The Roles of Risk and Honey Bee Colony Strength in Determining Almond Pollination Contract Provisions

July 22, 2016

Brittney Goodrich

Agricultural and Resource Economics, University of California, Davis

goodrich@primal.ucdavis.edu

Selected Paper prepared for presentation at the 2016 Agricultural & Applied Economics Association Annual Meeting, Boston, Massachusetts, July 31-August 2

Abstract

Managed honey bee colonies provide pollination services, which are an essential input in the production of many crops in the United States. Over the last decade, the supply of U.S. honey bee colonies has become volatile as a result of multiple factors inhibiting colony health. This paper investigates the impact that colony supply uncertainty has on the California almond pollination market, the largest user of managed pollinators in the world. I develop a theoretical model and show that almond growers can reduce moral hazard in pollination agreements by paying beekeepers according to delivered colony strength. I utilize two unique datasets to identify determinants of almond pollination fees and test the predictions of the theoretical model. Using the California State Beekeeper's Association pollination fee survey for years 2008-2015, I find that providing low strength colonies for almond pollination results in lower fees collected by the beekeeper. I pair the beekeeper-reported data analysis with an empirical study of an almond grower pollination contract survey that I conducted at the 2015 Almond Conference. The results of the almond grower data analysis suggest that growers whose pollination contracts specify minimum colony strength requirements of at least the industry standard pay higher pollination fees than those who have lower or no colony strength requirements. The empirical results support the theoretical model finding that almond growers use colony strength requirements to elicit beekeeper effort. Since almond pollination represents only part of a commercial beekeeper's yearly income from honey production and pollination services, this paper highlights the need for additional research on the total economic impact of volatility of U.S. honey bee colony populations to effectively implement policies that promote managed pollinator health.

JEL Classifications: Q12, Q13, Q57

Keywords: Contracts, Pollination, Bees, Ecosystem Services, Colony Strength

1 Introduction

Managed honey bee colonies are an economically important component of United States (U.S.) agriculture. U.S. crops valued at over $18 billion dollars depend on managed honey bee colonies for pollination services, and California almond production is the largest user of such pollination services (NASS 2015). The California almond industry is reliant on securing the majority of U.S. managed honey bee colonies to meet its pollination needs. In 2016, almond pollination required approximately 76% of U.S. honey-producing colonies (NASS 2015). In turn, many U.S. beekeepers now consider almond pollination their main source of income.

In recent years, commercial beekeepers in the U.S. have experienced unpredictable spikes in winter mortality rates due to colony health issues, e.g., Colony Collapse Disorder (CCD), varroa mites, and poor nutrition. Beekeepers expect that a percentage of colonies will perish during the winter months, however volatility in colony health has resulted in unanticipated jumps in winter mortality rates.[1] U.S. managed honey bee colony health issues, especially CCD, have received media attention, drawing concern from the agriculture industry, general public and, consequently, policy makers. In 2015, the White House Pollinator Task Force released its *National Strategy to Promote the Health of Honey Bees and Other Pollinators* showing the commitment of the U.S. government to reducing the stressors to the U.S. honey bee colony population (Vilsack and McCarthy 2015).

The almond pollination market is extremely sensitive to volatility in the total number and health of U.S. honey bee colonies for two reasons: 1) the number of colonies almond pollination requires necessitates shipment from beekeepers across the U.S. and 2) almond bloom occurs in mid-February, almost simultaneously with the discovery of U.S. honey bee colony winter mortality. The objective of this paper is to identify the ways in which the uncertain supply of colonies impacts almond growers and beekeepers and their almond pollina-

---

[1] The Bee Informed Partnership reports that during the 2015-2016 winter, 16.9% colony loss was an economically acceptable winter colony loss rate but beekeepers averaged winter loss rates of 28.1%.

tion agreements. The primary focus is the influence of colony strength on almond pollination fees. Using a theoretical model and multiple econometric analyses, I find that more stringent colony strength requirements in almond pollination agreements are associated with higher almond pollination fees paid to beekeepers, and an increase in an individual beekeeper's mortality rate significantly decreases the per colony almond pollination fee she collects. This finding implies that an increase in average colony strength during almond pollination will increase the per colony pollination fee collected, since winter mortality rates are used as a proxy for colony strength in almond pollination. Almond pollination fees paid to beekeepers also vary systematically with other pollination agreement components. These findings are consistent with the theoretical model, which illustrates that almond growers are willing to pay a premium for a more secure pollinator supply.

The paper proceeds as follows: Section 2 begins by providing background information on honey bee colony strength and almond pollination agreements. Section 3 introduces the past economic literature on pollination services markets and outlines where this paper fits into the existing literature. In Section 4, I develop a theoretical principal-agent model to describe almond pollination contract decisions between the almond grower (principal) and beekeeper (agent). Section 5 includes two empirical analyses of almond pollination fees using survey data from beekeeper and almond grower perspectives. Finally, Section 6 concludes with a few closing comments.

2 Background

The use of managed honey bee colonies for almond pollination is complicated by the dynamic nature of honey bee colonies. To understand supply and demand factors in the almond pollination market, I first provide a description of honey bee biology as it relates to almond pollination, then I describe the moral hazard problem that arises in almond pollination agreements. Finally, I provide a description of the various contract components used to address the moral hazard issue in almond pollination agreements.

2.1 Honey Bee Biology

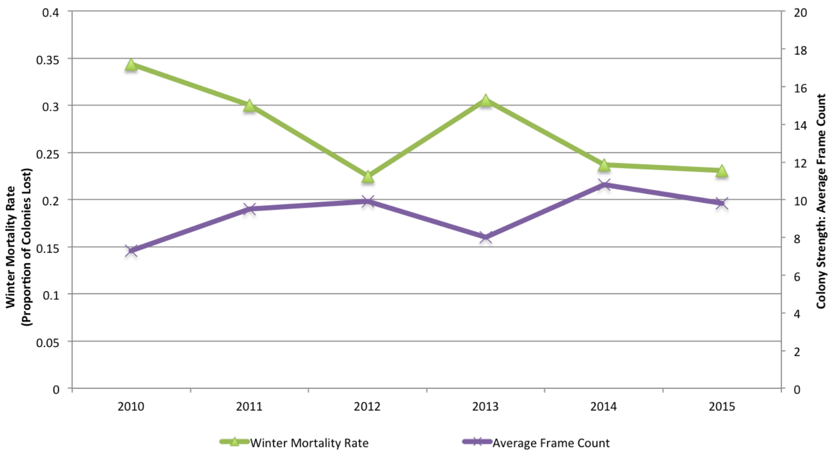
A hive is the physical container for a honey bee colony. It consists of a wooden box with frame inserts on which worker bees construct the comb that they use to store honey and developing bee brood. Industry members define colony strength by counting the number of standard frames in a hive that are at least 75% covered in bees and brood. This is referred to as an "active" frame. In pollination agreements, almond growers, beekeepers and almond pollination brokers refer to various colony strength requirements in terms of the number of active frames per hive.

Honey bee colonies exhibit increasing returns to scale in pollination; Sheesley et al. (1970) found that one 12-frame hive will pollinate significantly more than three 4-frame hives. This relationship between colony strength and pollination efficiency of a hive influences growers' almond pollination decisions, so almond pollination agreements often contain minimum colony strength requirements.

Moeller (1977) discusses that a honey bee colony is a superorganism (an organism made up of many organisms) that a beekeeper manages by manipulating the colony's natural cycle. The superorganism would continue living forever if it does not fall victim to terminal health inhibitors, e.g., starvation or CCD. It follows from the dynamics of the superorganism that health issues and beekeeping input decisions during one time of the year carry over into subsequent time periods (Champetier et al. 2015).

The winter mortality rate is the primary statistic reported by beekeepers, researchers and policy makers in reference to honey bee colony health. Due to the dynamics of the honey bee colony, winter mortality rates are a good indicator of colony health, especially during almond pollination. As displayed by Figure 1, winter mortality rates and colony strength during almond pollination are highly negatively correlated, or when winter mortality rates are high, average colony strength during almond pollination is low. This correlation occurs

Figure 1: Almond Pollination Colony Strength and U.S. Winter Mortality Rates, 2010-2015



Source: Goodrich, B. & Goodhue, R.E. "Honey Bee Colony Strength in the California Almond Pollination Market." *ARE Update* 19(4) (2016): 5-8.
Data Sources: The Pollination Connection; Bee Informed Partnership Winter Loss Surveys

because colony health inhibitors that cause high winter mortality rates make it more costly for beekeepers to increase colony strength for almond pollination. This adds to uncertainty in the supply of honey bees for almond pollination because when fewer colonies are available, the colonies that are available are likely of lower strength.

The dynamics of honey bee colonies play an important role in the almond pollination market as shown in Figure 2. Almond bloom occurs almost immediately after colony overwintering takes place. During winter across most of the U.S. there is very little forage for honey bees to make honey for food and rear brood. Thus, during late fall colonies naturally shrink in size, i.e., brood production ceases, so that they may survive on food stores throughout the winter (Figure 2b). It is not economical for a beekeeper to increase colony size until natural forage becomes available, otherwise she will have to provide colonies with costly food supplements.

Figure 2a displays a timeline of important events influencing colony strength and numbers for almond pollination. This timeline was developed with information obtained through interviews with beekeepers, almond growers and almond pollination brokers. The biggest influence on winter mortality rates are beekeeping decisions made in the fall in preparation for overwintering, e.g., honey extraction and varroa treatments, and these management decisions are often made prior to contracting for almond pollination. A beekeeper that over extracts honey may leave colonies with too little stored food to sustain the colony over winter and increase her winter mortality rates.[2] Many exogenous factors affect the outcomes of fall management decisions, so uncertainty exists in the beekeeper's return on specific actions to decrease winter mortality rates. For example, a varroa treatment could be made ineffective if nearby colonies are highly infested with varroa mites. Winter weather, which varies by region, is a key exogenous influence on overwintering mortality.

A healthy colony coming out of winter will be much less costly to expand for almond pollination, in terms of supplemental food and pest/disease treatment costs, than a weak colony. Thus, there are two components of a beekeeper's delivered colony strength for almond pollination: 1) Effort and inputs in preparation for almond pollination that are influenced by almond pollination fees and contract provisions, and 2) Random error associated with exogenous variables that influenced overwinter mortality rates. The ability of a beekeeper to increase colony strength is correlated with winter mortality rates through exogenous colony health shocks. Contracting with a high colony strength standard prior to realization of winter mortality rates is risky for the beekeeper, given that it may end up being very costly for her to meet these colony strength requirements.

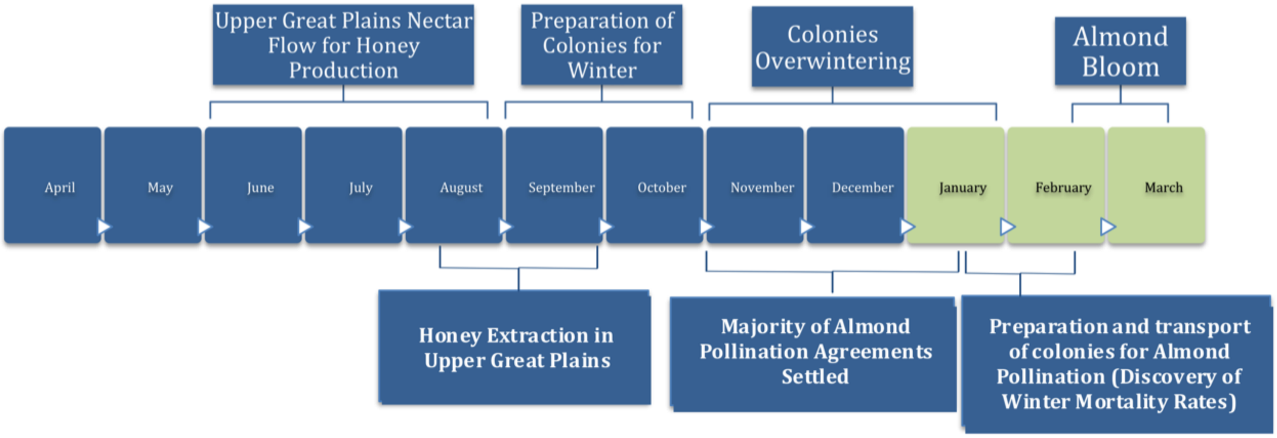
The timing of Upper Great Plains honey production is included in Figure 2a due to the significance this honey producing area holds in commercial beekeeping operations. Many commercial beekeeping operations transport their colonies to this area for summer honey production due to its abundance of bee forage with relatively low pesticide levels. In recent years, approximately 20 percent of U.S. honey producing colonies have been registered for honey production in North Dakota alone. In 2015, North Dakota, South Dakota and Montana accounted for 43 percent of total U.S. honey production. Better pesticide-free honey flow during the summer results in stronger colonies coming out of winter for almond pollina-

---

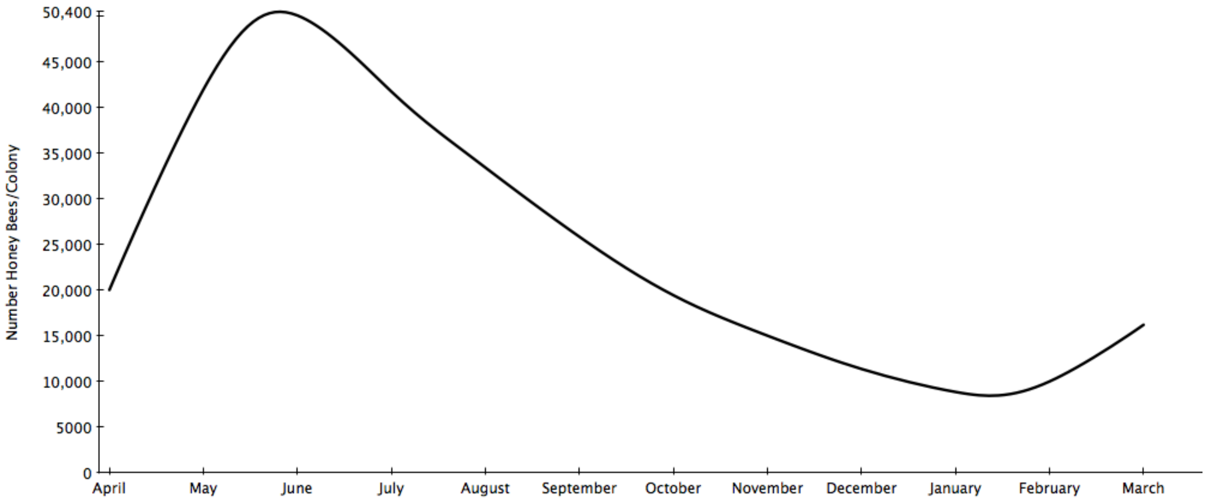
[2] To reduce confusion, I use female pronouns to describe the beekeeper and male pronouns to describe the almond grower throughout the rest of the paper.

Figure 2: Dynamics of Honey Bee Colony Population

(a) Almond Pollination Key Event Timeline



(b) Honey Bee Population Dynamics in Temperate Climate



Adapted from: ScientificBeekeeping.com "IPM 3 Fighting Varroa 3: Strategy-Understanding Varroa Population Dynamics" Figure 1 http://scientificbeekeeping.com/ipm-3-strategy-understanding-varroa-population-dynamics/

tion.[3] Because of the large number of colonies located in the Upper Great Plains during the summer months, its honey production plays an important role in the number and strength of colonies available for almond pollination.

2.2 Almond Pollination Industry

In 2015, there were 890,000 bearing acres of almonds which required approximately 1.8 million honey bee colonies for pollination (NASS 2015). Nearly half of those required colonies (approximately 853,000) entered California between January 1 and February 15 (CDFA 2015). That amounts to nearly one third of the 2.8 million colonies in the U.S. on January 1, 2015 being trucked in to California specifically for almond bloom.

As of 2012, in California there were 7,052 almond operations and 991 honey producing operations. There were nearly 23,000 honey producing operations nationwide (NASS 2012). If almond operations contract with two beekeepers on average, which reflects the average number for respondents to the Almond Board of California 2015 Almond Conference survey, this results in roughly 14,000 pollination agreements transacted each almond pollination season. Given the large number of colonies being transported across the U.S. for almond pollination, forward contracting benefits both the beekeeper and almond grower by reducing the risk borne by each party. A grower can forward contract to ensure delivery of the specified number of colonies at the desired strength, while the beekeeper can lock in a price to guarantee coverage of her costs of transporting colonies for almond pollination.

2.3 Moral Hazard in Almond Pollination Agreements

As seen in Figure 2a, almond pollination agreements are typically settled in late fall and winter months. Consequently, many almond growers make pollination decisions regarding the number of hives to stock per acre, colony strength requirements, and per-colony pollination

---

[3] Personal communication with Dr. Gordon Wardell, Director of Pollination Operations at Wonderful Orchards.

fees prior to almond bloom which typically begins in mid-February. These decisions are made under uncertainty in multiple dimensions: the weather at the time of almond bloom and the number and strength of available colonies. If weather during bloom is sub-optimal, a grower would prefer more bees per acre to ensure high yields. The grower can increase bees per acre by increasing either colony strength requirements and/or the number of hives per acre. In recent years, the number of colonies has been equal to or less than the quantity desired during almond bloom, so growers typically have a difficult time finding additional colonies during almond bloom (Traynor 2016). This limited number of colonies during almond bloom has highlighted the importance of advanced almond pollination decision-making.

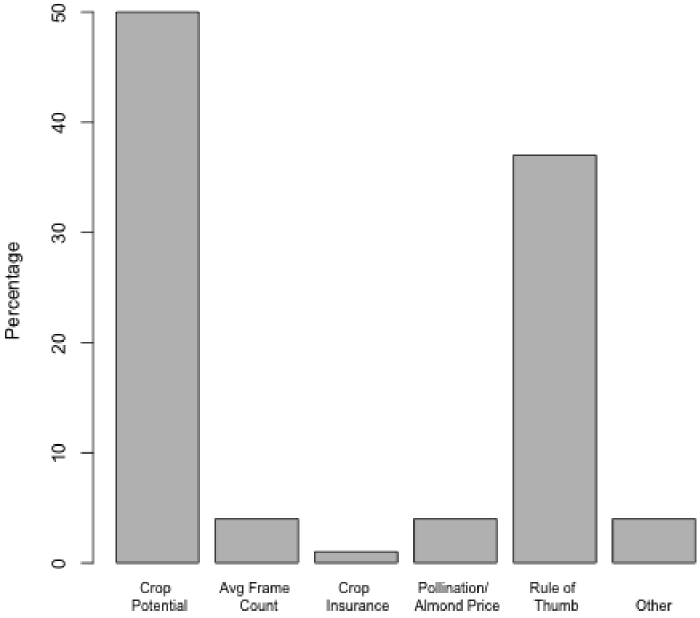
Almond pollination agreements are made prior to beekeeper discovery of winter mortality rates and colony preparation input decisions for almond pollination (Figure 2). Because beekeepers make their pollination contract decisions before knowing winter mortality rates, they make agreements while unaware of the costs of inputs necessary to provide colonies at a given average colony strength. In order to meet colony strength requirements for almond pollination, beekeepers must provide food supplements to colonies to jumpstart their transition from a natural winter dormant state (Figure 2b). Even providing food supplements does not guarantee a strong colony because of the many colony health inhibitors that beekeepers face. Thus, uncertainty exists in both the strength and number of colonies at the time of contracting for almond pollination.

Moral hazard arises in almond pollination agreements primarily because of the time period between almond pollination decision-making and the beginning of almond bloom. Almond growers are unable to observe the inputs and effort a beekeeper puts in to providing colonies for his pollination needs. A beekeeper could invest a substantial amount of inputs and labor into increasing colony strength for almond pollination, only to experience high winter mortality rates and corresponding low colony strength because of exogenous shocks due to colony health issues. Thus, risk aversion on the behalf of the beekeeper creates a moral hazard problem. Almond growers cannot easily distinguish between low and high strength colonies, which adds to the moral hazard problem. Since effort and inputs are costly, without colony strength requirements and inspections, beekeepers would prefer to provide colonies in their natural winter state of low strength for almond pollination.

2.4 Hive Density and Colony Strength

An industry rule of thumb hive density of two honey bee hives per acre of almonds emerged in interviews with almond growers, beekeepers and pollination brokers. This rule of thumb, along with previous literature and findings of the the Almond Board of California (ABC) 2015 Almond Conference pollination contract survey (see Section 5.2) suggest that the demand for the number of colonies for almond pollination is likely exogenous to price and colony strength. Growers at the 2015 Almond Conference were asked about the main factors influencing the number of hives they stock per acre (Figure 3). Half of the growers answered that their density decisions were influenced by factors affecting crop potential, such as the orchard variety and age, while 37 percent of growers stated that the rule of thumb was most influential. Only four percent of growers stated that they consider the average frame count stipulated in their contract when making hive density decisions, and four percent use a relative comparison of almond prices to pollination costs to determine hive density. This is consistent with a finding of Rucker et al. (2012) that hive densities were relatively inelastic to pollination fees and were mostly influenced by crop-specific fixed effects. This topic deserves further investigation, as no concrete explanation for this inelastic relationship exists. Rucker et al. hypothesized that the inelasticity could be due to the small portion of total almond operating expenses that pollination represents. University of California Cooperative Extension estimates that pollination expenses vary based on orchard age from 9-17% of total operating costs throughout an orchard's useful life (Connell et al. 2012). The Rucker et al. explanation is plausible, however, 17 percent which is the percent for mature almond orchards, is likely considered a substantial portion of operating costs. Alternatively, I hypothesize the inelasticity could be due to the current gap in knowledge of the direct link

Figure 3: Primary Factor Influencing Hive Density (N=100)



between colony strength, hive density and almond yields. Since almond pollination demand for colonies is relatively inelastic to pollination fees and colony strength, the total number of bearing almond acres is the primary measure of colony demand in a given year.

Although the number of colonies demanded for almond pollination may be essentially fixed based on the total number of bearing almond acres, the strength of colonies demanded varies depending on pollination fees and grower preferences. Almond pollination agreements (both oral and written) often contain minimum requirements for colony strength to address the moral hazard issue. Growers typically cannot easily estimate the colony strength of hives provided to their almond orchards, but they can obtain this information by paying for a colony strength inspection to be performed by a trained inspector. The inspector surveys a sample (typically 10-25%) of hives provided to an almond orchard and counts the number of active frames in each hive. The active frames per hive are averaged across the sample, and this average is reported to the almond grower and beekeeper so that it may be compared with the minimum colony strength requirement.

The most common colony strength requirement is the minimum average frame count, in which the average number of active frames reported in a colony strength inspection must meet this minimum. Approximately 86 percent of almond growers surveyed at the ABC 2015 Almond Conference reported that their largest almond pollination agreement contained a minimum average frame count requirement, and nearly half of the respondents reported a minimum average of eight active frames. This substantial share of growers is consistent with information obtained from industry interviews that the standard contract specifies a minimum average frame count of eight frames. Nearly 70 percent of growers who used only oral pollination agreements in 2015 reported the use of a minimum average frame count, so colony strength requirements are not restricted to formal written agreements. If the minimum average frame count requirement is not met, growers can impose monetary and non-monetary penalties on beekeepers which can be specified explicitly in an agreement or are implicit, such as a decision not to contract with the beekeeper in the following year.

A minimum frame count requirement can be imposed so that the beekeeper is not paid for any individual hives that do not meet this minimum colony strength. This can be required in lieu of or in addition to a minimum average frame count. The minimum frame count incentivizes beekeepers to deliver colonies of uniform strength, which is not addressed by the minimum average frame count. Under the minimum frame count, a beekeeper is penalized for providing very low strength colonies even if her colonies would still meet the minimum average colony strength.

Some almond growers use incentive pollination contracts, where a beekeeper is paid per colony according to the average frame count she provides in comparison to a specified benchmark colony strength. If a beekeeper exceeds the benchmark colony strength she is paid a per-frame bonus for the average number of frames above the benchmark. Similarly, if a beekeeper does not meet the benchmark, a per-frame penalty is imposed for the average number of frames below the benchmark. Approximately 31 percent of the ABC 2015 Almond Conference survey respondents used contracts in 2015 that included either a per-frame bonus or per-frame penalty provision. Nearly 14 percent used both the per-frame bonus and per-frame penalty provisions.

Incentive pollination contracts require colony strength inspections since calculating a beekeeper's per-frame bonus or penalty involves her average frame count from inspection. However, almond pollination agreements that include minimum average or minimum frame count requirements do not necessarily involve mandatory colony strength inspections by a third party. Of those ABC 2015 Almond Conference survey respondents with minimum average frame count provisions (excluding those who offered incentive provisions and would pay for inspections every year), 64 percent reported that they never pay for third party colony strength inspections. This adds another dimension to the moral hazard problem, as beekeepers do not always know with certainty whether hives provided to an almond orchard will undergo an official inspection for colony strength. A beekeeper may be able to provide hives that do not meet colony strength requirements without penalty if the almond grower does not pay for a colony strength inspection.

3 Previous Literature

Previous work on pollination markets has concentrated on theoretically and empirically modeling the reciprocal benefits of honey bee pollination. Meade (1952) outlines the reciprocal benefits of pollination to a beekeeper and an apple grower: A beekeeper places bees near an apple orchard to produce honey. In doing so, the apple grower receives pollination, an input to apples, from the beekeeper's bees, and the beekeeper receives nectar, an input to honey, from the grower's apple orchard. Meade models the benefits as reciprocal externalities in which both the apple grower and beekeeper are not being paid for the benefit each is providing to the other party. Over 20 years later, Meade's market failure explanation was corrected by Cheung (1973), Gould (1973) and Johnson (1973) who each noted the existence of pollination markets prior to 1952.

Cheung (1973) provides one of the first econometric analyses of pollination markets using survey data from Washington state beekeepers. Cheung develops a basic model of multiple crops' pollination fees by using marginal products of pollination and honey production to explain reciprocal benefits. In doing so, he implicitly introduced the equilibrium bee wage concept, later discussed explicitly in Rucker et al. (2012), in which the beekeeper receives both a pollination fee and honey from pollinating a crop and, in theory, a grower and beekeeper would take both of these products into account when determining a pollination fee. Thus, in a perfectly competitive pollination market the bee wage should be equal across all crops, despite the fact that crops differ in marginal pollination value and honey products. Cheung tests this relationship with the Washington pollination fee data and finds that it holds.

Rucker et al. (2012) extend the Cheung (1973) analysis by developing a more detailed theoretical model of reciprocal benefits. This model describes the determinants of the equilibrium bee wage and pollination fees through the use of comparative statics. Rucker et al. outline and econometrically test empirical predictions of pollination fee and stocking density determinants, using an extensive collection of U.S. pollination fee data. The data set consists of survey data from beekeepers in Oregon and Washington collected by Michael Burgett of Oregon State University from 1979 to 2009. The authors find that stocking densities are relatively inelastic across crops, and that the prices of and potential for honey production in crops, as well as varroa mite indicators and diesel fuel prices, are influential in determining pollination fees.

This paper expands on previous work by accounting for uncertainty and differences in colony strength and focusing on almond pollination agreements to discover specific factors influencing almond pollination fees. An advantage of focusing on the California almond pollination market stems from the ability to ignore the influence of honey sales from almond pollination. Almond honey is unpalatable to humans, so beekeepers cannot sell it as a byproduct of almond pollination. I develop a theoretical model to show the influences of moral hazard and uncertainty in colony strength on almond pollination agreements. Additionally, I analyze two unique datasets that provide information on individual pollination agreements from both the beekeeper and almond perspectives: the California State Beekeeper's Association (CSBA) Pollination Fee Survey and a pollination contract survey I conducted at the ABC 2015 Almond Conference. Neither dataset has been used in previous economic work on pollination services. In doing so, this paper provides an increased understanding of the function of the California almond pollination market and the full extent to which recent colony health issues have impacted almond pollination fees and contract provisions.

4 Theoretical Model

I use a traditional principal-agent model to incorporate the influence of uncertainty and moral hazard on almond pollination agreements, in which the almond grower is the principal and the beekeeper is the agent. This model follows closely to that outlined in Anglin and Arnott (1991) who describe a general principal-agent model in the context of residential real estate brokerage. I choose to investigate the specific case of a risk-neutral principal and risk-averse agent in the context of pollination agreements in order to obtain a closed-form solution.

4.1 Beekeeper

The beekeeper is a risk averse agent with a utility function of the exponential form u(x)=1-e^{-Ax} where $A = \frac{-u''(x)}{u'(x)} > 0$ is the beekeeper's coefficient of absolute risk aversion and x represents the beekeeper's income.

Hive density and acreage are fixed and normalized to one. There are two possible outcomes that can occur and the beekeeper influences the likelihood of each outcome by exerting costly effort, e. The average colony strength of hives provided to an almond orchard is a random variable defined as:

$$b = \begin{cases} b_H & \textit{with probability } p(e), \\ b_L & \textit{with probability } 1 - p(e), \end{cases} \tag{1}$$

where $b_H > b_L$. The probability the high colony strength outcome occurs, $p(e)$, is a concave function of effort, thus it is assumed to have the properties: $p'(e) > 0$, $p''(e) \leq 0$, and $p'''(e) = 0$. A beekeeper can increase her probability of providing high colony strength by exerting additional effort, but the marginal returns to doing so are decreasing in the amount of effort provided. I assume that the beekeeper faces a linear disutility of effort, $c(e)$, i.e., $c'(e) > 0$ and $c''(e) = 0$.

The beekeeper is paid a fixed pollination fee by the grower according to the following schedule:

$$t = \begin{cases} t_H & \textit{when } b = b_H, \\ t_L & \textit{when } b = b_L. \end{cases} \tag{2}$$

Thus, the beekeeper maximizes expected utility by choosing effort as follows:

$$\underset{e}{max}\ E[U(e)] = p(e)\left(1 - e^{-At_H}\right) + (1 - p(e))\left(1 - e^{-At_L}\right) - c(e). \tag{3}$$

The beekeeper takes the payments t_H and t_L as given, so her first order condition is:

$$p'(e)\left(e^{-At_L} - e^{-At_H}\right) - c'(e) = 0. \tag{4}$$

4.2 Almond Grower

The risk neutral almond grower faces the following yield function, which is dependent on the colony strength the beekeeper provides to the almond orchard:

$$y = \begin{cases} y_H & \textit{when } b = b_H, \\ y_L & \textit{when } b = b_L, \end{cases} \tag{5}$$

where $y_H > y_L$. I assume that the grower cannot access additional colonies from another beekeeper during almond pollination which reflects reality in the almond pollination market in recent years. I also assume that the almond grower perfectly observes the delivered colony strength and the corresponding yield.[4]

The grower's expected profits are:

$$E[\pi] = p(e)\left(Py_H - t_H\right) + (1 - p(e))\left(Py_L - t_L\right), \tag{6}$$

where P is the price of almonds. The grower chooses the payments t_H and t_L that he will make to the beekeeper based on the probabilities of the realized value of the average colony strength, b. The almond grower offers his optimal payment schedule to the beekeeper prior to the beekeeper's effort decision.

4.3 Event Sequence

First, the almond grower and beekeeper engage in a contract which specifies a payment to be made at the time of pollination according to the level of delivered colony strength, i.e., t_H for delivered colony strength b_H and t_L for delivered colony strength b_L. At the time of contracting, the almond grower has full information regarding the beekeeper's utility and cost functions, as well as the probability distribution of the colony strength outcomes. After contracting, the beekeeper exerts effort, e, and incurs her corresponding cost of effort. This results in the observation of the level of colony strength, and the almond grower pays the beekeeper according to the realized colony strength.

4.4 Observable Effort Solution

If the almond grower observes the amount of effort a beekeeper puts in, the almond grower could condition the beekeeper's payment on the beekeeper's effort level directly. This case is

---

[4] It would be beneficial to investigate uncertainty in delivered colony strength and yield benefits in future models so as to more accurately represent reality.

the first best scenario and does not involve moral hazard. Under observable effort, the grower chooses the payment schedule to offer the beekeeper as well as his own optimal effort level by maximizing expected profits subject to the beekeeper's participation constraint which ensures that the beekeeper's expected utility is greater than her reservation utility. I normalize the beekeeper's reservation utility to zero. The almond grower's optimization problem is:

$$\begin{gathered} \underset{e,\ t_H,\ t_L}{max}\ E[\pi] = p(e)\left(Py_H - t_H\right) + \left(1 - p(e)\right)\left(Py_L - t_L\right) \quad s.t. \\ p(e)\left(1 - e^{-At_H}\right) + \left(1 - p(e)\right)\left(1 - e^{-At_L}\right) - c(e) \geq 0. \qquad (\Gamma) \end{gathered} \tag{7}$$

The following first order conditions result from the almond grower's optimization problem under observable effort:

$$p'(e)\left[P\triangle y - (t_H - t_L)\right] - \Gamma\left[p'(e)\left(e^{-At_L} - e^{-At_H}\right) - c'(e)\right] = 0, \tag{8}$$

$$p(e) + \Gamma p(e) A e^{-At_H} = 0, \tag{9}$$

$$\left(1 - p(e)\right) + \Gamma\left(1 - p(e)\right) A e^{-At_L} = 0, \tag{10}$$

where $\triangle y = y_H - y_L$ is the difference in yield benefit to the grower from the difference in provided colony strength, and $\Gamma = -\frac{e^{-At_H}}{A} = -\frac{e^{-At_L}}{A}$ is the multiplier associated with the participation constraint in (7). From the first order conditions $\Gamma < 0$ implies that the beekeeper's participation constraint is binding and that $t_H = t_L$. Using this information, the first best solution is characterized by:

$$\begin{gathered} t_H = t_L = t_{FB} = -\frac{\ln(1 - c(e_{FB}))}{A}, \\ \frac{c'(e_{FB})}{p'(e_{FB})(1 - c(e_{FB}))} = AP\triangle y. \end{gathered} \tag{11}$$

With observable effort, an almond grower can specify a given amount of effort, e_{FB}, and make the beekeeper's payment independent of the observable outcome. The beekeeper will comply and exert optimal effort, e_{FB}, because doing so provides an expected utility equal to her reservation utility of zero.

4.5 Unobservable Effort (Moral Hazard) Solution

In the case where effort is unobservable, the only information a grower obtains regarding beekeeper effort is obtained indirectly through the observed colony strength outcome. Thus, the grower must present the beekeeper with a pricing schedule that induces her to exert the grower's optimal level of effort. To find the optimal pricing schedule, the grower maximizes expected profits subject to the beekeeper's participation constraint and the beekeeper's incentive compatibility constraint:

$$\begin{gathered}\underset{e,\ t_H,\ t_L}{max}\ E[\pi] = p(e)\left(Py_H - t_H\right) + (1-p(e))\left(Py_L - t_L\right) \quad s.t. \\ p(e)\left(1-e^{-At_H}\right) + (1-p(e))\left(1-e^{-At_L}\right) - c(e) \geq 0, \qquad (\lambda) \\ p'(e)\left(e^{-At_L} - e^{-At_H}\right) - c'(e) = 0, \qquad (\mu)\end{gathered} \tag{12}$$

where λ and μ are multipliers for the participation and incentive compatibility constraints, respectively.

The first order conditions for the grower's optimization problem under unobservable effort are:

$$p'(e)\left[P\triangle y - (t_H - t_L)\right] - \lambda\left[p'(e)\left(e^{-At_L} - e^{-At_H}\right) - c'(e)\right] - \mu\left[p''(e)\left(e^{-At_L} - e^{-At_H}\right) - c''(e)\right] = 0, \tag{13}$$

$$p(e) + Ae^{-At_H}\left[\lambda p(e) + \mu p'(e)\right] = 0, \tag{14}$$

$$1 - p(e) + Ae^{-At_L}\left[\lambda p(e) - \mu p'(e)\right] = 0. \tag{15}$$

These equations can be simplified to the following, given the beekeeper's first order condition in (4) and $c''(e) = 0$:

$$P\triangle y = \frac{\mu}{\lambda}\frac{p'(e)}{Ap(e)(1-p(e))} + \frac{\mu p''(e)\left(e^{-At_L} - e^{-At_H}\right)}{p'(e)}, \tag{13$'$}$$

$$\lambda = -\frac{e^{At_H}}{A} - \mu\frac{p'(e)}{p(e)}, \tag{14$'$}$$

$$\lambda = -\frac{e^{At_L}}{A} + \mu\frac{p'(e)}{(1-p(e))}. \tag{15$'$}$$

Since $\mu \leq 0$, equation (15$'$) implies that $\lambda < 0$ and the participation constraint is binding. Equation (13$'$) implies that as long as $P\triangle y > 0$, μ is negative and the incentive compatibility constraint is binding. Thus, solving this system of equations, the solution to the optimization problem with unobserved effort is characterized by:

$$\begin{aligned}
P\triangle y &= \tfrac{\mu}{\lambda}\tfrac{p'(e_{SB})}{Ap(e_{SB})(1-p(e_{SB}))} + \tfrac{\mu p''(e_{SB})\left(e^{-At_L}-e^{-At_H}\right)}{p'(e_{SB})}, \\
t_H^* &= -\tfrac{1}{A}\ln\left[(1-c(e_{SB})) - \tfrac{(1-p(e_{SB}))c'(e_{SB})}{p'(e_{SB})}\right], \\
t_L^* &= -\tfrac{1}{A}\ln\left[(1-c(e_{SB})) + \tfrac{p(e_{SB})c'(e_{SB})}{p'(e_{SB})}\right], \\
\mu^* &= \tfrac{p(e_{SB})(1-p(e_{SB}))}{Ap'(e_{SB})}\left[\left((1-c(e_{SB})) + \tfrac{p(e_{SB})c'(e_{SB})}{p'(e_{SB})}\right)^{-1} - \left((1-c(e_{SB})) - \tfrac{(1-p(e_{SB}))c'(e_{SB})}{p'(e_{SB})}\right)^{-1}\right], \\
\lambda^* &= -\tfrac{1}{A}\left[(1-p(e_{SB}))\left((1-c(e_{SB})) + \tfrac{p(e_{SB})c'(e_{SB})}{p'(e_{SB})}\right)^{-1} + p(e_{SB})\left((1-c(e_{SB})) - \tfrac{(1-p(e_{SB}))c'(e_{SB})}{p'(e_{SB})}\right)^{-1}\right].
\end{aligned} \tag{16}$$

Because the following relationship holds:

$$(1-c(e_{SB}))\text{-}\frac{(1-p(e_{SB}))c'(e_{SB})}{p'(e_{SB})}=(1-c(e_{SB}))+\frac{p(e_{SB})c'(e_{SB})}{p'(e_{SB})}\text{-}\frac{c'(e_{SB})}{p'(e_{SB})}<(1-c(e_{SB}))+\frac{p(e_{SB})c'(e_{SB})}{p'(e_{SB})},$$

the payment to the beekeeper under the high bee outcome, t_H^*, is greater than the payment in the low bee outcome, t_L^*. Additionally, without further assumptions, it is possible for $t_H^* \leq 0$ and/or $t_L^* \leq 0$. I focus on the solution in which $t_H^*, t_L^* > 0$, i.e., the almond grower pays the beekeeper a positive fee for pollination services in both the low and high cases. This is the only realistic case in the almond pollination market.[5]

The solution under moral hazard in (16) provides a hypothesis that can be tested empirically. The solution shows that imposing effective incentives to mitigate moral hazard in almond pollination involves specifying a colony strength standard ($b \geq b_H$), and paying beekeepers a higher pollination fee per colony when this standard is met (t_H^*) and a lower pollination fee per colony if the standard is not met (t_L^*). If a grower offers to pay a beekeeper the same payment regardless of colony strength outcome, this provides no incentive to the beekeeper to exert effort towards providing high colony strength for almond pollination. This hypothesis will be tested empirically in Section 5 where the colony strength standard is the minimum average active frame count.

5 Empirical Analysis of Almond Pollination Fees

Colony supply and demand factors influence almond pollination fees. Additionally, the overall design of the contract, which includes provisions that determine the actual colony strength provided by the beekeeper, affect the pollination fee paid to the beekeeper. A general relationship between the per-colony pollination fee and determinants for beekeeper-almond grower pair i in year t is:

$$Fee_{it} = f\left(ColonyStrength_{it},\ ContractProvisions_{it},\ Supply_t,\ Demand_t\right) + \epsilon_{it}. \tag{17}$$

where ϵ_{it} is a random error.

$ColonyStrength_{it}$ represents the colony strength the beekeeper delivers to the grower's almond orchard in year t, and $ContractProvisions_{it}$ represents the contract provisions agreed upon between the members of each beekeeper-almond grower pair in year t. Contract provi-

---

[5] This is not true for all pollination cases, as discussed by Cheung (1973) and Rucker et al. (2012).

sions include minimum colony strength requirements, as well as other variables, e.g., pesticide spraying, hive delivery coordination. $Supply_t$ and $Demand_t$ are supply and demand factors associated with colonies available for almond pollination in year t.

The theoretical model outlined in Section 4 showed that a beekeeper's delivered colony strength for almond pollination is influenced by the pollination fee and contract stipulations when a random error component exists due to colony health inhibitors. This is because the beekeeper makes effort decisions, i.e., optimal e^*, after being offered a price schedule dependent on colony strength for almond pollination, i.e., t_H^* for b_H and t_L^* for b_L. An endogeneity issue arises in (17): the pollination fee is determined by the delivered colony strength, but delivered colony strength is also determined by the fee and colony strength schedule offered. Thus, an instrument is required. As seen in Figure 1, winter mortality rates are highly (negatively) correlated with colony strength during almond pollination, and as discussed in Section 2.1, are likely not influenced by almond contract stipulations. If available, winter mortality rates could be used as an instrument for $ColonyStrength_{it}$.

The following subsections present analyses of almond pollination fee determinants using datasets from both the almond grower and beekeeper perspectives. Because neither contains all of the variables necessary to estimate (17), both datasets are utilized because in combination they contain all of the components of (17). Analyzing both beekeeper- and almond grower-provided data provides a more comprehensive understanding of how uncertainty in colony strength impacts decisions on both ends of the pollination agreement.

5.1 California State Beekeeper's Association (CSBA) Pollination Survey Analysis

The CSBA surveys its members yearly to collect pollination colony rental information. The survey asks about the fees charged per colony and the number of colonies provided for pollination services in various pollinated crops in California, as well as the beekeeper's winter mortality rate. I use survey data for individual beekeepers from the years 2008 through 2015 to determine the influence of colony strength on pollination fees. Table 1 displays summary statistics for these data, as well as regional almond bearing acreage data collected from the 2008-2015 NASS California Almond Acreage Reports. The CSBA data include a total across years of 274 observations, of which 27 individual beekeepers reported pollination fees for multiple regions in the same year. So, the 274 observations are responses from 244 beekeepers. The survey responses are anonymous so the data are a repeated cross-section.

Table 1: CSBA Data 2008-2015 Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Max
Per-Colony Fee	274	152.75	16.34	120.00	194.00
Individual Winter Mortality Rate	274	25.11	16.10	0.00	90.00
Region: Sacramento-North	274	0.22	0.42	0	1
Region: Merced-San Joaquin	274	0.33	0.47	0	1
Region: Kern-Madera	274	0.45	0.50	0	1
Sacramento-North Bearing Acreage	8	117,346	9,404.11	104,553	131,323
Merced-San Joaquin Bearing Acreage	8	223,351.4	13,380.52	203,519	241,794
Kern-Madera Bearing Acreage	8	331,842.6	32,620.65	271,259	367,018

5.1.1 Hypothesized Fee Determinants

As shown in Table 1, the CSBA dataset does not contain all necessary variables to estimate equation (17). However, the data can be used to identify the effect of colony strength on the almond pollination fee collected with added assumptions. First of all, instead of using grower-beekeeper pairs in time t, each variable is assumed to be an average over all of a beekeeper's pollination contracts with different growers in an almond-producing region and is subscripted with bt for beekeeper b in year t. The variable of interest, $ColonyStrength_{bt}$, the colony strength provided by beekeeper b in year t, is not observed in this survey data. As discussed previously, winter mortality rates and colony strength during almond pollination are highly correlated, so beekeepers with lower winter mortality rates are likely able to produce stronger colonies at a lower cost. Thus, the percentage of colonies lost by beekeeper b over the winter between years $t-1$ and t, $WinterMort_{bt}$, is used as an exogenous proxy variable for the unobservable colony strength provided by beekeeper b in year t.

This CSBA dataset also does not include individual contract provisions for each observation. Thus, it is important to note that there could be omitted variable bias in this analysis if any of the variables are significantly correlated with specific contract requirements. This does not seem likely to be an issue since winter mortality rates are exogenous and realized after contract provisions are agreed upon, as described previously. One could argue that beekeepers are heterogeneous in skill levels, so beekeepers that have higher skills would have lower winter mortality rates on average and decide to engage in different contract provisions than beekeepers with lower skills. Currently, adequate data do not exist to test this hypothesis; this is an area that would benefit from future research.

Equation (18) provides a modified version of equation (17), and is a reduced-form representation of the relationship between the almond pollination fee received by beekeeper b in year t and exogenous determinants.

$$Fee_{bt} = \beta_0 + \beta_1 WinterMort_{bt} + \beta_2 Reg_{bt} + \beta_3 Reg_{bt} * RegionAcre_t + \beta_4 t + \sum_{i=1}^{27} IndividualFE_{ibt} + \epsilon_{bt} \tag{18}$$

Equation (18) can be estimated to identify the effect of colony strength on almond pollination fees collected. I expect that as a beekeeper's winter mortality rate decreases, average colony strength supplied at almond pollination increases. As predicted by the theoretical model, the increase in delivered colony strength causes the pollination fee to increase ($t_H^* > t_L^*$). Since colony strength was not a collected variable in this survey and winter mortality rate is used as an exogenous proxy variable, the effect of colony strength on the per-colony pollination fee requires an additional calculation. The coefficient on winter mortality rates in equation (18) can be decomposed as $\beta_1 = \alpha_1 \delta_1$ where α_1 is the true marginal effect of colony strength on the per-colony almond pollination fee, and δ_1 is the marginal effect of the winter mortality rate on colony strength. The CSBA data do not contain the necessary variables to identify the true relationship between colony strength and almond pollination fees, however I am able to obtain estimates given other available data represented in Figure 1. Table 2 displays results from the regression of average colony strength during almond pollination on its proxy, U.S. average winter mortality rates. As the average U.S. winter mortality rate increases by 1 percent, the average active frame count during almond pollination decreases by 0.23. Thus the coefficient estimate of the effect of an increase in colony strength of one active frame on the per-colony pollination fee is equal to $\hat{\alpha_1} = \frac{\hat{\beta_1}}{0.23}$.

Table 2: OLS Estimates Average Colony Strength During Almond Pollination on U.S. Average Winter Mortality Rate, 2008-2015

	Dependent variable:
	Average Active Frame Count
	Coefficient (95 Percent Confidence Interval)
Average U.S. Winter Mortality Rates	-0.23^{**}
$(-0.36, -0.11)$	
Constant	15.59^{***}
(12.11, 19.06)	
Observations	6
R^2	0.77
Adjusted R^2	0.71
F Statistic	13.26^{**} (df = 1; 4)
Note:	*p<0.1; **p<0.05; ***p<0.01

In equation (18), Reg_{bt} represents the region in which beekeeper b places colonies for almond pollination in year t. CSBA defines three almond producing regions in California: Madera-Kern (Madera, Fresno, Kings, Tulare and Kern counties), San Joaquin-Merced (San Joaquin, Stanislaus and Merced counties) and Sacramento-North (Tehama, Glenn, Butte, Colusa, Sutter, Yolo and Solano counties). These regional variables control for differences across regional almond pollination markets. Figure 4 plots regional variation in average pollination fees collected and winter mortality rates for survey respondents, as well as bearing almond acreage from 2008 to 2015. With the exception of 2013, the northern almond-producing region (Sacramento-North) averages higher almond pollination fees than the central almond-producing region (San Joaquin-Merced), signaling that distinct regional supply and demand influences may exist. Figure 4b shows that on average the Sacramento-North region respondents have lower winter mortality rates than those of the other two regions. Figure 4c displays a large difference in acreage between these three regions. The regional differences in pollination fees, winter mortality rates and almond bearing acreage depicted in Figure 4 suggest that region-specific supply and demand components exist. As an an additional regional colony demand control, I include an interaction variable between the beekeeper's pollination region and regional bearing almond acreage in year t, $Reg_{bt} * RegionAcre_t$.

Figures 4a and 4c display the increasing trend in both almond pollination fees and almond bearing acreage from 2008-2015. A trend variable is included in (18) to account for the yearly supply and demand influences that have led to this upward trend in fees. $IndividualFE_{ibt}$ represent individual fixed effects for each of the 27 individual beekeepers who reported collecting almond pollination fees in multiple regions in the same year.

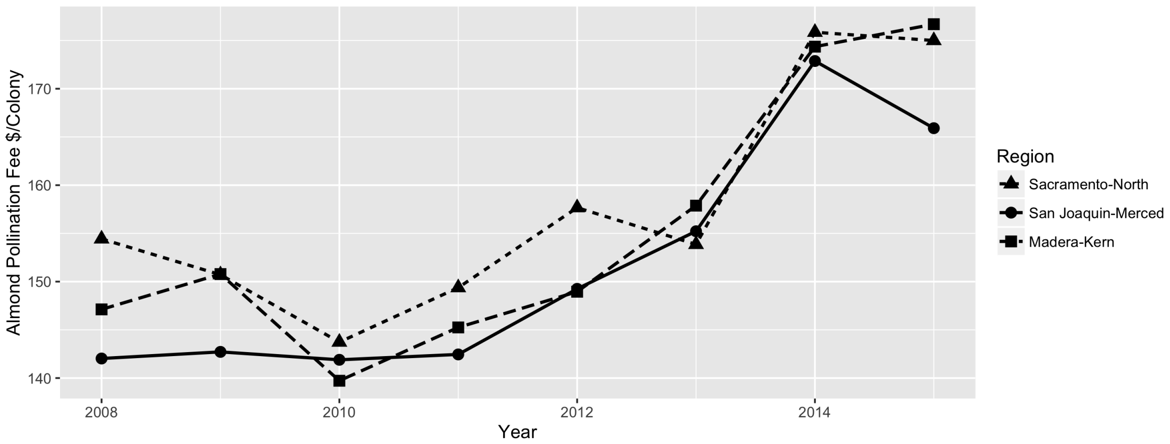
5.1.2 CSBA Results

Model (1) in Table 3 shows the Ordinary Least Squares (OLS) estimation results of equation (18). This model specification does a fair job explaining the variation of almond pollination fees, since the adjusted R^2 value is 0.41. The individual beekeeper's winter mortality rate and the trend variable are statistically significant at the 5 percent level and both have predicted signs.

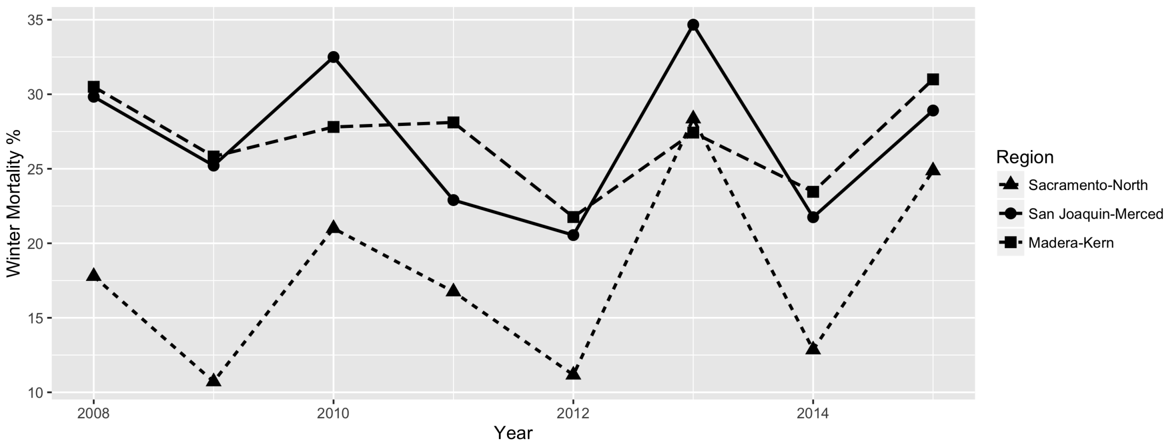
None of the region and region-acreage interaction variables are statistically significant in Model (1), so Models (2)-(4) in Table 3 are variations of Model (1) with either or both of the region and region-acreage interaction variables eliminated. Overall, Models (2)-(4) do not differ substantially from Model (1), however in Model (4) where there is no region control, the effect of a beekeeper's winter mortality rate increases. Figure 4b showed that

Figure 4: Regional Variation in Almond Pollination Markets

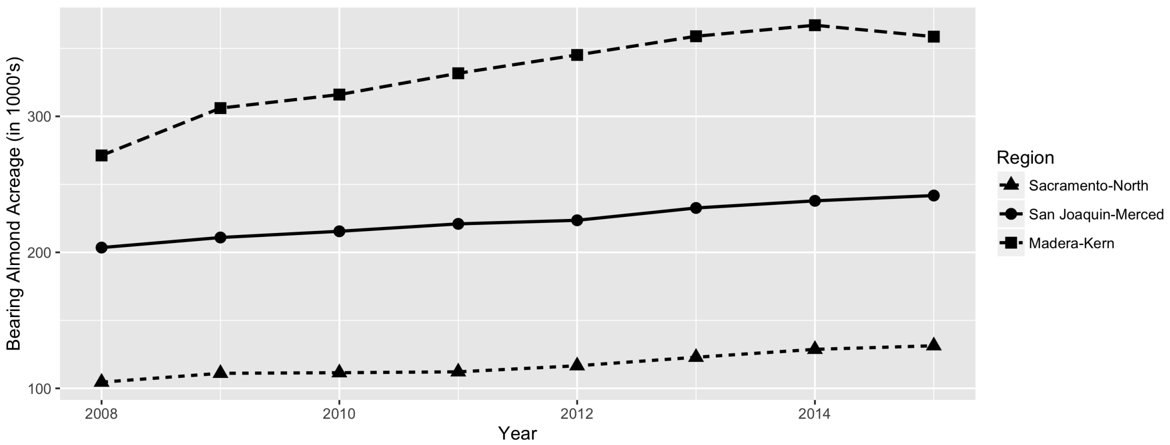
(a) CSBA Regional Average Fees 2008-2015



(b) CSBA Regional Average Winter Mortality Rates 2008-2015



(c) Regional Bearing Almond Acreage 2008-2015



Source: USDA NASS 2008-2015 Almond Acreage Reports winter mortality rates vary regionally, so controlling for the almond-producing region is important. Models (2) and (3) have equal R^2 and adjusted R^2 values, as well as similar coefficient estimates and standard errors of the overlapping variables. Thus, Models (1)-(3) are nearly equivalent and represent the best specification of determinants of per-colony almond pollination fees collected by beekeepers.

Models (1)-(3) in Table 3 indicate that a one percent increase in an individual beekeeper's winter mortality rate decreases the almond pollination fee she receives by approximately \$0.13 per colony. Over the 2015-2016 winter, the Bee Informed Partnership reported the average winter loss in the U.S. to be approximately 11 percentage points above the economically acceptable level. Thus, a beekeeper experiencing the U.S. average winter loss rate would lose \$1.43 per surviving colony compared to those with an acceptable winter loss level. This does not seem like a large amount given that the average fee across all regions in 2015 was \$175.52, however, these same beekeepers would have fewer colonies to rent for pollination increasing the negative impacts of colony health issues on beekeepers.[6]

The estimated effect of an increase in a beekeeper's average colony strength on the per-colony pollination fee can be calculated using the regression estimates in Tables 2 and 3. Using the 95 percent confidence interval of the winter mortality rate coefficient from proxy regression, along with the coefficient on winter mortality rates provided in Models (1)-(3) of Table 3, I find that an increase in average colony strength of one active frame leads to an estimated increase in per-colony almond pollination fees between \$0.36 to \$1.18.

---

[6] I find that a 10 percent decrease in winter mortality rates increases a beekeeping operation's almond pollination revenues by 14.8 percent, using the following assumptions: a per-colony fee of \$175, 4,500 colonies rented for almond pollination (the average for CSBA survey respondents 2008-2015), and a 28.1 percent winter mortality rate (the BIP U.S. average for 2015-2016).

Table 3: Determinants of Almond Pollination Fees: CSBA Data, 2008−2015

	Dependent variable:			
	Per-Colony Fee			
	Coefficient (Standard Error)			
	(1)	(2)	(3)	(4)
Beekeeper Winter Mortality Rate	-0.13^{**} (0.05)	-0.13^{**} (0.05)	-0.13^{**} (0.05)	-0.14^{***} (0.05)
Region: Merced-San Joaquin	3.71 (30.31)	−2.83 (1.76)		
Region: Sacramento-North	0.09 (27.06)	1.27 (2.06)		
Merced-San Joaquin*Acreage	−0.03 (0.14)		−0.01 (0.01)	
Sacramento-North*Acreage	0.01 (0.23)		0.01 (0.02)	
Trend	3.73^{***} (0.52)	3.68^{***} (0.37)	3.69^{***} (0.37)	3.72^{***} (0.37)
Constant	140.45^{***} (2.83)	140.62^{***} (2.34)	140.57^{***} (2.29)	140.38^{***} (2.13)
Individual Fixed Effects	Yes	Yes	Yes	Yes
Observations	274	274	274	274
R^2	0.49	0.49	0.49	0.48
Adjusted R^2	0.41	0.42	0.42	0.41
F Statistic	6.86^{***} (df = 33; 240)	7.36^{***} (df = 31; 242)	7.37^{***} (df = 31; 242)	7.66^{***} (df = 29; 244)

Note: Acreage in 1000s $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

5.2 Almond Board of California (ABC) Pollination Contract Survey Analysis

I conducted an almond pollination contract survey at the ABC 2015 Almond Conference. In this survey, I collected responses from a total of 114 almond growers on various components of their almond pollination agreements as well as characteristics of their almond operations. Table 4 displays summary statistics for the variables used in this analysis. In the analysis that follows, regressions are performed on complete observations only, reducing the sample size to 59. Summary statistics are reported for the 59 grower responses used in this analysis. The variables *Form*, *Average Frame Count* $\geq$*8*, *Bonus Offered*, *Inspection*, *Hives/Acre*, *Provider*, *Region*, and $\geq$*3 Beekeepers* are categorical variables, and all other variables are continuous. Variables are described in detail in the following paragraphs.

Contract Provisions The variable *Per-Colony Fee* is the per-colony fee reported by the almond grower for his largest almond pollination contract in 2015. *Average Frame Count* $\geq$*8* is a binary variable that equals 1 if a grower specified a minimum average frame count of at least eight frames (the industry standard) for his largest pollination contract in 2015, and 0 if a below-standard minimum average frame count was specified (this includes no specification of minimum average frame count).

Bonus Offered is a binary variable that equals 1 if the grower offered a contract in 2015 that provided a per-frame bonus for colonies that exceeded a benchmark colony strength, and equals 0 if the grower did not offer a contract of this type.

Growers were asked if nine specific clauses not directly related to colony strength were included in any of their 2015 pollination agreements. The clauses related to pesticide application, consequences for late-placement of hives and beekeeper access to hives after placement were the most common. The variable *Complexity* represents the number of additional clauses that each grower selected.

Table 4: 2015 ABC Almond Pollination Contract Survey Summary Statistics (N=59)

Statistic	Mean	St. Dev.	Min	Max
Per-Colony Fee	171.41	15.95	135	215
Average Frame Count ≥8	0.76	0.43	0	1
Complexity	1.98	2.18	0	9
Bonus Offered	0.17	0.38	0	1
Region: Sacramento-North	0.10	0.30	0	1
Region: Merced-San Joaquin	0.34	0.48	0	1
Region: Madera-Kern	0.56	0.50	0	1
<1.6 Hives/Acre	0.14	0.35	0	1
1.6-2 Hives/Acre	0.49	0.50	0	1
>2 Hives/Acre	0.37	0.49	0	1
Form: Oral	0.42	0.50	0	1
Form: Written	0.44	0.50	0	1
Form: Both Written and Oral	0.14	0.35	0	1
Inspect: Every Year	0.25	0.44	0	1
Inspect: Col Strength Low	0.10	0.30	0	1
Inspect: Never	0.64	0.48	0	1
≥3 Beekeepers	0.39	0.49	0	1
Provider: Direct Beekeeper	0.47	0.50	0	1
Provider: Broker	0.03	0.18	0	1
Provider: Both Broker and Beekeeper	0.49	0.50	0	1
Years Experience	19.59	14.03	2	60
Yield in Tons	2.16	0.51	0.82	3.50

Other Pollination Agreement Variables *Form* represents the form(s) of almond pollination agreement the grower reported using in 2015. It can take on one of three values: Written, Oral, or Both.

The variable *Inspection* describes the almond grower's decision to pay for colony strength inspections. The variable has three options: Inspect, Inspect If Low, and Never Inspect. A grower "inspects" if he pays for a colony strength inspection every pollination season. He "inspects if low" by paying for a colony strength inspection only in years when colony strength seems low, and a grower "never inspects" if he never pays for a colony strength inspection.

Hive density is represented as a categorical variable and corresponds to the almond grower's reported average number of hives per acre across all mature almond orchards in 2015. As discussed in Subsection 2.4, hive densities reported by growers were exogenous to pollination fees and colony strength specifications, and often reflected a rule of thumb of two hives per acre. Thus, the hive density variable is segmented into three categories about the rule of thumb: <1.6 Hives/Acre, 1.6-2 Hives/Acre, and >2 Hives/Acre.

The *Region* variable is a categorical variable that classifies growers into the almond-producing regions described in Subsection 5.1.1.

Grower Characteristics Almond growers can choose to contract directly with a beekeeper for their pollination needs, or they may contract through a pollination broker who procures hives from beekeepers. Pollination brokers absorb some of the risk otherwise borne by almond growers because they guarantee the grower delivery of strong colonies. The *Provider* variable determines the pollination provider(s) used by an almond grower in 2015. It takes on one of three values: Broker, Direct Beekeeper, or Both.

The variable *≥3 Beekeepers* represents the total number of beekeepers that supplied colonies to a grower's almond orchard(s) in 2015. This variable is 1 if a grower was supplied by at least three beekeepers, and 0 if supplied by less than three. The number three was chosen because most growers (over 60%) worked with one or two beekeepers in 2015. Using at least three beekeepers seemed to signal a different type of grower, perhaps a grower with more almond acreage.[7]

Years Experience is the number of years the almond grower has been growing almonds. $Yield$ is the average almond yield in tons per acre across all of the grower's mature orchards in 2015.

5.2.1 Econometric Model

The objective of this analysis is to provide a reduced-form model that estimates the general model of equation (17). Since almond pollination supply and demand influences for 2015 can be controlled for by the use of a constant and region dummy variables, the only fee determinant from equation (17) not contained in this dataset is the average colony strength that each grower received in 2015. Ninety-eight percent of the growers in this analysis reported that they received at least the minimum colony strength specified for the majority of delivered colonies in 2015, or did not monitor colony strength in 2015. So even though delivered colony strength may be influenced by contract provisions, omitted variable bias should not be an issue in this analysis. This is because these growers will likely not have adjusted down pollination fees due to delivered colony strength in 2015 since they received at least their contracted colony strength.

A complication of this analysis is that pollination fees and contract provisions are often determined simultaneously, especially for written pollination contracts. Thus, running a simple OLS regression of per-colony pollination fees on other contract provisions would lead to biased coefficient estimates. To mitigate simultaneity bias, I specify a seemingly unrelated regression (SUR) model which specifies the four endogenous contract provisions as dependent variables:

---

[7] A technical error with the interactive survey method used caused the almond acreage variable collected to be unusable.

$$
\begin{aligned}
&Fee = \beta_0 + \beta_1 AvgFC + \beta_2 Complexity + \beta_3 Bonus + \beta_4 Region + \sum_{i=5}^{8} \beta_i GrowerCharacteristic_i + \epsilon_F \\
&AvgFC = \alpha_0 + \alpha_1 Fee + \alpha_2 Complexity + \alpha_3 Bonus + \alpha_4 HiveDensity + \sum_{i=5}^{8} \alpha_i GrowerCharacteristic_i + \epsilon_A \\
&Complexity = \gamma_0 + \gamma_1 Fee + \gamma_2 Form + \sum_{i=3}^{6} \gamma_i GrowerCharacteristic_i + \epsilon_C \qquad (19) \\
&Bonus \ = \mu_0 + \mu_1 AvgFC + \mu_2 Complexity + \mu_3 Fee + \mu_4 Inspection + \sum_{i=5}^{8} \mu_i GrowerCharacteristic_i + \epsilon_B,
\end{aligned}
$$

where the grower characteristic control variables are *$\geq$3 Beekeepers*, *Provider*, *Years Experience*, and *Yield*. The hypothesized signs of the relationships in this system of equations are provided in Table 5. The relationships are discussed in detail in the paragraphs that follow. Since *Average Frame Count Specification* and *Bonus Offered* are binary variables, their regressions can be interpreted as linear probability models.

Per-Colony Fee Determinants The per-colony fee regression is the relationship of interest of this paper, since the objective is to measure the impact that colony strength and contract provisions have on the per-colony pollination fees. As predicted by the theoretical model, I anticipate that a minimum average frame count requirement of eight frames or higher will lead to higher pollination fees paid than a lower colony strength requirement. I predict that almond pollination fees will be higher as contract complexity increases, or number of additional clauses increases. I hypothesize that the use of a bonus provision involves higher pollination fees paid due to the increased incentive for high strength colonies and guaranteed colony strength inspections.

As in the CSBA empirical analysis, the region is expected to have an influence on the almond pollination fee due to region-specific supply and demand factors each year. I assume the region will not affect other contract provisions because contract provisions in a given year are likely related to grower preferences rather than supply and demand factors for that year.

Table 5: Hypothesized Relationships in Almond Pollination Contract System of Equations

	Dependent variable:			
	Per-Colony Fee	Average Frame Count ≥8	Complexity	Bonus Offered
Per-Colony Fee		+	+	+
Average Frame Count ≥8	+			+
Complexity	+	+		+
Bonus Offered	+	+		
Region: Sacramento-North	*ind.*			
Region: Merced-San Joaquin	−			
< 1.6 Hives/Acre		−		
> 2 Hives/Acre		+		
Form: Oral			−	
Form: Both Written and Oral			*ind.*	
Inspect: Every Year				+
Inspect: Col Strength Low				*ind.*
≥ 3 Beekeepers	+	+	+	+
Provider: Broker	+	+	+	−
Provider: Both	*ind.*	*ind.*	+	*ind.*
Years Experience	−	+	+	*ind.*
Yield in Tons	+	+	+	+

Note: ind.=indeterminate

The baseline region used is the Madera-Kern region. I anticipate that if results from the grower survey are consistent with that of 2015 average almond pollination fees in the CSBA dataset (Figure 4a), the San-Joaquin-Merced region will see lower fees than the Madera-Kern region, and there will be no large difference in fees between the Sacramento-North and Madera-Kern regions.

Regarding the grower characteristic control variables, it seems likely that large growers would pay beekeepers more per colony since they need to procure a larger number of colonies for pollination. Because of this, I anticipate that growers who worked with at least three beekeepers will likely pay higher pollination fees. The base specification for the pollination provider is contracting through a beekeeper directly. Since the pollination broker assumes some of the grower's coordination and risk, I predict that contracting through only a broker will lead to higher pollination fees paid than when contracting with a beekeeper directly. It is unclear how fees would differ between a grower who contracted through both a beekeeper directly and a broker compared to a grower who contracted directly through a beekeeper, so this sign is indeterminate. I predict that yield will increase pollination fees paid to beekeepers. Higher yields on average are likely associated with more efficient and skilled almond growers. Thus, growers with higher yields may realize the importance of securing reliable beekeepers and pay higher fees accordingly. I predict that as experience increases, pollination fees paid will decrease as a result of increased knowledge of pollination agreement negotiations.

Average Frame Count ≥8 Requirement Determinants The *Average Frame Count ≥8* variable regression represents the likelihood that a grower specifies a colony strength requirement of at least the industry standard minimum average frame count in his largest almond pollination agreement based on other contract provisions and grower characteristics. As the pollination fee increases, it seems likely that almond growers would implement high colony strength requirements to help ensure the yield benefits from pollination cover costs.

Thus, as pollination fees increase, I predict an increase in likelihood that a grower will specify a minimum average frame count of at least eight frames. Complexity would likely impact the specification of an average frame count, since a more complex contract in terms of additional clauses likely translates to the grower being more strict with respect to colony strength, as well. By nature of agreements including the bonus provision, a grower who specifies a bonus provision will also likely have specified a minimum average frame count of at least the industry-standard eight frames.

As discussed in Section 2.4, the number of hives per acre is likely relatively inelastic with respect to both pollination fees and colony strength provisions, so it can be used as an explanatory variable in this system. The base hive density category is the category from *1.6-2 Hives/Acre.* I hypothesize that a grower's hive density preference above or below the rule of thumb highlights an underlying risk preference due to weather uncertainty at the time of bloom. Growers in the low hive density category (*<1.6 Hives/Acre*) are potentially willing to bear more risk than those in the rule of thumb category and may stock fewer bees per acre (recall that bees per acre is the number of hives per acre combined with average colony strength per hive). Since these growers are less concerned with the number of bees per acre, they likely contract using low colony strength requirements, decreasing the likelihood that a minimum average frame count of at least eight frames is specified. Similarly, the growers in the high hive density category (*>2 Hives/Acre*) are likely more risk averse to weather uncertainty and are more likely to contract using at least an eight-frame minimum average frame count requirement to increase the number of bees per acre. Hive density is a related pollination agreement variable that is likely influential on the average frame count specification, but not directly influential on the per-colony pollination fee, contract complexity or whether a bonus is offered. The non-influence on the per-colony fee is clear, since the number of colonies per acre should not influence the amount paid per colony. Additionally, hive density should not influence the number of additional clauses given that none of them relate to hive density specifically. Since the minimum average frame count is by nature imbedded into the bonus provision contract, it is assumed that this weather-uncertainty risk preference represented by hive density impacts the decision to offer a bonus provision only indirectly through the minimum average frame count decision.

If a grower reported contracting with at least three beekeepers, it is likely that he will specify a minimum average frame count of at least the industry standard to ensure he will receive enough bees for adequate pollination. This comes from the assumption that a grower with at least three beekeepers is likely a larger grower who needs many colonies for almond pollination. This is ideal for large growers since it is difficult and costly to find colonies at the time of pollination if the grower's initial delivered colony strength is low. Securing high strength hives is imperative for almond pollination brokers since brokers transact with many beekeepers and almond growers and find it very costly to monitor and replace low strength hives at the time of pollination. Because of this, many brokers implement colony strength provisions in pollination agreements. Thus, I hypothesize that contracting only through a pollination broker will increase the likelihood of specifying a minimum average frame count of at least eight frames in comparison to contracting directly through a beekeeper. It is unclear how contracting through both a pollination broker and beekeeper will differ from contracting through a beekeeper directly with respect to the specification of an average frame count. I predict that the number of years experience will increase the likelihood of specifying at least an eight-frame minimum average frame count due to the increased experience in the pollination market. I anticipate that an increase in yield will increase the likelihood of specifying a minimum average frame count of at least eight frames due to its potential correlation with almond growing efficiency.

Complexity Determinants The complexity variable is a measure of the number of clauses included in a grower's 2015 pollination agreement(s) that are not directly related to colony strength provisions. Thus, it seems unlikely that the number of clauses would be affected by either the average frame count provision or whether or not the contract includes a bonus provision, so neither are included as regressors in the econometric model in (19). However, it is likely that an increase in the pollination fee would increase the number of clauses specified. For example, a grower who pays a high pollination fee may place more importance on specifics of the agreement, such as the timing of hive placement or the specification of the consequences of late hive placement. Thus, the pollination fee is the only contract provision included as a regressor in the complexity regression, and I expect an increase in fee to increase complexity.

The form(s) of agreement used in 2015 influences the complexity of the agreement, but does not likely influence the other endogenous variables directly. The per colony fee will likely not be influenced directly by whether the agreement is written or oral, but indirectly through the contract's complexity, which is influenced by the form of agreement. Both growers using only written agreements, as well as growers using only oral agreements often specify a minimum average frame count of at least eight frames, so the form of agreement doesn't seem to directly impact the decision to implement specific colony strength requirements. However, the indirect influence of the form through complexity may better reflect grower preferences for contract stringency. The grower's likelihood of specifying a bonus provision is again not likely influenced by the form of agreement directly. A bonus provision would likely only be used in a written contract, however not all written contracts have bonus provisions. Thus, the influence of the form of agreement through the complexity of the agreement may provide a better predictor of whether a bonus provision was specified. The base form of pollination agreement in the regression is the written contract. A written contract will likely be more complex and have more clauses specified than an oral agreement. Oral agreements may still have "clauses" or colony strength provisions, in which case they are discussed between the grower and beekeeper rather than written explicitly in a contract. It is likely much easier to include many clauses in a written document rather than discussing many individual issues with all of the grower's beekeepers. So the sign of the oral agreement coefficient is expected to be negative. It is unclear how the number of clauses would differ between a grower using both forms of agreement and a grower using only a written agreement, so this effect is indeterminate.

An almond grower who contracted with at least three beekeepers is expected to have a contract of higher complexity than one who contracted with fewer than three beekeepers. The more beekeepers a grower coordinates with, the more important are coordination specifics and other issues not directly related to colony strength. Thus, larger growers or growers with more beekeepers will likely have more complex contracts. Additionally, since the survey asked about the clauses in any of the grower's 2015 agreements, a grower with more agreements would likely have more clauses. A grower's pollination provider may influence the complexity of his contract since a pollination broker likely requires more complex contracts than a beekeeper. This is due to the pollination broker's coordination with many beekeepers and almond growers at once. The coefficient on the pollination broker provider variable is expected to be positive. Since a pollination broker likely requires a more complex contract, it is likely that a grower who contracts with both a beekeeper directly and a broker will also have more complex contracts. The coefficient on both providers is expected to be positive as well. I anticipate the number of years experience will increase the complexity of agreements due to increased experience (and potentially the number of coordination problems) in the almond pollination market. I hypothesize that as yield increases, the complexity of agreements will increase due to higher almond growing efficiency.

Bonus Provision Determinants The *Bonus Offered* regression shows the likelihood of contract provisions and grower characteristics in influencing a grower to offer a per-frame bonus provision for high strength colonies in 2015. Similar to the average frame count specification, I hypothesize that as the almond pollination fee increases, colony strength becomes more important to the almond grower and the use of bonus provisions may be more likely. I predict that the use of a minimum average frame count of at least the industry standard in a contract increases the likelihood of bonus provision use. If a grower cares about colony strength enough to specify at least the industry standard minimum requirement, he may be more likely to offer the beekeeper an incentive to provide high colony strength. An increase in the complexity of a grower's contract(s) likely increases the probability of bonus provision use. The more complex a contract is regarding non-colony strength related variables, the more likely it is to be complex with respect to colony strength related variables. Since bonus provisions are the most complex pollination agreements that currently exist, an increase in complexity will likely translate to an increase in the likelihood of specifying a bonus provision.

The colony strength inspection frequency variable is an exogenous determinant of the bonus provision, and does not likely impact the other contract provisions directly. Many growers who specify a minimum average frame count provision do not necessarily inspect due to the relationship with their beekeeper, and even if a minimum average frame count is not specified a grower could still pay for a colony strength inspection to determine if he wants to continue a relationship with his beekeeper in the future. Given that a beekeeper always faces the probability of inspection, the inspection frequency variable should not directly affect the per colony pollination fee, except for through its influence on the bonus provision. The inspection frequency should also not affect the overall complexity of a grower's agreement(s). In the regression, the base inspection category is that a grower never pays for a colony strength inspection. A grower who never pays for a colony strength inspection is not likely to offer a bonus provision since an inspection is required by nature of the bonus provision, while a grower who pays for a colony strength inspection every year is likely to offer a bonus provision. Thus, the coefficient on the inspect every year variable is expected to be positive. If a grower reported that he pays for colony strength only when colony strength seems to be low, it is unlikely that he offers a bonus provision since an inspection every year is required for the bonus provision. Thus, the sign on this coefficient is indeterminate since it is held in comparison to the baseline of never inspecting.

If a grower contracted with at least three beekeepers in 2015, I hypothesize it is more likely that he will offer a bonus provision since larger growers need to secure many colonies for adequate pollination. A bonus provision may incentivize beekeepers to provide their highest strength colonies to these growers. Pollination brokers are less likely to be involved with bonus provisions since they coordinate with many beekeepers and growers during pollination. A bonus provision would add another costly component to the already complex brokering coordination, so the coefficient on the broker only variable is likely negative. It is unclear how the likeliness of a bonus provision would change among growers who work with both a beekeeper directly and a pollination broker in comparison with growers who work with a beekeeper only. So, the sign on the both provider variable is indeterminate. The relationship between the likelihood of offering a bonus provision and years experience is indeterminate. Growers with more experience in almond pollination markets could be more likely to use bonus provisions due to past experiences, however bonus provisions are possibly viewed as complicated by older almond growers, those growers with the most experience. I anticipate that an increase in yield will increase the likelihood of bonus provision use due to the hypothesized correlation between yield and almond growing efficiency.

5.2.2 Results

Table 6 displays OLS regressions of the system of equations in (19) and Table 7 provides the corresponding SUR regression estimates. The OLS coefficients differ in magnitude from that of the SUR model and OLS standard errors are larger, especially in the *Per-Colony Fee* regression. The difference in coefficients and standard errors and the significance of the Breusch-Pagan test statistic in the SUR regression show that it is important to use the SUR estimates to reduce simultaneity bias. Because of the lack of significance of grower characteristic variables in the *Complexity* and *Bonus Offered* regressions in Table 7, Table 8 specifies a second model with those variables dropped. Model (2) is similar to Model (1) in Table 7 with regards to R^2 and coefficient estimates. Variations of this SUR model were also run excluding *$\geq$3 Beekeepers* and *Yield* from the *Average Frame Count $\geq$8* regression and

Yield from the *Per-Colony Fee* regression, however it was determined that these variables provide valuable information, so Model (2) in Table 8 is the best specification of this system of equations.

Per-Colony Fee Results From Table 8, it can be concluded that growers who specify a minimum average frame count of at least the industry standard eight frames pay on average \$14.86 more per colony than growers who specify a minimum average of less than the industry standard. This finding supports the hypothesis derived in the theoretical model that optimal pollination agreements include higher pollination fees for higher specified colony strength.

As predicted, the complexity of a contract increases the per-colony pollination fee (see Table 5 for hypothesized relationships). Each additional clause specified in a grower's pollination agreement is estimated to increase his per-colony fee paid by \$5.07. Contrary to the hypothesized relationship, offering a bonus provision decreased the per-colony pollination fee paid. This could be due to the wording and order of the survey questions. If a grower offered the bonus provision, it is unknown whether he reported the base pollination fee offered for the benchmark colony strength, or the pollination fee he paid after bonuses or penalties were applied as a result of delivered colony strength. If a majority of these growers reported benchmark fees prior to the addition of bonuses, the estimate will not reflect the relationship discussed in Subsection 5.2.1.

The Sacramento-North and Merced-San Joaquin regions did not have statistically significant different pollination fees compared to the Madera-Kern region. This was expected for the Sacramento-North region, however the Merced-San Joaquin was expected to have lower fees.

The grower characteristics *≥3 Beekeepers* and *Years Experience* have the hypothesized signs and are statistically significant at the 10 percent level. Growers who coordinated with at least three beekeepers paid higher pollination fees on average. An increase in the number

Table 6: OLS Estimates: Almond Pollination Contract System

	Dependent variable:			
	Coefficient (Standard Error)			
	Per-Colony Fee	Average Frame Count ≥8	Complexity	Bonus Offered
	(1)	(2)	(3)	(4)
Per-Colony Fee		0.01^{**} (0.005)	0.05^{***} (0.02)	-0.01^{**} (0.003)
Average Frame Count ≥8	6.90 (4.95)			0.16 (0.11)
Complexity	3.36^{***} (0.89)	−0.03 (0.03)		0.05^{**} (0.02)
Bonus Offered	-10.19^{*} (5.41)	0.24 (0.16)		
Region: Sacramento-North	−4.75 (6.47)			
Region: Merced-San Joaquin	−6.79 (4.41)			
<1.6 Hives/Acre		-0.36^{**} (0.16)		
>2 Hives/Acre		0.005 (0.14)		
Form: Oral			-1.41^{**} (0.61)	
Form Both Written and Oral			0.54 (0.81)	
Inspect: Every Year				0.34^{***} (0.10)
Inspect: When Low				0.19 (0.14)
Years Experience	-0.40^{***} (0.14)	0.01^{*} (0.005)	0.04^{*} (0.02)	−0.005 (0.003)
Yield in Tons	6.09 (3.68)	−0.12 (0.11)	0.07 (0.51)	−0.02 (0.08)
Provider: Broker	−5.68 (10.02)	−0.18 (0.29)	−0.22 (1.44)	−0.21 (0.23)
Provider: Both	−6.40 (4.41)	0.19 (0.13)	0.44 (0.61)	-0.23^{**} (0.10)
≥3 Beekeepers	7.68 (4.84)	−0.03 (0.15)	−0.57 (0.65)	0.35^{***} (0.11)
Intercept	159.03^{***} (8.78)	−0.81 (0.77)	-7.37^{**} (3.07)	1.38^{**} (0.53)
Observations	59	59	59	59
R^2	0.44	0.33	0.37	0.46
Adjusted R^2	0.32	0.19	0.27	0.35
F Statistic	3.70^{***} (df = 10; 48)	2.38^{**} (df = 10; 48)	3.62^{***} (df = 8; 50)	4.16^{***} (df = 10; 48)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 7: SUR Estimates Model (1): Almond Pollination Contract System

	Dependent variable:			
	Coefficient (Standard Error)			
	Per-Colony Fee	Average Frame Count ≥ 8	Complexity	Bonus Offered
Per-Colony Fee		0.02^{***} (0.00)	0.08^{***} (0.01)	-0.01^{***} (0.00)
Average Frame Count ≥ 8	14.73^{***} (3.98)			0.31^{***} (0.09)
Complexity	5.07^{***} (0.76)	-0.05^{*} (0.03)		0.06^{***} (0.02)
Bonus Offered	-16.73^{***} (4.50)	0.47^{***} (0.14)		
Region: Sacramento-North	-1.88 (5.11)			
Region: Merced-San Joaquin	-3.73 (3.50)			
< 1.6 Hives/Acre		-0.30^{**} (0.14)		
> 2 Hives/Acre		0.00 (0.11)		
Form: Oral			-1.11^{**} (0.52)	
Form: Both Written and Oral			0.43 (0.69)	
Inspect: Every Year				0.29^{***} (0.09)
Inspect: Col Strength Low				0.16 (0.12)
≥ 3 Beekeepers	8.82^{**} (4.28)	-0.15 (0.13)	-0.67 (0.60)	0.36^{***} (0.09)
Provider: Broker	-5.12 (8.97)	-0.12 (0.26)	-0.03 (1.32)	-0.19 (0.20)
Provider: Both	-8.97^{**} (3.93)	0.27^{**} (0.12)	0.52 (0.56)	-0.27^{***} (0.09)
Years Experience	-0.53^{***} (0.12)	0.01^{***} (0.00)	0.05^{***} (0.02)	-0.01^{**} (0.00)
Yield in Tons	4.51 (3.28)	-0.14 (0.09)	-0.09 (0.47)	0.01 (0.08)
Intercept	156.19^{***} (7.78)	-1.86^{***} (0.66)	-12.10^{***} (2.70)	1.99^{***} (0.47)
Observations	59	59	59	59
R^2	0.35	0.28	0.33	0.43
Breusch-Pagan Test Statistic:	17.19^{***}			
Note:				$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 8: SUR Estimates Model (2): Almond Pollination Contract System

	Dependent variable:			
	Coefficient (Standard Error)			
	Per-Colony Fee	Average Frame Count ≥8	Complexity	Bonus Offered
Per-Colony Fee		0.02*** (0.00)	0.08*** (0.01)	−0.01*** (0.00)
Average Frame Count ≥8	14.86*** (4.01)			0.32*** (0.09)
Complexity	5.07*** (0.76)	−0.05* (0.03)		0.06*** (0.02)
Bonus Offered	−17.16*** (4.51)	0.48*** (0.14)		
Region: Sacramento-North	−2.09 (5.14)			
Region: Merced-San Joaquin	−3.90 (3.52)			
< 1.6 Hives/Acre		−0.30** (0.14)		
> 2 Hives/Acre		0.00 (0.11)		
Form: Oral			−0.94* (0.50)	
Form: Both Written and Oral			0.42 (0.66)	
Inspect: Every Year				0.29*** (0.09)
Inspect: Col Strength Low				0.15 (0.12)
≥ 3 Beekeepers	7.67* (4.10)	−0.16 (0.13)		0.36*** (0.09)
Provider: Broker	−5.10 (8.54)	−0.12 (0.26)		−0.19 (0.20)
Provider: Both	−8.00** (3.75)	0.27** (0.11)		−0.27*** (0.09)
Years Experience	−0.53*** (0.12)	0.01*** (0.00)	0.05*** (0.02)	−0.01** (0.00)
Yield in Tons	4.34 (3.04)	−0.13 (0.09)		
Intercept	156.51*** (7.35)	−1.91*** (0.66)	−11.57*** (2.65)	2.03*** (0.46)
Observations	59	59	59	59
R^2	0.35	0.27	0.32	0.42
Breusch-Pagan Test Statistic:	16.95***			
Note:				*p<0.1; **p<0.05; ***p<0.01

of years experience an almond grower had decreased his almond pollination fee by \$0.53. It is likely that increased experience in the almond pollination market gives growers an edge in pollination negotiations. The coefficient on contracting through an almond pollination broker is not statistically different from zero, contrary to the hypothesis of being positive. This could be due to the low number of growers in this sample who contracted through only a pollination broker in 2015 (3%). Almond growers who contracted through both a pollination broker and a beekeeper directly paid an estimated \$8.00 less per colony than growers who contracted directly through a beekeeper only. The almond grower's average yield did not have a significant impact on the almond pollination fee paid in 2015.

Average Frame Count ≥8 Results An increase in per-colony pollination fee increases the likelihood of the specification of at least the industry standard minimum average frame count. Additionally, the specification of a bonus provision increased the probability of the specification of a minimum average frame count of at least eight frames. Both of these relationships are consistent with predictions (Table 5). According to Table 8, an increase in contract complexity decreases the likelihood that an average frame count is specified, which is contrary to the hypothesized relationship. The coefficient on complexity is relatively small given the values complexity takes on, I interpret this as the complexity variable having little influence on the average frame count specification.

In comparison to the rule of thumb category (*1.6-2 Hives/Acre*), the low hive density category (*<1.6 Hives/Acre*) decreases the probability of specification of a minimum average frame count of at least eight frames. This is consistent with the hypothesized relationship. The high hive density category (*>2 Hives/Acre*) was estimated to have no significant influence on the specification of the minimum average frame count in comparison to the rule of thumb category. This is inconsistent with the hypothesized relationship, and could be due to the grouping of minimum average frame counts into the category eight and above. This relationship deserves to be explored further in future work.

The grower characteristics $\geq$*3 Beekeepers, Provider: Broker* and *Yield* all have influences on the minimum average frame count specification that are not statistically significantly different from zero. Growers who contract through both a beekeeper and pollination broker were more likely to specify a minimum average frame count of at least eight frames in comparison to those growers who only contract directly through a beekeeper. An increase in the number of years experience growing almonds, increases the likelihood that an almond grower specifies a minimum average frame count of at least the industry standard. This suggests that growers with more experience in the almond pollination market find it optimal to specify colony strength provisions in their contracts.

Complexity Results Table 8 shows that an increase in per-colony pollination fees increases the complexity of the almond grower's pollination agreement(s). The use of oral pollination agreements in 2015 decreased the complexity of pollination agreement(s) in comparison to the use of written contracts. Using both written and oral pollination agreements in 2015 in comparison to using only written agreements in 2015 did not result in a significant differences in the complexity of a grower's pollination agreement(s). This makes sense given that the complexity measures the number of clauses included in any of a grower's 2015 pollination agreements. Thus, the written contract complexity would be represented for growers who used both forms of agreements. As discussed previously, the number of beekeepers used, the pollination provider and the yield did not have any significant impacts on the complexity of a grower's 2015 pollination agreement(s). The more experience a grower had, the more complex his pollination agreement(s). This is consistent with the predicted relationship and shows that growers who have experience in the almond pollination market have found it advantageous to include clauses regarding coordination and other various issues in almond pollination transactions.

Bonus Provision Results Contrary to the hypothesized relationship, Table 8 shows that as per-colony pollination fees increase, the likelihood of the grower's contract(s) containing a bonus provision decreases. As described in the *Per-Colony Fee* results, this estimated relationship could be due to the difference in the benchmark pollination fee and the pollination fee including bonuses paid to the beekeeper. As expected, the specification of an industry standard average frame count and an increase in complexity increased the likelihood that a bonus provision was specified.

Growers who reported paying for colony strength inspections every year were more likely to offer a bonus provision than growers who never pay for inspections. There was no significant difference in likelihood of offering a bonus provision between growers who never pay for inspection and growers who pay for inspection only in years of low colony strength. This makes sense, since it is unlikely that either of these grower types will offer a bonus provision by nature of bonus provision contracts.

Growers who contracted with at least three beekeepers were more likely to offer a bonus provision than growers with fewer than three beekeepers. This finding was consistent with the predicted relationship. The coefficient on the pollination broker variable has the correct sign of the hypothesized relationship, however is not statistically significant, likely due to the insufficient number of observations in this category. A grower who contracted with both a beekeeper and a pollination broker in 2015 was less likely to offer the per-frame bonus provision than a grower who contracted with only a beekeeper directly. The number of years experience had a significant negative relationship with offering a bonus provision. An almond grower's yield did not have a significant impact on the grower's use of a bonus provision.

6 Conclusion

Honey bee colony health issues have lead to volatile honey bee colony populations in recent years. This create riskiness for beekeepers in honey production and in filling their pollination agreements, as well as for growers trying to acquire a sufficient number of healthy honey bee colonies for crop pollination. The large use of managed honey bee colonies in the U.S. for almond pollination, as well as the timing of almond bloom, makes almond pollination markets extremely sensitive to the fluctuations and uncertainty in honey bee colony populations. Thus, it was important to explore this sector as a first step in determining impacts of colony uncertainty on U.S. agriculture as a whole.

This paper theoretically modeled almond pollination decisions under uncertainty in the average colony strength provided to a particular orchard. The moral hazard problem due to unobserved beekeeper effort can be alleviated by the almond grower basing the pollination fee on the observed average colony strength provided to the orchard. This gives the beekeeper an incentive to invest effort to meet colony strength requirements.

Two empirical analyses were performed to determine whether almond growers implement moral-hazard reducing incentives and discover factors that influence almond pollination fees. The CSBA data analysis of beekeeper-reported fees showed that an individual beekeeper's winter mortality rate decreased the per-colony almond pollination fee collected by that beekeeper. Winter mortality rates were used as a proxy for colony strength provided for almond pollination, thus the analysis concluded that providing lower strength colonies for almond pollination results in lower per-colony fees collected by the beekeeper.

Similarly, the analysis using data from an almond pollination contract survey conducted at the ABC 2015 Almond Conference showed that growers with contracts specifying a minimum average frame count of at least the industry standard eight frames as a minimum threshold for colony strength paid more than those growers whose contracts did not. Additionally, almond growers with more experience in almond pollination transactions were more likely to specify at least the industry standard minimum colony strength. This signals that almond growers, especially those with more experience, find it important to include colony strength provisions in their agreements and these growers are willing to pay a premium to procure colonies at higher strength. Moreover, a finding that the higher the per-colony fee, the more likely it is to specify an industry standard minimum average frame count suggests that as colony demand for almond pollination increases, the use of minimum colony strength requirements will increase.

The findings of the empirical analyses support the conclusion of the theoretical model. Many almond pollination agreements attempt to correct the moral hazard problem by imposing minimum colony strength standards that elicit optimal beekeeper effort. Almond growers who do not specify colony strength requirements often pay less per colony than growers who do, however they may receive lower strength colonies. Low strength colonies may lead to lower yields, especially in years of sub-optimal weather for almond pollination. Additionally, an added risk to not explicitly stating almond pollination contract requirements is that it will be impossible to solve a dispute over low yields due to low strength colonies if a colony strength requirement was not outlined in the pollination contract.

This study opens the door for future research on the volatility of U.S. honey bee colony populations impacting U.S. agriculture and honey production. Almond pollination only makes up a short time period in the commercial migratory beekeeping year, thus the total effect of the risk from colony health inhibitors on beekeeper livelihoods and U.S. agriculture is far reaching and complex. This area of research will only become more important in future years as countries all over the world implement policies to help their dwindling bee populations.

References

Anglin, P. M., Arnott, R., 1991. Residential real estate brokerage as a principal-agent problem. The Journal of Real Estate Finance and Economics 4(2), 99–125.

CDFA, 2015. California border protection stations apiary shipments. California Department of Food and Agriculture Plant Health and Pest Prevention .

Champetier, A., Sumner, D. A., Wilen, J. E., 2015. The bioeconomics of honey bees and pollination. Environmental and Resource Economics 60, 143–164.

Cheung, S. N., 1973. The fable of the bees: An economic investigation. Journal of Law and Economics 16(1), 11–33.

Connell, J., Krueger, W., Buchner, R., Niederholzer, F., DeBuse, C., Klonsky, K., De Moura, R., 2012. Sample costs to establish an almond orchard and produce almonds: Sacramento valley micro-sprinkler irrigation. Davis, CA, USA: University of California Cooperative Extension .

Gould, J., 1973. Meade on external economies: Should the beneficiaries be taxed? Journal of Law and Economics 16(1), 53–66.

Johnson, D. B., 1973. Meade, bees, and externalities. Journal of Law and Economics 16(1), 35–52.

Meade, J. E., 1952. External economies and diseconomies in a competitive situation. The Economic Journal 62(245), 54–67.

Moeller, F. E., 1977. Overwintering of honey bee colonies. Production Research Report-Agricultural Research Service, US Dept. of Agriculture (USA) .

NASS, 2015. USDA NASS QuickStats.

NASS, U., 2012. Census of agriculture. US Department of Agriculture, National Agricultural Statistics Service, Washington, DC .

Rucker, R. R., Thurman, W. N., Burgett, M., 2012. Honey bee pollination markets and the internalization of reciprocal benefits. American Journal of Agricultural Economics 94(4), 956–977.

Sheesley, B., Poduska, B., et al., 1970. Relative values of honeybee colonies for almond pollination. American Bee Journal 110(9), 346–347.

Traynor, J., 2016. Almond grower newsletter. Scientific Ag Co.

Vilsack, T., McCarthy, G., 2015. National strategy to promote the health of honey bees and other pollinators.