silage piles	91	93	93
Milking parlor			
5)* Flush or hose milking parlor immediately prior to, after, or during each milking	100	100	99
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	99	99
7) Use non-manured-based and non-separated solids based bedding for at least 90% of the bedding material for freestalls	1	3	3
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	96	97
Corral			
9)* Scrape, vacuum, or flush concrete lanes in corrals at least once every day for mature cows	99	100	100
10) Install shade structures for corrals with light-permeable roofing material	1	1	2
11) Manage corrals such that the depth of manure does not exceed 12 inches	85	86	86
12) Use lime or a similar absorbent material in the corrals	0	1	1
Liquid manure handling and application			
13) Remove solids from the waste with a solid separator	89	83	89
14) Use a phototropic lagoon	0	1	1
15) Use an anaerobic treatment lagoon	1	1	2
16) Allow liquid manure to stand in fields no more than 24 hours after irrigation	97	95	95
Number of dairy farms	128	302	933

Notes: Mitigation measures with a "*" are mandatory in Phase II of Rule 4570. Some of the mandatory measures are not applicable to all dairies.

Table 3: Characteristics of Dairy Production in Regions of California

Region	Number of Farms	Number of Cows	Milk Production (cwt/year)	Average Herd Size	Milk Production per Farm (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 farm are reported in hundredweight (cwt) per year, and milk yield is in hundredweight per cow per year.

Table 4: Summary Statistics of Dairy Farms

Year	Number of Observations	Number of Farms	Number of Milking Cows	Number of Dry Cows	Milk Yield (cwt/milking cow/month)	Fat Test (%)	SNF Test (%)	Price of Alfalfa ($/ton)	Price of Concentrates & Additives ($/ton)	Wage Rate ($/hr)
2006	709	189	914	144	19.70	3.80	8.84	164.40	173.78	13.16
			(816)	(141)	(3.42)	(0.35)	(0.20)	(25.46)	(34.17)	(3.13)
2007	658	179	997	160	20.10	3.78	8.84	175.59	205.64	13.16
			(865)	(148)	(3.33)	(0.36)	(0.19)	(25.36)	(42.55)	(2.67)
2008	632	168	1,072	169	20.21	3.79	8.85	213.15	258.04	13.32
			(956)	(154)	(3.53)	(0.37)	(0.20)	(35.10)	(66.47)	(2.50)
2009	593	154	1,081	173	19.87	3.77	8.86	169.74	232.06	12.99
			(942)	(156)	(3.66)	(0.41)	(0.25)	(52.77)	(65.47)	(2.37)
2010	580	151	1,124	177	20.19	3.75	8.88	146.11	218.12	12.99
			(967)	(160)	(3.68)	(0.43)	(0.22)	(27.58)	(46.11)	(2.27)
2011	576	147	1,154	181	20.46	3.81	8.89	211.29	269.87	12.80
			(984)	(162)	(3.85)	(0.43)	(0.22)	(56.84)	(48.82)	(2.28)
2012	529	139	1,157	182	20.73	3.83	8.90	229.16	304.15	12.87
			(1041)	(176)	(3.89)	(0.44)	(0.24)	(49.85)	(70.27)	(2.35)

Notes: Milk yield is reported in hundredweight per milking cow per month. Price of alfalfa, price of concentrates and additives, and wage rate are in 2005 dollars. Standard deviations are in parentheses.

Table 5: Summary Statistics of Costs of Production

A: Total costs of production and feed costs

	Total ($/cwt)			Feed ($/cwt)		
Year	Large CAFs	Medium CAFs	Other	Large CAFs	Medium CAFs	Other
2006	13.18	13.50	14.28	6.65	6.89	7.47
	(1.68)	(1.88)	(2.51)	(0.65)	(0.81)	(1.61)
2007	13.86	14.51	15.19	7.37	7.75	8.32
	(1.47)	(2.07)	(3.19)	(0.78)	(1.35)	(2.17)
2008	15.70	16.98	17.54	8.95	9.88	10.22
	(1.55)	(3.05)	(4.13)	(0.93)	(1.95)	(2.90)
2009	14.20	15.37	15.97	8.04	8.84	8.86
	(1.45)	(3.62)	(4.33)	(0.98)	(2.16)	(2.67)
2010	12.74	13.64	14.49	7.08	7.65	7.91
	(1.35)	(2.52)	(3.54)	(0.77)	(1.64)	(1.93)
2011	14.30	15.51	16.34	8.87	9.67	10.09
	(1.53)	(3.17)	(3.76)	(1.08)	(2.05)	(2.46)
2012	15.25	16.28	17.49	9.93	10.60	11.40
	(1.57)	(3.51)	(4.58)	(1.11)	(2.40)	(3.29)

B: Costs of hired labor and operating costs

	Hired Labor ($/cwt)			Operating ($/cwt)		
Year	Large CAFs	Medium CAFs	Other	Large CAFs	Medium CAFs	Other
2006	1.44	1.58	1.62	2.69	2.58	2.73
	(0.35)	(0.43)	(0.59)	(0.61)	(0.68)	(0.78)
2007	1.39	1.53	1.67	2.71	2.59	2.72
	(0.37)	(0.38)	(0.57)	(0.59)	(0.63)	(0.80)
2008	1.38	1.56	1.84	2.77	2.74	2.95
	(0.34)	(0.47)	(0.66)	(0.57)	(0.80)	(0.96)
2009	1.39	1.53	1.89	2.65	2.71	2.85
	(0.35)	(0.46)	(0.76)	(0.54)	(0.93)	(1.14)
2010	1.36	1.46	1.85	2.63	2.72	2.83
	(0.34)	(0.40)	(0.74)	(0.55)	(0.77)	(1.13)
2011	1.32	1.47	1.75	2.58	2.76	2.82
	(0.33)	(0.46)	(0.77)	(0.54)	(0.86)	(1.10)
2012	1.30	1.43	1.72	2.49	2.68	2.77
	(0.32)	(0.45)	(0.74)	(0.51)	(0.85)	(1.20)

Notes: This data set includes only the costs of activities related to milking and dry cows. The costs are reported in 2005 dollars. Standard deviations are in parentheses.

Table 6: Estimation Results of Specification (1): Total Costs and Elements

	Total	Feed	Hired Labor	Operating
Rule 4570	-0.245	-0.065	-0.039	0.030
	(0.168)	(0.081)	(0.028)	(0.043)
Rule 4570: Phase II	-0.109	-0.117	-0.034	0.129
	(0.237)	(0.154)	(0.059)	(0.080)
Farm FEs	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes
R-squared (within farm)	0.496	0.702	0.117	0.164
Observations	4277	4277	4277	4277
Farms	220	220	220	220

Notes: * p<0.10, ** p<0.05, *** p<0.01. All costs are in 2005 dollars per cwt of milk.
Standard errors reported in parentheses are clustered by farm.

Table 7: Estimation Results of Specification (2): Total Costs and Elements

	Total	Feed	Hired Labor	Operating
Rule 4570	-0.107	0.015	0.014	0.037
	(0.110)	(0.050)	(0.023)	(0.037)
Rule 4570: Phase II	0.074	-0.131	0.150***	0.111
	(0.189)	(0.135)	(0.051)	(0.079)
Price of alfalfa ($/ton)	0.012***	0.011***	0.001*	-0.000
	(0.001)	(0.001)	(0.000)	(0.001)
Price of concentrates & additives ($/ton)	0.021***	0.020***	0.001**	0.002***
	(0.001)	(0.001)	(0.000)	(0.000)
Wage rate ($/hour)	0.089***	0.020	0.062***	0.007
	(0.025)	(0.014)	(0.008)	(0.009)
Number of milking cows (1,000)	-1.307***	-0.524***	-0.237***	-0.488***
	(0.325)	(0.130)	(0.069)	(0.119)
Number of dry cows (1,000)	5.079***	2.838***	0.811***	1.224**
	(1.500)	(0.761)	(0.255)	(0.487)
Milk yield (cwt/milk cow/month)	-0.565***	-0.209***	-0.059***	-0.091***
	(0.041)	(0.019)	(0.007)	(0.009)
Fat test (%)	1.062***	0.668***	0.110*	0.322**
	(0.359)	(0.159)	(0.066)	(0.146)
SNF test (%)	-0.305	0.050	-0.016	-0.229*
	(0.390)	(0.249)	(0.086)	(0.116)
Trend: North Coast	-0.042	-0.006	-0.006	0.001
	(0.027)	(0.016)	(0.015)	(0.007)
Trend: North Valley (LCAFs)	-0.008	0.016*	-0.012***	-0.004
	(0.013)	(0.009)	(0.004)	(0.006)
Trend: North Valley (MCAFs)	-0.008	0.024***	-0.014***	0.005
	(0.012)	(0.009)	(0.004)	(0.006)
Trend: North Valley (other)	-0.001	0.026***	-0.001	-0.005
	(0.011)	(0.008)	(0.004)	(0.005)
Trend: South Valley (LCAFs)	-0.011	0.030***	-0.014***	-0.007
	(0.012)	(0.008)	(0.003)	(0.005)
Trend: South Valley (MCAFs)	-0.026**	0.022**	-0.020***	-0.014*
	(0.013)	(0.009)	(0.005)	(0.008)
Trend: South Valley (other)	-0.013	0.026***	-0.007*	-0.008
	(0.015)	(0.007)	(0.004)	(0.007)
Trend: Southern California	-0.006	0.041***	-0.006*	-0.018***
	(0.018)	(0.013)	(0.003)	(0.004)
Farm FEs	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes
R-squared (within farm)	0.763	0.879	0.274	0.278

Notes: * p<0.10, ** p<0.05, *** p<0.01. All costs are in 2005 dollars per cwt of milk. Standard errors reported in parentheses are clustered by farm. LCAFs indicate large confined animal facilities and MCAFs indicate medium confined animal facilities.

Table 8: Estimation Results of Specification (3): Total Costs and Elements

	Total	Feed	Hired Labor	Operating
Phase II: -4	0.151	-0.152	0.051	0.154
	(0.324)	(0.182)	(0.066)	(0.122)
Phase II: -3	0.542**	0.065	0.131**	0.247***
	(0.271)	(0.206)	(0.057)	(0.090)
Phase II: -2	0.328	-0.186	0.129**	0.268***
	(0.263)	(0.154)	(0.063)	(0.096)
Phase II: -1	0.181	-0.275	0.123	0.194
	(0.409)	(0.188)	(0.113)	(0.129)
Phase II: 0	0.208	-0.299*	0.140*	0.234**
	(0.272)	(0.163)	(0.078)	(0.111)
Phase II: 1	0.313	-0.196	0.212**	0.208*
	(0.311)	(0.209)	(0.088)	(0.120)
Phase II: 2	0.254	-0.278	0.197**	0.256*
	(0.315)	(0.220)	(0.087)	(0.129)
Phase II: 3	0.463	-0.155	0.222**	0.302**
	(0.332)	(0.261)	(0.099)	(0.126)
Phase II: 4	0.704	-0.090	0.310***	0.434**
	(0.622)	(0.407)	(0.111)	(0.202)
Phase II: 5	0.266	-0.397	0.338***	0.276*
	(0.389)	(0.294)	(0.109)	(0.145)
Phase II: 6	0.329	-0.474*	0.292***	0.391**
	(0.386)	(0.256)	(0.111)	(0.151)
Phase II: 7	0.715	-0.316	0.399***	0.564***
	(0.463)	(0.273)	(0.145)	(0.166)
Phase II: 8	1.067*	-0.013	0.389***	0.556***
	(0.604)	(0.352)	(0.139)	(0.209)
Covariates	Yes	Yes	Yes	Yes
Farm FEs	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes
Region-regulation time trends	Yes	Yes	Yes	Yes
R-squared (within farm)	0.775	0.870	0.345	0.369
Observations	2530	2530	2530	2530
Groups	141	141	141	141

Notes: * p<0.10, ** p<0.05, *** p<0.01. All costs are in 2005 dollars per cwt of milk. Standard errors reported in parentheses are clustered by farm. This table reports the estimated effects of Phase II on medium dairy CAFs between the fourth quarter of 2009 (-4) and the fourth quarter of 2012 (8).

Table 9: SUR Estimation Results of Specification (2): Total Costs and Elements

	Total	Feed	Hired Labor	Operating
Rule 4570	-0.107	0.015	0.014	0.037
	(0.076)	(0.044)	(0.020)	(0.031)
Rule 4570: Phase II	0.074	-0.131	0.150***	0.111*
	(0.145)	(0.083)	(0.038)	(0.060)
Price of alfalfa ($/ton)	0.012***	0.011***	0.001***	0.000
	(0.001)	(0.001)	0.000	0.000
Price of concentrates & additives ($/ton)	0.021***	0.020***	0.001***	0.002***
	(0.001)	0.000	0.000	0.000
Wage rate ($/hour)	0.089***	0.020***	0.062***	0.007
	(0.013)	(0.007)	(0.003)	(0.005)
Number of milking Cows (1,000)	-1.307***	-0.524***	-0.237***	-0.488***
	(0.108)	(0.062)	(0.028)	(0.045)
Number of dry Cows (1,000)	5.079***	2.838***	0.811***	1.224***
	(0.412)	(0.237)	(0.107)	(0.170)
Milk yield (cwt/milk cow/month)	-0.565***	-0.209***	-0.059***	-0.091***
	(0.012)	(0.007)	(0.003)	(0.005)
Fat test (%)	1.062***	0.668***	0.110***	0.322***
	(0.127)	(0.073)	(0.033)	(0.053)
SNF test (%)	-0.305*	0.050	-0.016	-0.229***
	(0.162)	(0.093)	(0.042)	(0.067)
Trend: North Coast	0.009	0.035***	-0.001	0.010*
	(0.014)	(0.008)	(0.004)	(0.006)
Trend: North Valley (LCAFs)	-0.008	0.016***	-0.012***	-0.004
	(0.010)	(0.006)	(0.003)	(0.004)
Trend: North Valley (MCAFs)	-0.008	0.024***	-0.014***	0.005
	(0.010)	(0.006)	(0.003)	(0.004)
Trend: North Valley (other)	-0.001	0.026***	-0.001	-0.005
	(0.007)	(0.004)	(0.002)	(0.003)
Trend: South Valley (LCAFs)	-0.029	0.071***	-0.012**	-0.006
	(0.018)	(0.010)	(0.005)	(0.008)
Trend: South Valley (MCAFs)	-0.045**	0.064***	-0.017***	-0.013*
	(0.019)	(0.010)	(0.005)	(0.008)
Trend: South Valley (other)	-0.032	0.068***	-0.005	-0.007
	(0.020)	(0.011)	(0.005)	(0.008)
Trend: Southern California	-0.006	0.041***	-0.006	-0.018**
	(0.018)	(0.010)	(0.005)	(0.007)
Farm FEs	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes
R-squared	0.914	0.944	0.819	0.788

Notes: * p<0.10, ** p<0.05, *** p<0.01. All costs are in 2005 dollars per cwt of milk. SUR estimates the full variance-covariance matrix of the coefficients. R-squared is not a well-defined concept when SUR is used. LCAFs indicate large confined animal facilities and MCAFs indicate medium confined animal facilities.

Table 10: Estimation Results of Specification (2): Feed Costs and Elements

	Feed Total	Dry Feed	Wet Feed	Concentrates & Additives
Rule 4570	0.015	-0.046	0.051	-0.057
	(0.044)	(0.048)	(0.036)	(0.044)
Rule 4570: Phase II	-0.131	-0.115	-0.023	-0.060
	(0.083)	(0.091)	(0.068)	(0.084)
Price of alfalfa ($/ton)	0.011***	0.010***	0.000	0.000
	(0.001)	(0.001)	(0.000)	(0.001)
Price of concentrates & additives ($/ton)	0.020***	0.002***	0.001*	0.014***
	(0.000)	(0.000)	(0.000)	(0.000)
Wage rate ($/hour)	0.020***	0.018**	0.000	0.001
	(0.007)	(0.008)	(0.006)	(0.007)
Number of milking cows (1,000)	-0.524***	-0.373***	-0.222***	0.043
	(0.062)	(0.068)	(0.051)	(0.062)
Number of dry cows (1,000)	2.838***	1.932***	1.025***	0.230
	(0.237)	(0.260)	(0.194)	(0.237)
Milk yield (cwt/milk cow/month)	-0.209***	-0.119***	-0.051***	-0.103***
	(0.007)	(0.008)	(0.006)	(0.007)
Fat test (%)	0.668***	0.332***	0.251***	-0.018
	(0.073)	(0.080)	(0.060)	(0.073)
SNF test (%)	0.050	-0.258**	-0.650***	0.923***
	(0.093)	(0.102)	(0.077)	(0.093)
Trend: North Coast	-0.006	-0.019**	0.022***	0.005
	(0.008)	(0.009)	(0.006)	(0.008)
Trend: North Valley (LCAFs)	0.004	-0.017	0.104***	-0.050***
	(0.016)	(0.018)	(0.013)	(0.018)
Trend: North Valley (MCAFs)	0.012	-0.005	0.104***	-0.060***
	(0.016)	(0.018)	(0.013)	(0.018)
Trend: North Valley (other)	0.014	-0.004	0.102***	-0.059***
	(0.016)	(0.017)	(0.013)	(0.018)
Trend: South Valley (LCAFs)	-0.018	-0.101***	0.077***	0.001
	(0.016)	(0.015)	(0.013)	(0.015)
Trend: South Valley (MCAFs)	-0.025	-0.105***	0.080***	0.000
	(0.016)	(0.016)	(0.013)	(0.015)
Trend: South Valley (other)	-0.022	-0.098***	0.081***	-0.018
	(0.017)	(0.016)	(0.014)	(0.015)
Trend: Southern California	0.043***	0.002	0.073***	-0.032**
	(0.015)	(0.016)	(0.012)	(0.014)
Farm FEs	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes
R-squared	0.944	0.719	0.692	0.841

Notes: * p<0.10, ** p<0.05, *** p<0.01. All costs are in 2005 dollars per cwt of milk. SUR estimates the full variance-covariance matrix of the coefficients. R-squared is not a well-defined concept when SUR is used. LCAFs indicate large confined animal facilities and MCAFs indicate medium confined animal facilities.

Table 11: Estimation Results of Specification (2): Operating Costs and Elements

	Operating Total	Utilities	Fuel & Oil	Maintenance	Miscellaneous
Rule 4570	0.036	0.006	0.011**	-0.006	-0.002
	(0.031)	(0.006)	(0.004)	(0.013)	(0.004)
Rule 4570: Phase II	0.107*	-0.005	-0.010	0.001	0.019***
	(0.060)	(0.012)	(0.008)	(0.024)	(0.007)
Price of alfalfa ($/ton)	0.000	0.000	0.000	-0.000*	0.000
	0.000	0.000	0.000	0.000	0.000
Price of concentrates & additives ($/ton)	0.002***	0.000**	0.000	0.000	0.000***
	0.000	0.000	0.000	0.000	0.000
Wage rate ($/hour)	0.007	0.004***	0.000	0.008***	-0.001
	(0.005)	(0.001)	(0.001)	(0.002)	(0.001)
Number of milking cows (1,000)	-0.494***	-0.044***	-0.038***	-0.016	0.001
	(0.045)	(0.009)	(0.006)	(0.018)	(0.005)
Number of dry cows (1,000)	1.276***	0.147***	0.082***	0.164**	0.003
	(0.171)	(0.035)	(0.023)	(0.070)	(0.021)
Milk yield (cwt/milk cow/month)	-0.092***	-0.019***	-0.010***	-0.014***	-0.002***
	(0.005)	(0.001)	(0.001)	(0.002)	(0.001)
Fat test (%)	0.300***	0.017	0.009	0.055**	0.024***
	(0.053)	(0.011)	(0.007)	(0.022)	(0.006)
SNF test (%)	-0.226***	0.010	-0.025***	0.048*	-0.013
	(0.067)	(0.014)	(0.009)	(0.027)	(0.008)
Trend: North Coast	0.000	0.002**	0.006***	-0.003	0.000
	(0.006)	(0.001)	(0.001)	(0.002)	(0.001)
Trend: North Valley (LCAFs)	0.034***	0.007***	0.006***	0.010**	0.001
	(0.012)	(0.002)	(0.002)	(0.005)	(0.001)
Trend: North Valley (MCAFs)	0.042***	0.007***	0.005***	0.012**	0.001
	(0.012)	(0.002)	(0.002)	(0.005)	(0.001)
Trend: North Valley (other)	0.031***	0.006**	0.004***	0.009**	0.003*
	(0.011)	(0.002)	(0.002)	(0.005)	(0.001)
Trend: South Valley (LCAFs)	0.066***	0.002	0.001	-0.008*	0.000
	(0.012)	(0.002)	(0.002)	(0.005)	(0.001)
Trend: South Valley (MCAFs)	0.059***	0.002	0.000	-0.009*	0.001
	(0.012)	(0.002)	(0.002)	(0.005)	(0.001)
Trend: South Valley (other)	0.065***	0.001	0.000	-0.005	0.003**
	(0.012)	(0.002)	(0.002)	(0.005)	(0.001)
Trend: Southern California	0.018	-0.001	0.003**	0.004	0.002
	(0.011)	(0.002)	(0.001)	(0.004)	(0.001)
Farm FEs	Yes	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes	Yes
R-squared	0.789	0.817	0.725	0.528	0.578

Notes: * p<0.10, ** p<0.05, *** p<0.01. All costs are in 2005 dollars per cwt of milk. SUR estimates the full variance-covariance matrix of the coefficients. R-squared is not a well-defined concept when SUR is used. LCAFs indicate large confined animal facilities and MCAFs indicate medium confined animal facilities.

Table 12: Estimation Results with Medium Dairy Farms

	Total	Feed	Hired Labor	Operating
Rule 4570: Phase II	0.370	0.277*	0.200***	0.132
	(0.245)	(0.155)	(0.052)	(0.114)
Price of alfalfa ($/ton)	0.008***	0.010***	0.000	0.000
	(0.002)	(0.001)	(0.000)	(0.001)
Price of concentrates & additives ($/ton)	0.020***	0.020***	0.001***	0.002***
	(0.001)	(0.001)	(0.000)	0.000
Wage rate ($/hour)	0.131***	0.006	0.073***	0.029***
	(0.020)	(0.013)	(0.004)	(0.009)
Number of milking cows (1,000)	-6.848***	-1.598***	-1.315***	-2.848***
	(0.555)	(0.352)	(0.119)	(0.258)
Number of dry cows (1,000)	9.197***	8.018***	1.013***	1.539***
	(1.121)	(0.711)	(0.240)	(0.522)
Milk yield (cwt/milk cow/month)	-0.655***	-0.218***	-0.067***	-0.103***
	(0.020)	(0.013)	(0.004)	(0.009)
Fat test (%)	1.260***	0.754***	0.202***	0.423***
	(0.224)	(0.142)	(0.048)	(0.104)
SNF test (%)	-0.427**	-0.169	0.013	-0.273***
	(0.207)	(0.131)	(0.044)	(0.096)
Farm FEs	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes
R-squared	0.932	0.948	0.849	0.777
Observations	1115	1115	1115	1115
Farms	62	62	62	62

Notes: * p<0.10, ** p<0.05, *** p<0.01. All costs are in 2005 dollars per cwt of milk. SUR estimates the full variance-covariance matrix of the coefficients. R-squared is not a well-defined concept when SUR is used.

Table 13: Estimation Results with Medium and Small Dairy Farms in the SJV

	Total	Feed	Hired Labor	Operating
Rule 4570: Phase II	0.129	-0.123	0.152***	0.172***
	(0.146)	(0.087)	(0.039)	(0.065)
Price of alfalfa ($/ton)	0.010***	0.010***	0.000	0.000
	(0.001)	(0.001)	(0.000)	(0.001)
Price of concentrates & additives ($/ton)	0.020***	0.019***	0.001***	0.001***
	(0.001)	(0.000)	(0.000)	(0.000)
Wage rate ($/hour)	0.108***	0.011	0.075***	0.017**
	(0.017)	(0.010)	(0.004)	(0.007)
Number of milking Cows (1,000)	-7.933***	-2.373***	-1.748***	-3.199***
	(0.504)	(0.299)	(0.135)	(0.226)
Number of dry Cows (1,000)	13.714***	9.370***	1.843***	3.194***
	(1.058)	(0.629)	(0.283)	(0.474)
Milk yield (cwt/milk cow/month)	-0.595***	-0.225***	-0.060***	-0.104***
	(0.015)	(0.009)	(0.004)	(0.007)
Fat test (%)	1.360***	0.545***	0.260***	0.250***
	(0.158)	(0.094)	(0.042)	(0.071)
SNF test (%)	-0.409**	-0.150	-0.012	-0.222***
	(0.188)	(0.112)	(0.050)	(0.084)
Farm FEs	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes
Regulation-specific time trends	Yes	Yes	Yes	Yes
R-squared	0.924	0.947	0.842	0.771
Observations	1818	1818	1818	1818
Farms	97	97	97	97

Notes: * p<0.10, ** p<0.05, *** p<0.01. All costs are in 2005 dollars per cwt of milk. SUR estimates the full variance-covariance matrix of the coefficients. R-squared is not a well-defined concept when SUR is used.

Table 14: Estimation Results with a Balanced Panel of Dairy Farms

	Total	Feed	Hired Labor	Operating
Rule 4570	-0.120	-0.006	0.028	0.041
	(0.074)	(0.041)	(0.025)	(0.034)
Rule 4570: Phase II	-0.093	-0.278***	0.179***	0.076
	(0.150)	(0.083)	(0.051)	(0.070)
Price of alfalfa ($/ton)	0.010***	0.009***	0.001*	0.000
	(0.001)	(0.001)	(0.000)	(0.000)
Price of concentrates & additives ($/ton)	0.020***	0.018***	0.001***	0.001***
	(0.001)	(0.000)	(0.000)	(0.000)
Wage rate ($/hour)	0.049***	-0.004	0.060***	-0.001
	(0.013)	(0.007)	(0.004)	(0.006)
Number of milking Cows (1,000)	-0.845***	-0.248***	-0.178***	-0.336***
	(0.112)	(0.062)	(0.038)	(0.052)
Number of dry Cows (1,000)	1.464***	1.363***	0.176	0.035
	(0.437)	(0.242)	(0.148)	(0.204)
Milk yield (cwt/milk cow/month)	-0.512***	-0.164***	-0.046***	-0.079***
	(0.012)	(0.007)	(0.004)	(0.006)
Fat test (%)	0.408***	0.382***	0.066	0.114*
	(0.135)	(0.075)	(0.046)	(0.063)
SNF test (%)	-0.049	0.102	0.008	-0.253***
	(0.207)	(0.114)	(0.070)	(0.096)
Trend: North Coast	-0.023	0.026***	-0.011**	-0.007
	(0.016)	(0.009)	(0.006)	(0.008)
Trend: North Valley (LCAFs)	-0.033**	0.068***	-0.034***	-0.017**
	(0.016)	(0.009)	(0.006)	(0.008)
Trend: North Valley (MCAFs)	-0.023	0.087***	-0.034***	-0.009
	(0.017)	(0.009)	(0.006)	(0.008)
Trend: North Valley (other)	-0.010	0.081***	-0.018***	-0.012*
	(0.014)	(0.008)	(0.005)	(0.007)
Trend: South Valley (LCAFs)	0.181***	0.067***	-0.054***	0.064***
	(0.027)	(0.009)	(0.006)	(0.013)
Trend: South Valley (MCAFs)	0.164***	0.053***	-0.060***	0.058***
	(0.028)	(0.010)	(0.006)	(0.013)
Trend: South Valley (other)	0.198***	0.057***	-0.041***	0.066***
	(0.029)	(0.008)	(0.005)	(0.013)
Trend: Southern California	0.011	0.059***	-0.011*	-0.016*
	(0.018)	(0.010)	(0.006)	(0.009)
Farm FEs	Yes	Yes	Yes	Yes
Region-quarter FEs	Yes	Yes	Yes	Yes
R-squared	0.904	0.944	0.823	0.760
Observations	2275	2275	2275	2275
Farms	82	82	82	82

Notes: * p<0.10, ** p<0.05, *** p<0.01. All costs are in 2005 dollars per cwt of milk. SUR estimates the full variance-covariance matrix of the coefficients. R-squared is not a well-defined concept when SUR is used. LCAFs indicate large confined animal facilities and MCAFs indicate medium confined animal facilities.

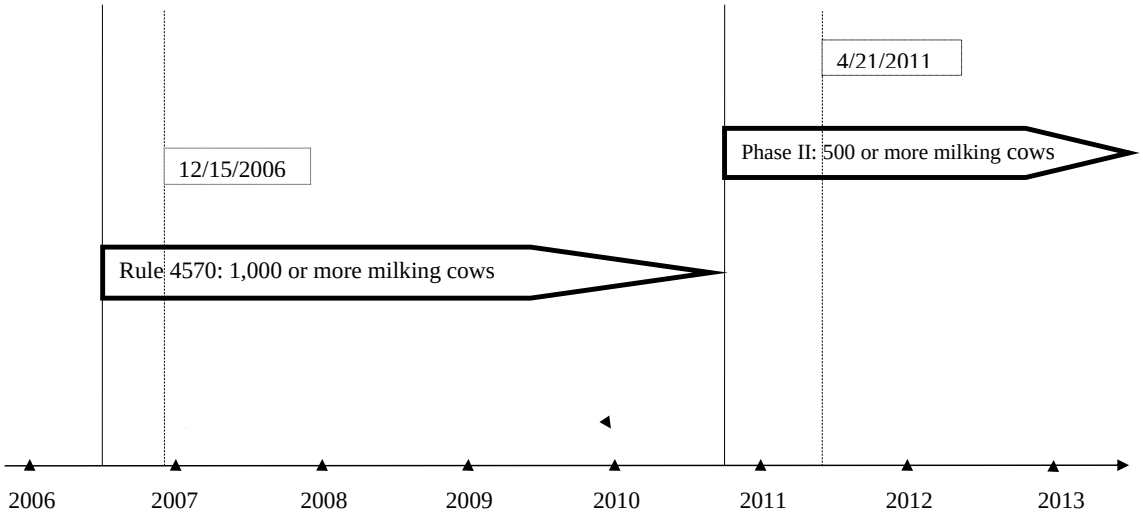
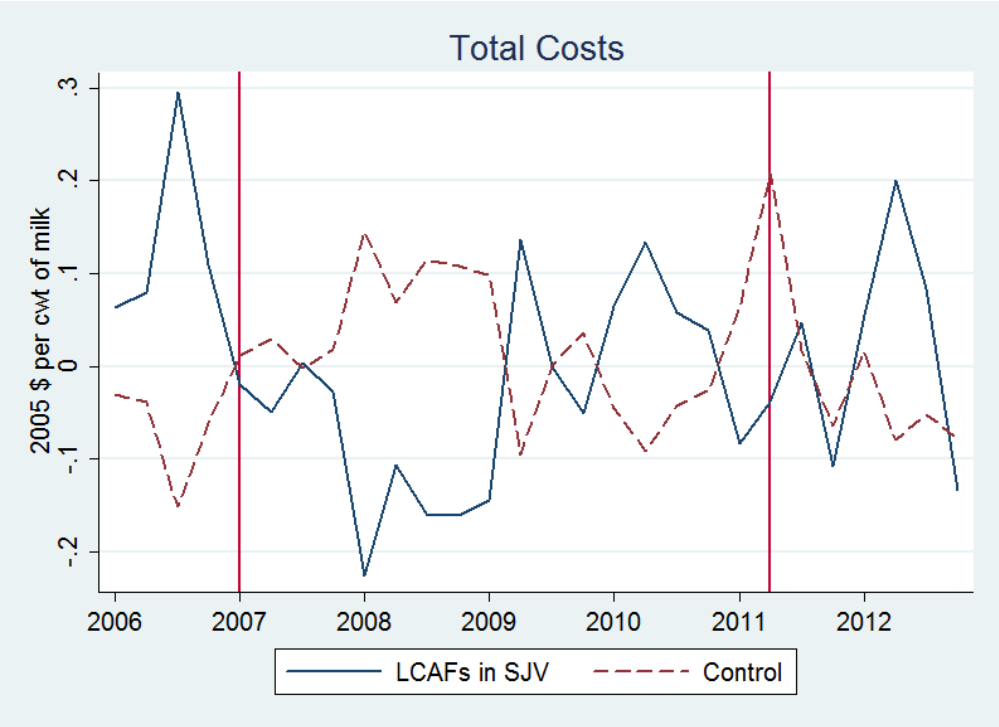
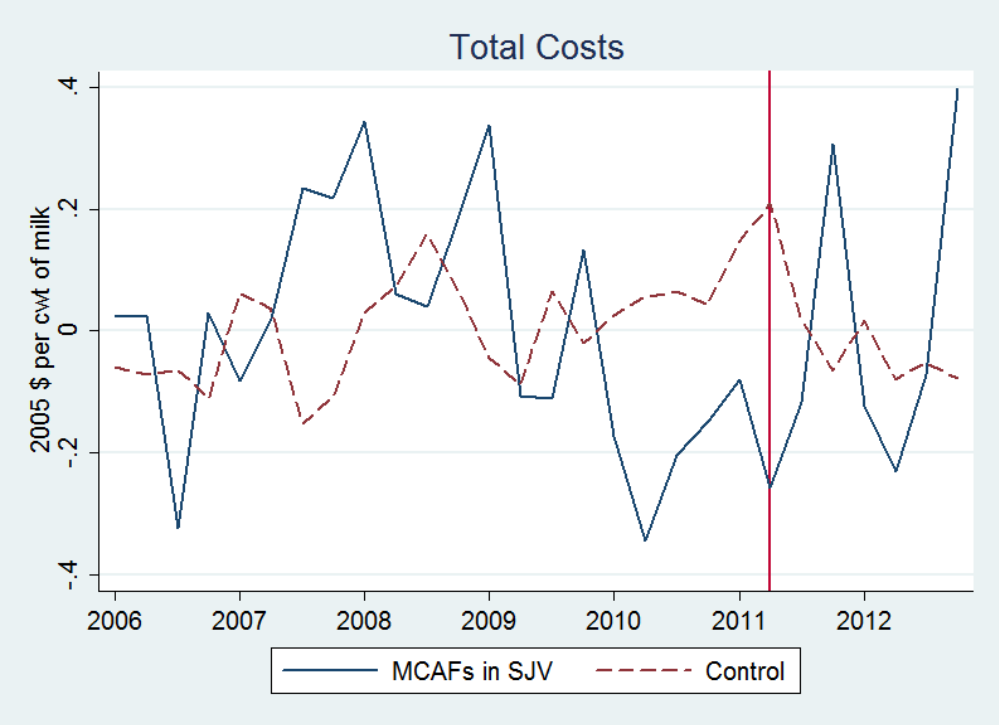


Figure 1: A Timeline of Rule 4570

Notes: The solid lines indicate the dates of the enactment of Rule 4570 and Phase II and the dashed lines indicate the due dates of the applications for permits.



Panel A



Panel B

Figure 2: Total Costs of Milk Production

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

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 are 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 and Additives: concentrates are products relatively high in energy and low in fiber, including grains, milled by-products, and protein products, such as rolled corn. Additives include micro and macro minerals, vitamins, and feed additives that improve feed efficiency.

Hired Labor Costs include 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, feed wagons, 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 include 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.

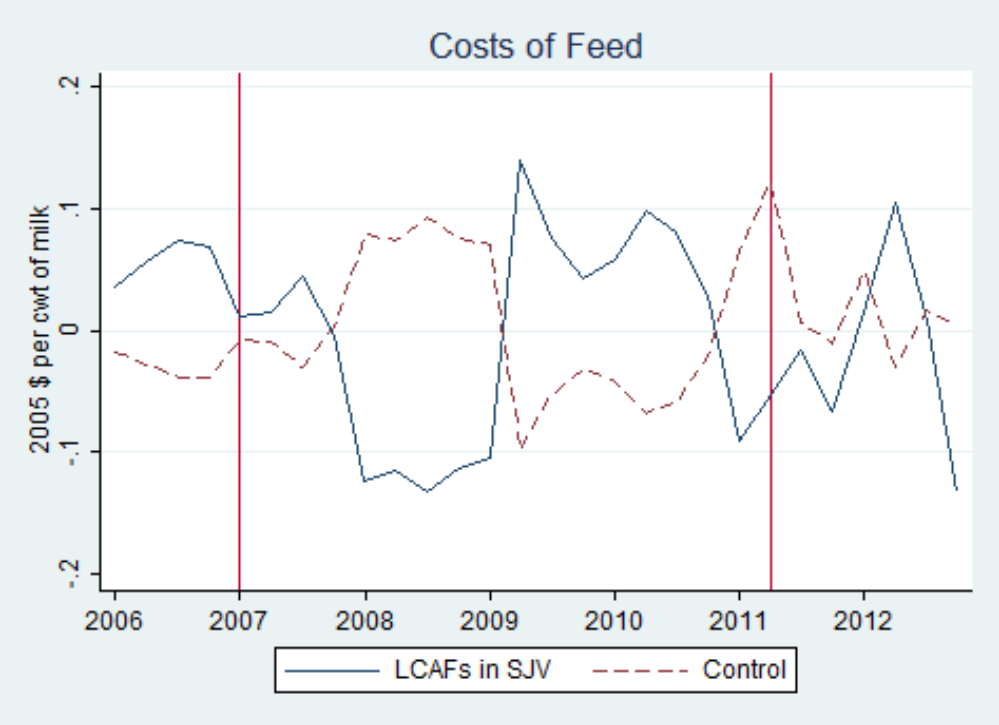
f) **Price of Alfalfa** is the average blend price of alfalfa hay fed to milking cows.

g) **Price of Concentrates & Additives** is calculated as the total costs of grain, minerals, and supplements, divided by the total tons fed to milking cows.

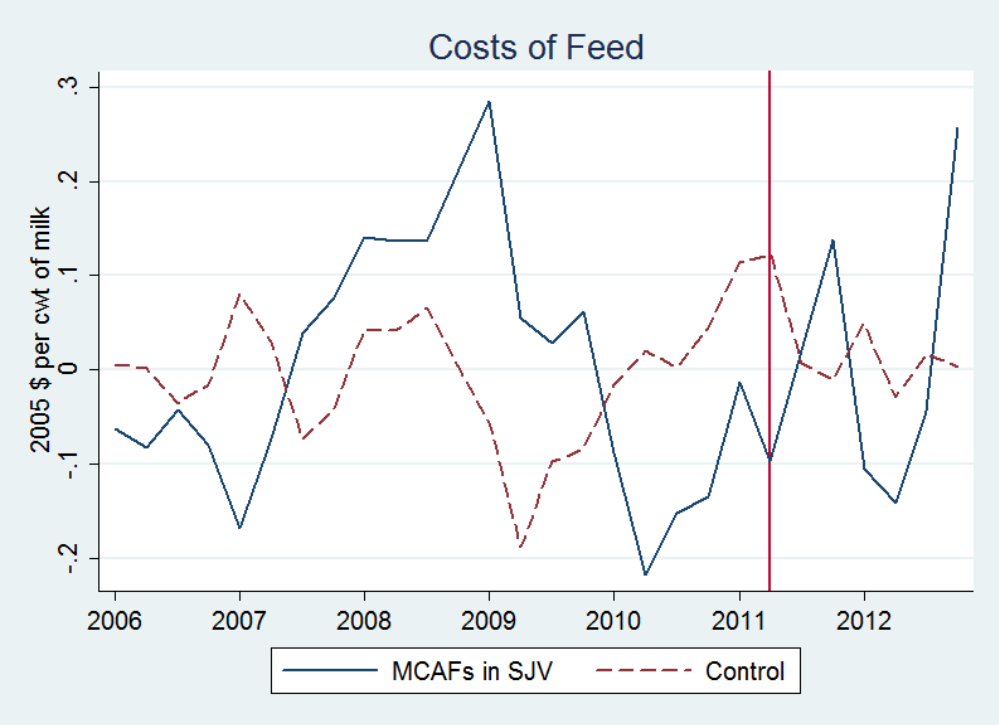
h) **Wage Rate** is the average hourly wage received by all hired employees, plus employer taxes and perquisites.

Appendix B. Residual Plots

Residual plots of feed costs, costs of hired labor, and operating costs are included in this appendix.

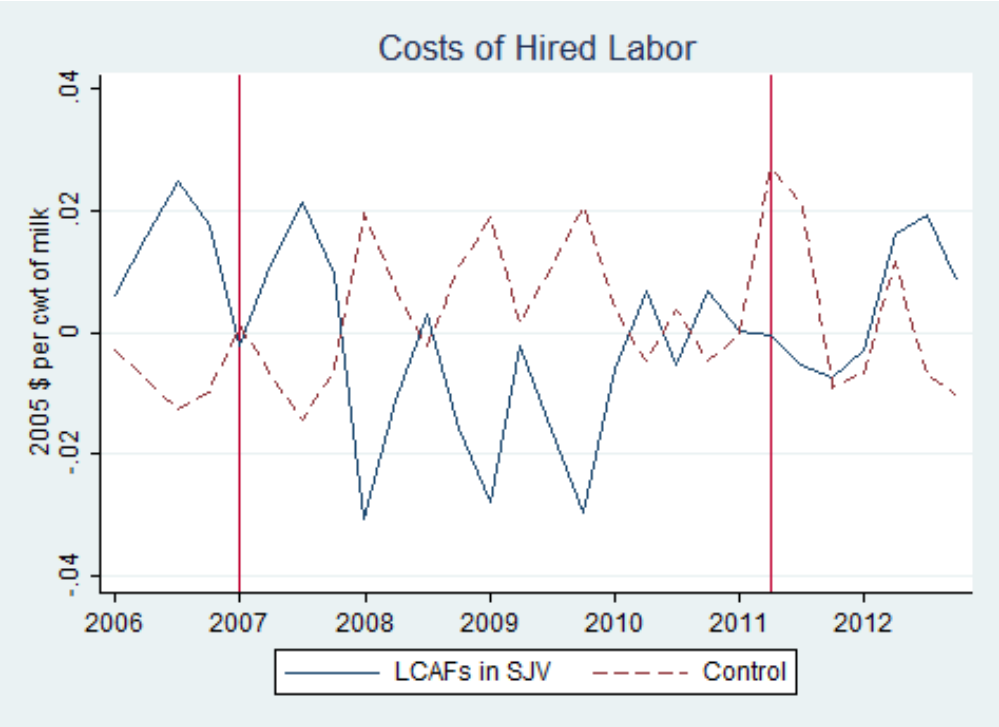


(a) Large dairy CAFs in the San Joaquin Valley versus control farms

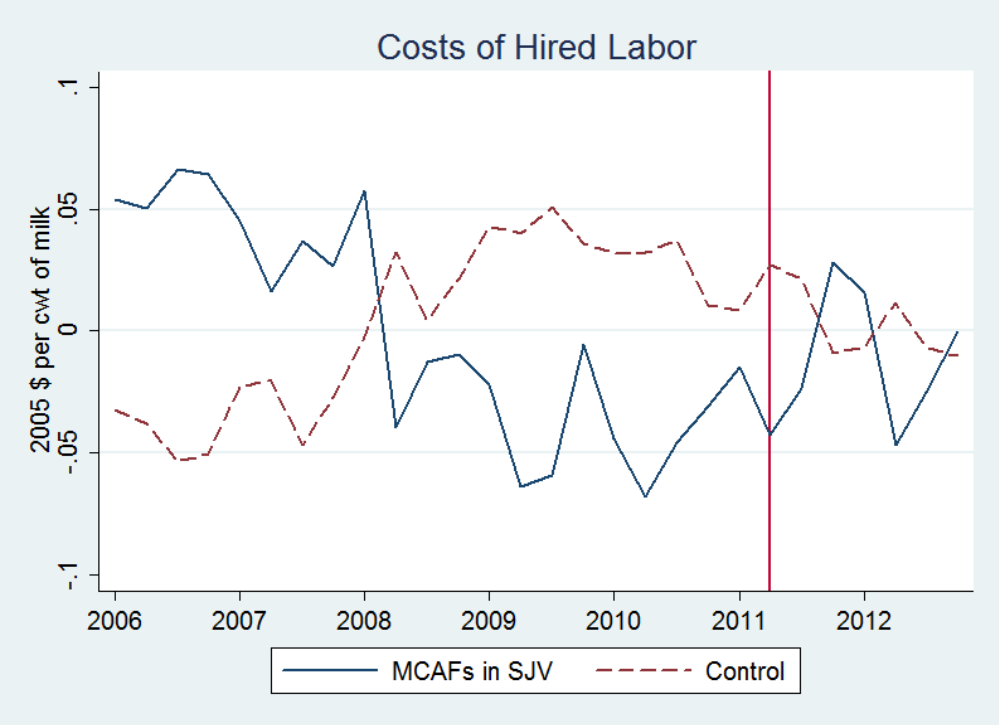


(b) Medium dairy CAFs in the San Joaquin Valley versus control farms

Figure 3: Feed Costs

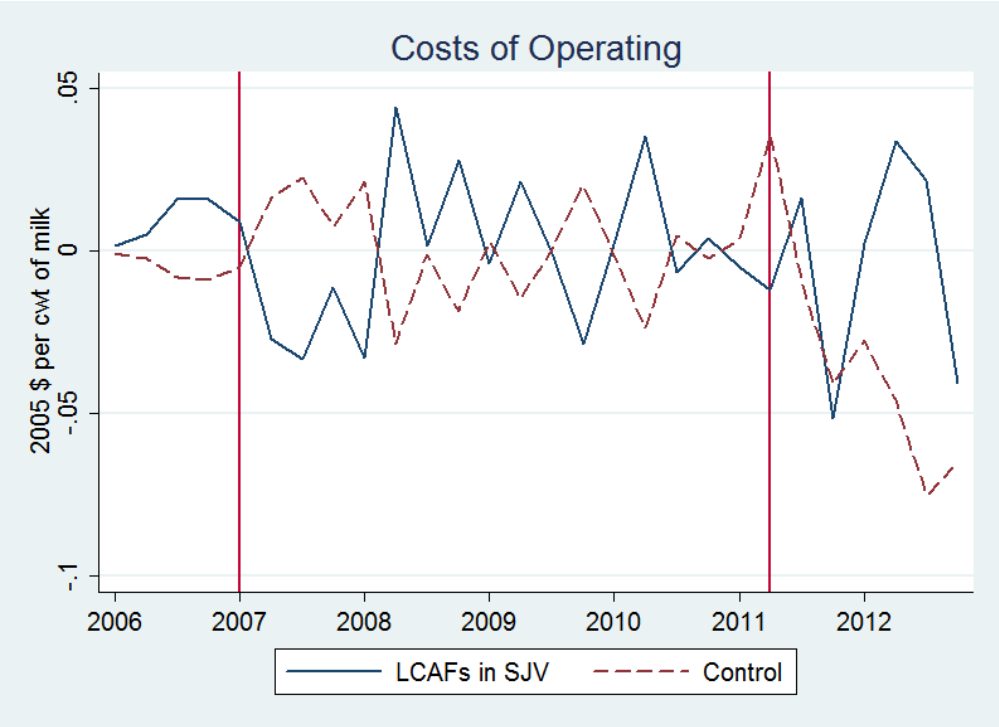


(a) Large dairy CAFs in the San Joaquin Valley versus control farms

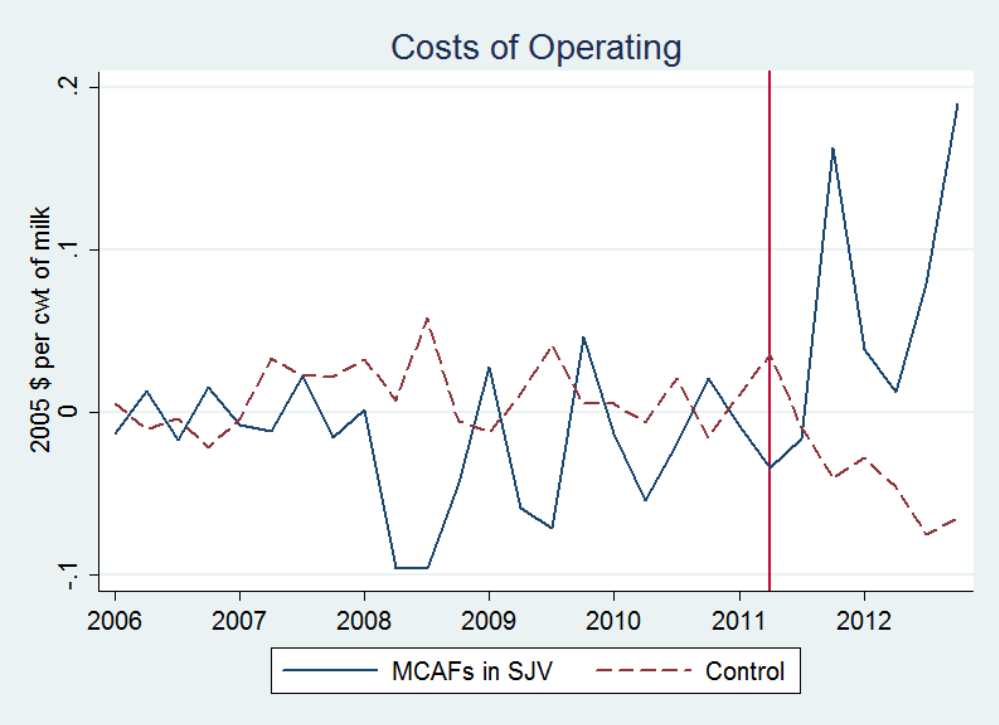


(b) Medium dairy CAFs in the San Joaquin Valley versus control farms

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

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