Measuring Beekeepers' Economic Value of Cover Crops and Contract Enhancements in Almond Pollination Agreements

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Abstract

Modern almond production heavily relies on pollination services from commercial beekeepers, utilizing nearly all colonies in the U.S. Because honey bee hive mortality has increased in recent years, almond growers may have opportunities to enhance pollination contracts to attract beekeepers and promote honey bee health such as planting bee-friendly cover crops and ensuring more pesticide protection. However, growers must assess these benefits relative to the cost of implementation, yet little information exists. Using a discrete choice experiment, we investigate and monetize the value of these new opportunities to commercial beekeepers who annually participate in almond pollination services. The analyzed sample of 81 commercial beekeepers represents approximately 19% of hives demanded for 2020-21 season. Our results demonstrate that beekeepers most value additional pesticide protection. Secondly, we find that beekeepers value two types of cover crops, brassica and soil builder mixes, but that legumes are unimportant, likely due to the timing of bloom. Our work shows there is potential for development of pollination contracts that could improve honey bee colony health, though future work must compare the costs of implementation of these practices.

Introduction

Beekeepers and almond producers are mutually dependent. Almond producers depend on honey bees to pollinate their orchards in early spring. Almond acreage has increased in recent decades such that now California's 1.2 million acres of almond require 88% of U.S. honey bee colonies (Goodrich and Durant 2020). The rising almond pollination fees due to this increased demand have caused pollination expenses to now represent 15% of annual operating expenses, where in many other pollinated crops, e.g., apples, plums, and cherries, pollination expenses account for less than 3% of annual operating expenses (Duncan et al. 2019; Klonsky and Stewart, 2014; Niederholzer et al., 2018, Grant et al. 2017). As the demand for colonies has increased, so has beekeepers' economic reliance on supplying almond pollination services. Almond pollination revenues now outweigh revenues from honey production: in 2020, U.S. beekeepers produced roughly $300 million worth of honey (USDA Honey Report, 2021) compared with almond pollination fees collected estimated at $460 million.[1] With so much relying on this relationship, technologies or management practices that result in a Pareto improvement should be of interest to both parties. Planting bee-friendly cover crops between orchard rows is one such management practice that can benefit both almond growers and beekeepers. Almond growers can benefit from improved soil health, water conservation, and mitigation of the impacts of climate change (Pathak et al. 2018). Beekeepers benefit from increased availability and diversity of food sources around almond bloom in early spring which can potentially lower feeding costs and improve colony health.

Despite the potential benefits to both almond growers and beekeepers, less than 6% of California almond growers use cover crops (Almond Board of California 2015). Economic concerns are a primary reason cited by growers for not adopting cover crop technology (CTIC and SARE 2017). Simulations support this, showing that it can take 10 years of accumulated benefits before almond growers break even (DeVincentis et al. 2020).

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[1] Estimated using numbers from Goodrich and Durant (2020): $192 per colony multiplied by 2.4 million colonies.

Due to the benefits to colony health from diverse food sources, beekeepers may be willing to accept a lower pollination fee in exchange for the planting of bee-friendly cover crops in almond orchards. This could help cover the grower's costs of establishing the cover crop, while lowering their pollination expenses, making it more likely that this mutually beneficial practice is adopted. This analysis investigates the economic value of cover crops among beekeepers, and the size of pollination fee discount they would be willing to accept in exchange for the improved nutrition and potential cost-savings associated with bee-friendly cover crops in almond orchards. We do so by utilizing a Discrete Choice Experiment (DCE) to understand beekeeper preferences regarding pollination contract clauses, including those related to cover crops.

We find that beekeepers value certain cover crop mixes, additional pesticide protections and up-front payment in their pollination agreements. Overwhelmingly beekeepers were willing to accept lower pollination fees for cover crop mixes that contain *Brassica* plants that bloom prior to and during almond bloom, and were not willing to accept lower fees for a cover crop mix composed of legumes that would not begin blooming until right at the end or after almond bloom. Pesticide protection had the highest economic value to beekeepers: they were willing to give up $8 per colony in additional revenue to have a guarantee that almond growers would not tank mix pesticides and only apply fungicides at night when bees are not flying. Assuming the preferred contract is adopted, beekeepers would be willing to accept a pollination fee per colony that is $18 lower than the standard agreement without those options, this constitutes a 10% reduction in the 2021 average fee reported by beekeepers.

Our findings show that there is potential for almond growers and beekeepers to work together to make mutually beneficial improvements in their almond pollination contracts. Importantly, two key improvements relate to additional pesticide restrictions and cover crops, practices likely to improve honey bee colony health and potentially lower abnormally high colony loss rates beekeepers have experienced over the last decade (Bruckner et al., 2020). High colony loss rates can severely impact beekeeping revenues from almond pollination, harming the economic sustainability of the U.S. commercial beekeeping industry (Goodrich, 2019b). Thus, improved colony health will lead to a more stable supply of pollination services for almonds and other crops that bloom after almonds. Future research should investigate the almond grower's costs of the pesticide restrictions and cover crop establishment to determine whether these changes result in a Pareto improvement. Nonetheless, given the number of colonies already required for almond production, and the fact that bearing acreage is still increasing, offering more attractive pollination contracts can help the grower secure a reliable source of pollination services.

Literature Review

Beekeeping and almond production have been interdependent for decades. California beekeepers easily met demand for California almond pollination in the 1950s and 1960s. It was not until the 1970s that increased demand for pollination services, and a corresponding increase in pollination fees, drew beekeepers from outside the state (Rucker et al. 2012). First to respond were beekeepers in neighboring states where transportation costs were lowest. By the 1990s, states as far as the Dakotas, Nebraska, and Texas were supplying colonies for almond bloom (Traynor, 2017).

Current almond pollination demand has drawn beekeepers from across the entire continental United States, requiring 88 percent of all US colonies (Goodrich and Durant 2020). This draw is differential due to differences in distance and the economies of scale inherent in colony transportation costs. Beekeepers with low transportation costs or low opportunity costs are already supplying at near full capacity.

Increases in pollination fees now attract beekeepers from the Eastern US, where elasticities remain high (Goodrich, Williams, and Goodhue, 2019). Given the number of colonies already required for almond production, and the fact that bearing acreage is still increasing, offering more attractive pollination contracts can attract beekeepers not already participating.

Almond pollination agreements today have higher requirements for minimum colony populations than in the past (Goodrich, 2019b). Almond bloom takes place in February, when little else is in bloom. A shortage of either sugar or pollen limits brood rearing, especially in the spring when forage is scarce and colony stores are running low (Brodschneider and Crailsheim, 2010). Before high strength requirements became the norm, beekeepers benefitted from the high-protein content of almond pollen to build colony strength after overwintering. However, the high colony strength requirements standard in almond pollination agreements today compel beekeepers to supplement with sugar and pollen prior to almond bloom (Topitzhofer et al., 2020A; Goodrich and Goodhue, 2020). The cost of doing so is high. Surveys of beekeepers in the Pacific Northwest revealed that beekeepers supplement colonies with 1.5 to 8 gallons of sugar syrup per colony, and up to 6 pounds of protein supplements per colony in the spring. At an average cost of $3.81 per gallon of sugar syrup, and $1.25 per pound of protein supplement, this adds up to $6 to $37.50 per colony each spring on supplemental feed (Topitzhofer et al., 2020B). While the inputs for beekeeping have not changed much between the 1970s and today, the share of costs attributed to feed has risen during this time from one percent of the total cost to over ten percent (Champetier and Sumner, 2019). Cost studies estimate the annual cost per colony to maintain colonies that are strong enough in early spring for almond pollination is over $200, with much of these costs going to feed in preparation for almond bloom (Traynor, 2017; Champetier and Sumner, 2019). Cover crops in almond orchards can provide additional forage for honey bees during a time when little other forage would be available.

In addition to providing forage during a forage-scarce time of year, cover crops in almond orchards would increase the diversity of honeybee nutrition. Both availability and diversity of pollen have a positive impact on colony health (Ellis et al., 2017). While multiple studies reveal short term gains in colony metrics, more long-term gains are seen in colonies under stress. For example, a field study found that bees supplemented with pollen showed beneficial long-term impacts only in years in where inclement weather severely limited forage. Another study controlled the type and diversity of pollen fed to colonies, to a similar result (Di Pasquale et al., 2013). In this case, pollen diversity had no significant impact on healthy bees, however, when parasitized honey bees that consumed polyfloral pollen fared better than those that consumed monofloral pollen. These findings are supported by a lab experiment which found that including a diversity of pollen in honey bee diets improved immunocompetence (Alaux et al., 2010). Colony nutrition, in terms of both quantity and diversity, clearly plays an important role in colony health.

Colony health decline has been attributed to a number of factors in addition to poor nutrition: parasites such as *Varroa destructor* mites and the gut fungus *Nosema ceranea*, pathogens and disease, and exposure to bee-toxic pesticides (Goulson et al. 2015). Given that most honey bee colonies in the U.S. pollinate almonds, the exposure to toxic pesticides while located in almond orchards has the potential to impact a large number of colonies. Durant et al. (2021) show that in recent years almond growers have decreased bee-toxic pesticide applications during almond bloom, however there are many sublethally toxic pesticides still applied in almond orchards during bloom. Rainy weather during almond bloom often requires growers to apply fungicides to their almond orchards when bees are located there. Many common fungicides have been shown to be sublethally toxic to bees (Mussen, Lopez, and Peng 2004) or synergistically toxic when mixed with other pesticides (Wade et al. 2019; Fisher II et al. 2017; Zhu et al. 2014). Sublethal and synergistic toxicities are currently not required to be put on pesticide labels, thus growers may use these products without knowing the risks to the honey bee colonies in their orchards. The Almond Board of California (ABC) developed recommended Honey Bee Best Management Practices (BMPs) (https://www.almonds.com/almond-industry/orchard-management/honey-bee-best-management-practices) based on this shortcoming. The BMPs recommend almond growers only spray fungicides in the late afternoon or evening, avoid tank-mixing products during bloom because some agrochemicals might have synergistic toxicities for honey bees, and avoid applying all insecticides during bloom.

Colony health has a large and increasing economic impact on beekeepers. The share of costs dedicated to pest treatment, including *Varroa*, has increased from 0.5 percent to 4 percent between 1976 and 2018, from \$0.86 to \$10.04 per hive per year (Champetier and Sumner, 2019). A longitudinal study on colony management between almond seasons also found that treatments for disease, and specifically for Varroa, were the costliest management action apart from establishment costs, surpassing even costs of transportation (Degrandi-Hoffman et al., 2019). To worsen the impact, colony losses frequently occur at the end of the year. At this point losses are especially costly as financial resources have been invested in maintaining those colonies. The economic losses can compound quickly: poor colony health can result in fewer colonies to rent out for almond pollination and lower colony strength resulting in lower almond pollination fees collected for surviving colonies. Goodrich (2019b) estimates a 10% increase in winter mortality rates decreased beekeeping revenues from almond pollination by 16%. Currently, beekeepers in the Pacific Northwest report overwintering up to 50 percent more colonies than required for almond pollination to counteract anticipated losses (Topitzhofer et al., 2020A). Improving colony health, and the likelihood that colonies will survive the winter, would therefore have a significant impact on the economics of beekeeping.

The contribution of additional forage to honey bee health has been confirmed in the literature. One study looks directly at the impact of supplementing colony forage with rapini, a freeze-tolerant mustard, in the month before almond pollination (Carroll et al., 2018). Colony performance and worker mass were not impacted. However, colonies with access to rapini experienced lower mortality than non-supplemented colonies. Another study shows that colonies in apiary sites within foraging distance of US Conservation Reserve Program locations fared better than colonies without access to these conservation areas (Ricigliano et al., 2019). Colonies with access showed greater survival potential, larger adult population, and increased brood production. The difference cannot be attributed to agrochemical exposure or pathogens, including Varroa. Authors attribute the difference to increased availability and diversity of forage near CRP lands.

These results build a strong case that beekeepers may be willing to accept lower revenue for the inclusion of bee friendly cover crops in almond orchards. This analysis is not the first to consider the importance of cover crops as an additional forage source. A review article on potential approaches to provide more diverse forage sources to honey bees in an ever more monoculture-oriented landscape highlights the role that cover crops could play (Decourtye et al., 2010). A USDA report notes that in the presence of insufficient forage, beekeepers could pay farmers to provide habitat. Authors propose this would be most appropriate where the opportunity cost is low, for example in the Dakotas (Hellerstein et al., 2017). Planting bee friendly cover crops in almond orchard would also fit this, as the opportunity cost for growers is low and they can reap agronomic benefits.

If beekeepers accept a lower pollination fee for the provision of bee-friendly cover crops, this would appear in the pollination agreements between beekeepers and almond growers. Little research exists on pollination contracts in general. Research on almond pollination contracts has found that almond growers in 2015 used formal written contracts and informal handshake agreements to roughly the same extent, and written agreements tended to be used by larger, more experienced growers with higher yields (Goodrich, 2019a). Goodrich and Goodhue (2020) found that minimum colony strength requirements and enforcement are important determinants of almond pollination fees. Other commonly-used clauses in almond pollination agreements included (i) beekeepers having access to colonies after initial colony placement in the almond orchard, (ii) pesticide application while colonies are in the almond orchard, and (iii) late colony placement (Goodrich, 2019a).

Methods

Discrete choice experiments (DCE) can be used to investigate contract preference by determining how parties react to hypothetical changes in contracts. This method has been used to look at marketing contract attribute preferences among fresh tomato growers (Vassalos et al., 2016), the role of trust, risk, and time preferences in contracts for Ghanaian pineapple farmers (Fischer and Wollni, 2018), and management-related attribute preferences among a variety of growers in Mississippi and Texas (Hudson and Lusk, 2004). Similarly, we developed a DCE to explore beekeeper preferences for different almond pollination contract attributes.

In our DCE, beekeepers answer a series of choice sets and choose their preferred contract based on a series of attributes and levels. The DCE design focused on eliciting beekeeper preferences for cover crops as well as other attributes that coincide with emerging or potential trends within commercial beekeeping, embedded within the larger context of preferred pollination rental agreements. The attributes used in the DCE appear in Table 1, listed in the same order of appearance as shown in the choice sets. These attributes and their levels stem from prior research on pollination contracts, initial interviews with industry and scientific experts, and several rounds of feedback from additional personal interviews.

Beekeepers were guided through the meanings of all contract attributes in a short video before completing the DCE, made up of five attributes described below.

Absolute minimum colony strength: If this clause is included in the contract, the beekeeper will not be paid for colonies with too few bees (less than 4 active frames within the hive). All agreements maintained a minimum average colony strength requirement of 8-frames, the industry standard (Goodrich and Goodhue, 2020). The absolute minimum of 4 active frames was determined to be commonly used through interviews with industry.

Prepayment: Specifies whether beekeepers receive no prepayment, or prepayment of either 10% or 40% of the total pollination fee in advance of almond bloom. From conversations with industry participants, prepayment is becoming more common as a way to decrease risks associated with either side defaulting on the pollination contract.

Pesticide clause: Prohibits the grower from tank mixing multiple pesticides and daytime applications of fungicides, both of which have been shown to be harmful to honey bee colonies. In a survey of almond growers from 2015, roughly 30% of growers stated their pollination contracts contained specifics about pesticide application (Goodrich, 2019a). This specific pesticide clause was developed based on the Almond Board of California's recommended Honey Bee BMPs.

Cover crop: Four levels of cover crops were considered, the presence of either a legume mix, brassica mix, soil builder mix (a diverse mix of grains, brassicas and legumes), or no cover crop. The cover crop mixes were based on mixes offered by the Project *Apis m.* Seeds for Bees program. All were described as covering 50% of the almond orchard (in between tree rows) (Personal communication with Billy Synk of Project *Apis m.*). Each cover crop will provide different benefits to the honey bees and the almond grower.

The legume mix is made up of multiple varieties of clover, and will not begin blooming until March or April. Many beekeepers will remove colonies from almond orchards prior to the clover bloom, and as such their colonies would not receive the nutritional benefits from these cover crops. Legumes provide erosion control, weed suppression, and nitrogen fixing benefits to the almond orchard (Project *Apis m*., 2020a).

The brassica mix contains canola, white and yellow mustards, and daikon radish. If timely rain and irrigation occur before November, this mix will bloom in early February, potentially providing nutritious pollen before almond orchards start to bloom. The brassica mix provides organic matter, weed suppression, and increased water filtration to the almond orchard Project *Apis m*., 2020b).

The soil builder mix contains triticale, bell beans, peas, canola, yellow mustard and daikon radish. Because it's a mix of grains, brassicas and legumes, it combines the benefits of the legume and brassica mix for both growers and honey bee colonies.

Cover crop contingency: Indicates either a $2 or $5 discount off of the pollination fee ($/hive) if cover crops are planted by a specified date or if they bloom by a specified date. These discounts were based on discussions with industry and an almond pollination contract provided by a commercial beekeeper.

The discount was explained to beekeepers as potentially necessary due to the additional time and expense to the grower of planting cover crops. Conversely, while cover crop discounts may be reasonable given the resources required, some beekeepers may counter, desiring a contingency to assure the cover crops provide substantial benefits to the bee hives. In particular, we feature two discount contingency levels: 1) the grower must plant the cover crop by October 10th (recommended by Project *Apis m*.), or 2) a guarantee that the cover crop has bloomed by February 1st for brassica or Soil Builder cover crops, or by March 15th for legumes. The latter contingency provides a much stronger guarantee to the beekeeper than the former. Both are expected to have a positive coefficient, matching their desirability to beekeepers, and counteract some or all of the negative impact from a discount.

Price: The base price ($/hive) for the contract, excluding conditional clauses above. There are four levels based on recent pollination surveys (Goodrich and Durant, 2020; Goodrich and Goodhue, 2020): $190, $195, $200, and $205.

The DCE design occurred in Ngene using an efficient design. Because no prior studies exist, uninformed priors were used, only specifying an expected sign per parameter, or small magnitude adjustments for attributes with ordinality (price, percentage prepayment, discount level, and discount contingency level). Importantly, the discounts are conditional on the presence of a cover crop because a discount would only be offered in exchange for additional benefit to the beekeeper. Similarly, the plant and bloom contingency attributes are conditional on the presence of a discount, testing whether such contingencies decrease the disutility to beekeepers associated with the lower price.

The design was based on the appearance of two new pollination agreements featuring the aforementioned attributes, compared to a status quo alternative, described as a standard agreement without any of these attributes, for a price of $200 per hive, which matches industry figures from the 2019 almond pollination market (Goodrich and Durant, 2020). A standard opt-out alternative (foregoing placement of the hive and associated revenue) was deemed inappropriate based on interviews with beekeepers. Based on the number of attributes and levels, our design featured 24 choice sets, blocked into three groups, with the appearance order of the eight choice sets randomized per person. An example choice set appears in Figure 1.

Several other important considerations were made in the DCE design. The standard agreement remained fixed in the first position. The first and second new agreement were placed in the center and right columns, but were randomized in their order of appearance to reduce position bias (Campbell and Erdem 2015). Because of the extensive new information related to cover crops and cover crop contingencies, the instructions to the DCE as well as the attribute descriptions were communicated as a YouTube video to enhance respondent cognizance (Campbell and Erdem, 2015). A link to the DCE attribute descriptions also appeared with each choice set. As with almost all DCE, these elicited choices by the beekeeper represent stated preferences, which may raise concern for hypothetical bias (Penn and Hu, 2018). Conversely, the elicitation is framed as Willingness to Accept (WTA), the level of compensation/revenue they are willing to forego to obtain these contracts for their bees. While concern for the validity of stated preference remain, recent evidence suggests that HB in WTA is lower than WTP studies (Lloyd-Smith and Adamowicz 2018; Penn and Hu 2021) .

Modeling Approach

To model beekeeper preferences, we assume that respondents choose the utility-maximizing contract, corresponding to a random utility framework:

$$\boldsymbol{U_{ijn} = x_{ijn}\beta + e_{ijn}} \tag{1}$$

Individual *i* derives utility from alternative *j* in scenario *n* based on a vector of unknown coefficients $\boldsymbol{\beta}$ that correspond to the observable attributes $\boldsymbol{x_{ijn}}$, including contract price, plus a component of utility that is unobservable to researchers but affects respondent choice, e.

If the unobservable utility component is assumed to be iid and follow an extreme value type I distribution, then the probability of the *j*th alternative being selected in eq (1) can be modelled as a conditional logit model. Because of restrictive properties of conditional logit models, we instead rely on a mixed logit model, which assumes that the unknown parameters $\boldsymbol{\beta}$ are random variables that may vary across respondents as in equation (2).

$$\boldsymbol{P_{ij} = \int \frac{exp(x_{ijn}\beta)}{\sum_{k=1}^{J}(x_{ikn}\beta)} h(\beta) d\beta}$$

$$\boldsymbol{x = [Hive\ Price, Minimum\ Colony\ Strength, 10\%\ Prepay, 40\%\ Prepay, Pesticide\ Protection,}$$
$$\boldsymbol{Legume, Brassica, Soil\ Builder, \$2\ discount, \$5\ discount, Plant\ Contingency, Bloom\ Contingency]} \tag{2}$$

We estimate this model via maximum simulated likelihood using 2500 Halton draws within Stata 16. The CE attribute levels identify main effects of the attribute levels, though we can also consider interaction effects.

Because the \$2 and \$5 discount are expressed in the same units as Hive Price, this provides two opportunities for how to model such information. In one model, cover crop discounts are assumed to be equivalent to a change in price, so are subtracted from hive price, and no longer separably measurable. This allows an unconditional effect of the Plant and Bloom contingency on the probability. In the second, we directly model the interaction of the $2 and $5 discount with the plant and bloom contingencies as four separate interaction dummies, Plant2, Plant5, Bloom2, and Bloom5. For a given contingency, we expect a $2 discount to be preferred to a $5 discount. For a given discount, we expect the bloom contingency to be preferred to the plant contingency.

Data Collection and Results

Data analyzed in this study comes from an online survey of beekeepers. The survey used the Qualtrics platform and was composed of a brief screening section, the main body, video explanation and DCE, and an optional post-survey. The main body gathered information on the beekeeping operation including current almond pollination contract arrangements and features, general characteristics such as income and relative reliance on honey versus pollination income, and prior experiences with almond pollination. We advertised the survey individually using beekeeper emails and connections with industry participants. The survey was also advertised through larger beekeeping groups via social media and email lists, including the American Honey Producers Association, Bee Culture Magazine, Project *Apis m*., Bee Informed Partnership, and the California State Beekeeper's Association. Respondents who completed the survey received a gift card. The survey opened on February 15 and closed April 30, 2021. This timing purposefully overlapped with almond pollination so that almond pollination decisions, would be at the front of beekeepers' minds.

Approximately 110 beekeepers participated in the online survey. The number of useable responses equals 81. While a seemingly small sample, these beekeepers represented 19% of the estimated 2.5 million bee colonies necessary for the 2021 almond pollination season. Descriptive statistics of the sample as well as known information of the population appear in Table 2.

Model Results

Model results from the beekeeper cover crop DCE appear in Table 3, based on 647 completed choice sets. Recall that because the discount attribute is measured in the same scale as price, its level has been incorporated into the price attribute, and therefore not modeled as a separate parameter in this first model.

To begin, we see that the coefficient for price is positive and significant, matching expectation; all else equal, beekeepers prefer contracts that provide more compensation for their hives, coinciding with a Willingness to Accept framework. While the alternative-specific Standard Agreement has a negative sign, its insignificance indicates that beekeepers are indifferent between conventional agreements and a new agreement with the reference level per attribute, meaning without a requirement for Absolute Minimum Colony Strength, no prepayment, no pesticide clause, no cover crop, or associated contingencies. The Absolute Minimum Colony Strength coefficient is also not statistically significant, suggesting little dispreference among beekeepers. Among the prepayment levels, while 10% is not significant, there is marginal evidence that the 40% prepayment level is preferred by beekeepers. The presence of the Pesticide Protection was significant and had the largest magnitude among any attributes considered. This suggests that avoiding tank mixing and only spraying at night is extremely important to beekeepers.

Among the cover crops studied, the presence of legumes is not significant. The brassica and soil builder cover crop mixes are both positive and statistically significant. A Wald test shows that the brassica coefficient is not significantly larger than soil builder. This means that beekeepers equally value the two types of cover crops. This is valuable information from the almond grower's perspective in that they can choose to plant soil builder, gaining the improved soil benefits from the legumes and grains, without reducing the attractiveness to the beekeepers.

Finally, in this model specification in which discounts are embedded within the price coefficient we expect the cover crop contingencies to have a positive coefficient, showcasing their value to beekeepers. Neither the Planting Contingency nor the Bloom contingency are significant though, suggesting such contract clauses do little to alleviate disutility of discounts. This may be cultural: the surveyed beekeepers indicated they engaged in at least 101 handshake agreements, compared with at least 78 written contracts.[2] Such customs may explain why such legalism may not offer value to the beekeepers.

Next, we inspect the corresponding standard deviations for each attribute level to investigate unobservable preference heterogeneity. Standard agreements, minimum colony strength, 40% prepayment and pesticide protection are each statistically significant. This indicates considerable heterogeneity in preferences among commercial beekeepers. For example, while the mean of standard agreement is not significant, the significant standard deviation indicates that beekeepers are divided on whether they prefer the standard agreement versus a new agreement.

Interestingly, none of the standard deviations of the three cover crop types are significant. This showcases fairly uniform preferences among beekeepers for the cover crops, ubiquitously uninterested in legumes, but a consistent preference for brassica and soil builder. This information is useful to almond growers in need of new or additional hives and that the latter two cover crops can widely attract beekeepers.

For further investigation, we provide alternative model specifications to explore the effects of the cover crop types, discounts, and contingencies, shown in Table 4. Model II considers the joint effect of a discount with each contingency, demonstrated by the four interaction variables, $2 Discount-Plant, $5 Discount-Plant, $2 Discount-Bloom, and $5 Discount-Bloom. In this case, $2 and $5 discounts without a contingency are still embedded within price. This model allows us to further explore the contingencies. First, we expect a $2 discount to be preferred to a $5 discount, or less negative for the Plant and Bloom contingencies. Second, we expect the Bloom contingency to be preferred to the Plant contingency since the former offers more assurance to the beekeeper versus the latter.

The results of this model are largely similar. First, the price coefficient is nearly the same, showcasing that the effect of price is stable regardless of the discounted contingencies. Further, Pesticide Protection, Brassica, and Soil Builder all remain significant. In this case, 40% is now statistically significant and 10% is marginally significant.

Turning to the discount contingency interaction variables, we see that all are negative and several are significant. Whereas in Model I, the effect of the Plant and Bloom contingency are not significant without the discount, the significance of these variables demonstrate that the discount is a primary driver in beekeeper preferences. Specifically, the negative sign of all four interactions shows beekeepers are less likely to choose any alternative with a discount, though only significantly for $2 Discount-Bloom. None of the Wald tests show evidence in support of expectations ($2 Discount-Plant=$5 Discount-Plant, $2 Discount-Bloom=$5 Discount-Bloom, $2 Discount-Plant=$2 Discount-Bloom, and $5 Discount-Plant=$5 Discount-Bloom).

As a further exploration of this, Model III considers three-way interactions of each cover crop type with Plant2, Plant5, Bloom2, and Bloom5. This showcases whether preferences for discounts and contingencies vary with the cover crop provided. In this case, $2 Discount-Plant, $5 Discount-Plant, $2 Discount-Bloom, and $5 Discount-Bloom represent the effect specific to Legume, and the other sets of interactions are for Brassica and Soil Builder. None of these interactions are significant. This is a mixture

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[2] Possible answers to the number of contracts in each category were truncated at 3+, so we do not know the exact number.

of the prior two results in that it shows that the contingencies are relatively unimportant, but so is the discount. It is important to remember though that the analysis is based on a rather limited sample size.

Given the consistency of these models, we calculate beekeeper WTA of the significant attribute levels based on Model I, shown in the rightmost columns of Table 3 as well as 90% confidence intervals based on the Krinsky-Robb method. Pesticide protection has the highest economic value of about $8, meaning that beekeepers would be willing to give up $8 in additional revenue per hive to have this guarantee in their contract. For cover crops, beekeepers are willing to accept $6.52 and $5.62 less revenue in return for the provision of brassica or soil builder cover crops. Notably, these values and their confidence intervals are much lower than the discounts used in DeVincentis et al. (2020). Lastly, beekeepers would accept over $3 less per hive if they received 40% of the payment at the beginning of the almond bloom. This may be attractive to growers with adequate cashflow to cover an earlier expense.

Conclusion and Discussion

Caveats

An important consideration to keep in mind is that the lack of statistical significance among some attributes and levels may be an underpowered test. On the other hand, our design does satisfy Johnson and Orme's rule of thumb for minimum sample size requirements in DCE analysis.

Next Steps

The significance and value of several of the characteristics suggests that next steps of determining whether such value is greater than or less than costs of implementation. For example, the 40% prepayment to the beekeeper provides value to the beekeeper, but barring opportunity cost and cash flow limitations, is a relatively costless improvement available to the grower. Given its high value to beekeepers, prioritizing efforts to determine the costs of implementing the additional pesticide restrictions of no tank mixing and no day time applications.

In the case of cover crops, this improved information can update DeVincentis et al.'s previous analysis regarding more realistic discounts for rented bee colonies. DeVincentis et al. estimate that direct establishment costs of cover crops in almond orchards range from $22.50-$75.00 per acre, though it should be noted this was for a legume mix, which clearly beekeepers do not prefer. Using the industry rule of thumb of two hives per acre of almonds, our results suggest discounts with the use of brassica or soil builder mixes of $11.24-$13.04 per acre, not enough to make up for establishment costs, though with the other soil and weed suppression benefits this could make a difference to almond growers. Not to mention, the benefits from having a potentially more secure supply of pollinators.

Citations

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Figures

Figure 1: Example Choice Scenario

	Standard Agreement	1st New Agreement	2nd New Agreement
Absolute Min. Colony Strength	--	<4 Frames → Not paid	--
Feb. 1st % Prepayment	--	10%	40%
Pesticide Clause	--	No mix/ No day	--
Cover Crop	--	Soil Builder	Brassica
Cover Crop Contingency	--	Plant Oct. 10th → $2 off	$5 off
Initial Price (excludes discounts)	**$200**	**$190**	**$205**

Tables

Table 1: Attributes and Levels

Attribute (Number of Levels): Predicted Sign	**Description**
Price (4): Positive	The amount of revenue the beekeeper receives in exchange for providing pollination services from their honey bee hive. 1. $190 2. $195 3. $200 4. $205
Absolute Minimum Colony Strength (2): Negative	A clause stating that no payment will be made for bee colonies with less than 4 frames of bees. 1. No Clause* 2. Clause present
Prepayment (3): Positive	A clause that stipulates the grower will prepay a percentage of the pollination fee to the beekeeper by February 1: 1. None* 2. 10% 3. 40%
Pesticide Clause (2): Positive	A clause that stipulates additional restrictions to the grower: 1. None* 2. Prohibited from tank mixing and daytime applications of fungicides
Cover Crop (4): Positive	Different types of cover crops between orchard rows, about 25% of orchard area: 1. None* 2. Legume mix 3. Soil Builder mix 4. Brassica mix
Cover Crop Contingency and Discount (5): Negative	Appears if and only if a cover crop is present: 1. None* 2. $2 Discount only if grower plants the cover crop by Oct. 10th 3. $5 Discount only if grower plants the cover crop by Oct. 10th 4. $2 Discount only if the cover crop blooms by Feb. 1st (Brassica and Soil Builder) or Mar. 15th (Legume) 5. $5 Discount only if the cover crop blooms by Feb. 1st (Brassica and Soil Builder) or Mar. 15th (Legume)

* indicates reference level for dummy-coded attributes.

Table 2: Sample Characteristics

	Population	Sample	% of Population
Number of colonies in U.S. on January 1, 2020	2,880,000	462,575	16%
Number of estimated colonies demanded (population) and rented (sample) for almond pollination	2,500,000	2,575	19%
Number of beekeeping operations	60,650	81	0.13%
Average honey bee colonies/operation	47	5,711	

Sources: USDA NASS Honey Bee Colonies Report and 2017 Agricultural Census, Estimated almond pollination demand from Goodrich and Durant (2020)

Descriptive Statistics of Sample Pollination Rental Agreements

Characteristics	**Mean (Std. Dev.)**
Base Fee	$187.19 (24.70)
Minimum Average Frame Count	6.95 (1.4)
Absolute Minimum Frame Count	4.75 (2.01)
Forage	
No Pollinator Habitat	49%
Provide temporary or permanent bee forage	16%
Not sure	17%
Pesticide Agreement Details	
No details specified	34%
Applied only during bee inactivity	21%
Minimum notification	20%

Table 3: Model Results

Attribute	Coefficient	Std. Err.	Std. Dev.	Std. Err.	Mean WTA	90% KR CI
Price	0.112***	(0.017)				
Standard Agreement	-0.909	(0.572)	3.375***	(0.562)		
Minimum Colony Strength	0.117	(0.152)	0.598**	(0.238)		
10% Prepayment	0.281	(0.198)	0.391	(0.491)		
40% Prepayment	0.388*	(0.204)	0.727**	(0.305)	3.45	(0.53, 6.03)
Pesticide Protection	0.895***	(0.186)	0.874***	(0.228)	8.02	(5.52, 11.1)
Legume	0.222	(0.287)	0.059	(0.461)		
Brassica	0.744**	(0.308)	0.013	(0.440)	6.52	(2.33, 11.58)
Soil Builder	0.626**	(0.308)	0.545	(0.382)	5.62	(1.14, 11.32)
Contingency-Fall Planting	0.007	(0.210)	0.246	(0.613)		
Contingency-Spring Bloom	-0.014	(0.196)	0.125	(0.425)		
Log-likelihood						

Table 4: Alternative model specifications

	II				III			
	Coef.	Std. Err.	Std. Dev.	Std. Err.	Coef.	Std. Err.	Std. Dev.	Std. Err.
Price	0.120***	(0.018)			0.138***	(0.021)		
Standard Agreement	-0.744	(0.591)	3.392***	(0.558)	-0.967	(0.632)	3.444***	(0.56)
Min. Colony Strength	0.118	(0.152)	0.580**	(0.241)	0.092	(0.199)	0.566**	(0.244)
10% Prepayment	0.378*	(0.202)	0.360	(0.505)	0.530**	(0.268)	0.444	(0.418)
40% Prepayment	0.574***	(0.221)	0.653**	(0.304)	0.613**	(0.269)	0.603*	(0.311)
Pesticide Protection	0.954***	(0.189)	0.889***	(0.216)	0.783***	(0.213)	0.901***	(0.216)
Legume	0.269	(0.287)	0.008	(0.436)	0.138	(0.414)	0.005	(0.507)
Brassica	0.811**	(0.314)	0.004	(0.484)	0.812**	(0.374)	0.016	(0.602)
Soil Builder	0.716**	(0.314)	0.538	(0.358)	0.225	(0.398)	0.525	(0.348)
$2 Discount-Plant	-0.329	(0.301)	0.189	(1.646)	-0.694	(0.602)		
$5 Discount-Plant	-0.464*	(0.263)	0.113	(1.099)	-0.588	(0.600)		
$2 Discount-Bloom	-0.515**	(0.247)	0.012	(0.356)	-0.543	(0.649)		
$5 Discount-Bloom	-0.084	(0.323)	0.019	(0.708)	0.072	(0.507)		
Brassica $2 Discount-Plant					0.829	(0.977)		
Brassica $5 Discount-Plant					-1.232	(0.947)		
Brassica $2 Discount-Bloom					-0.376	(0.809)		
Brassica $5 Discount-Bloom					-0.215	(0.855)		
Soil Builder $2 Discount-Plant					0.778	(0.923)		
Soil Builder $5 Discount-Plant					1.264	(0.935)		
Soil Builder $2 Discount-Bloom					0.990	(0.954)		
Soil Builder $5 Discount-Bloom					0.335	(0.871)		
LL	-505.49				-499.729			
AIC	1060.985				1057.458			