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Theme Overview: Pollination Service Markets: Evolution and Outlook

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Will there be enough pollinators for agriculture in the foreseeable future? How well has the beekeeping industry performed as a supplier for agriculture's pollination needs? How has beekeeping responded to elevated loss rates and the growing demand for pollination services? In the last decade, concerns over the effect of pollinator loss on crop production have entered environmental policy discussions regarding land use change, pesticide use and spraying practices as well as the movement toward less crop diversity and more intensive chemical use on farms. Many farms, however, acquire pollination services through pollination markets rather than the local environment by renting colonies of honey bees (*Apis mellifera*) from migratory beekeepers. Throughout the year, these beekeepers move about the country producing honey, renting colonies for crop pollination, and managing their colonies' reproductive cycle. While honey bees themselves depend critically on forage and nutrition in the natural environment, the movement of colonies and intermediation of beekeepers unwinds the link between a farm's local habitat and its pollinator availability.

Articles in this Theme:

The following five articles in this *Choices* theme discuss the origins, operations, and institutions of these remarkable markets with two main themes. The first is that farmers do not leave crop pollination to chance but instead utilize well-developed markets for pollination services when necessary. The second is that the growth of the California almond industry has reshaped the revenue structure and orientation of beekeeping toward pollination service provision and away from honey production.

Rucker, Thurman, and Burgett explain the origins of pollination markets and their market response to elevated colony loss rates and the growth of almond industry. Goodrich details how formal and informal contractual relationships coordinate the timely delivery of scattered colonies to California *en masse* and increasingly address long-standing quality assurance problems through contract incentives. Champetier, Lee, and Sumner show how almond growers are gradually reducing their need for colony rentals in response to high fees by adopting an almond variety that requires less pollination. In a separate article, Champetier, Lee, and Sumner then describe the factors limiting the expansion of colony numbers and how the supply of honey bee colonies in California in the winter supply of honey bee colonies in California depends on the amount of forage land in North Dakota in the summer. Finally, Ferrier describes the evolution of government programs supporting beekeepers and the early findings of new data on beekeeping colony loss and pollination markets.

Beekeeping is a peculiar kind of agriculture. The crop is a liquid. The farmers move regularly. The livestock flies, possesses six legs, and will die to protect its home. Moreover, because honey bees provide a critical pollination service input in farm production, problems for beekeepers have the potential to create problems for many other crop producers. Despite these oddities, pollination markets behave like other markets, and the same invisible hand at work in markets for other farm inputs is also at work in pollination markets.

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Honey Bee Mortality, Markets, and the Food Supply

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JEL Classifications: Q11, Q15, Q54, Q57

Keywords: Colony Collapse Disorder, Honey bees, Markets, Pollination

Honey Bees and Colony Collapse

Bees are dying. This biological fact has become a rallying cry for some policy advocates. Different groups have raised concern over the implications of honey bee mortality—and recent increases in mortality rates—for the food supply, for the livelihoods of commercial beekeepers, for the role of pesticides in agriculture, and for the conservation of semi-wild lands and innumerable species of invertebrate pollinators. These separate issues are united by the insect most congenial to humans, *Apis mellifera*, the European honey bee.

The honey bee is not native to North America but was brought by European colonists in the 1600s. Managed bees moved west with American settlers, finally arriving in California in the 1850s. Bees established feral colonies early on, and managed and wild colonies of honey bees are now found across the continent.

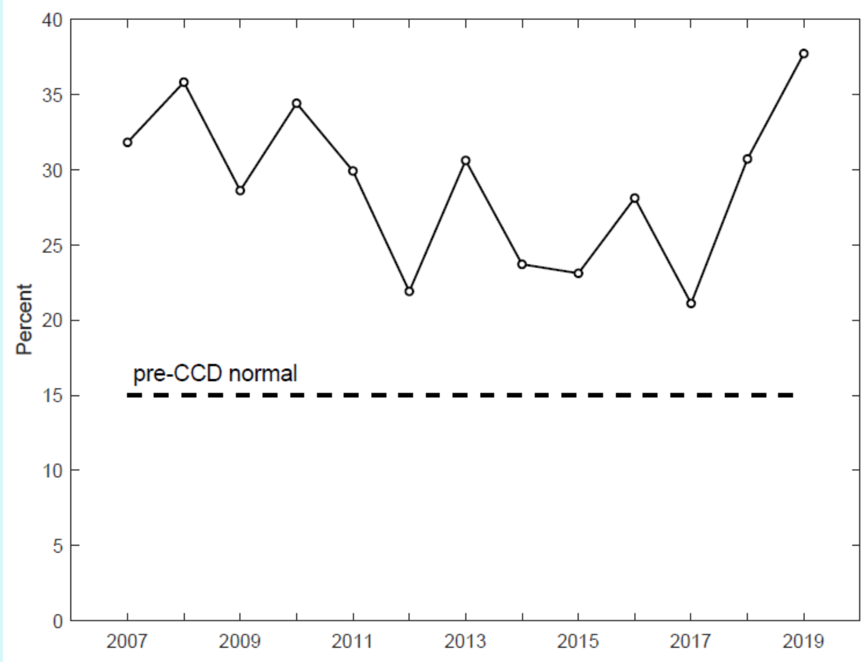
Until the twentieth century, the primary reason for humans to keep bees was honey. As the *Apis–Homo* partnership evolved, the value of bees as pollinators came to be understood. Bees were valued for their contributions to (primarily) fruit production and, eventually, that value was recognized and enhanced by pollination service contracting as early as 1910. Today, U.S. markets for bees' pollination services are routine, connecting migratory beekeepers who move their bees by truck from crop to crop—almonds, cherries, apples, pears, cranberries, blueberries, and many other fruits and vegetables. While pollinating, and after the blooming season, bees still produce honey harvested by beekeepers.

Since the beginning, American beekeepers have dealt with illnesses and parasites that afflict bees, starting with the widespread scourge of American foulbrood in the American colonies and extending through today. Arguably the most damaging threat, the invasive *Varroa* mite, arrived in North America from Asia in the early 1980s. But broad public awareness of honey bees and beekeeping (broad, but mostly superficial, we would argue) began in late 2006 with Colony Collapse Disorder (CCD).

In October 2006, David Hackenberg, a Pennsylvania beekeeper, took almost 3,000 honey bee colonies to Florida for the winter. In mid-November, Hackenberg discovered that two-thirds of his hives were practically empty—no adult worker bees in the hives and no dead bees nearby. Other beekeepers across the country reported similar experiences of high colony mortality and the same unusual symptoms. The phenomenon was dubbed Colony Collapse Disorder. Colonies with CCD contained brood (developing young), food stores (honey and bee pollen), and the queen—but virtually no worker bees, alive or dead.

The summary indicator of CCD was an increase in overwinter mortality from a pre-CCD expectation of 15% (15 out of 100 colonies failing to survive their winter period of semi-dormancy) to rates that, since 2006 and through 2019, have averaged around 30% (see Figure 1).

Figure 1. Overwinter Mortality Post-CCD



Immediately following the discovery of CCD, alarm bells were rung and countless articles and reports appeared in the media. Secretary of Agriculture Mike Johanns in 2007 laid out his view of the economic threat, warning that "[i]f left unchecked, CCD has the potential to cause a $15 billion direct loss of crop production and $75 billion in indirect losses."

Noted food writer Michael Pollan, in a 2007 *New York Times* article, better captured the CCD zeitgeist:

> *[T]he lifestyle of the modern honeybee leaves the insects so stressed out and their immune systems so compromised that, much like livestock on factory farms, they've become vulnerable to whatever new infectious agent happens to come along.*

Press accounts of dwindling pollinators have grown steadily since that time. In 2014, President Obama, inaugurating a multiagency Pollinator Health Task Force, announced:

> *The continued loss of commercial honey bee colonies poses a threat to the economic stability of commercial beekeeping and pollination operations in the United States, which could have profound implications for agriculture and food (White House Office of the Press Secretary, 2014, p. 1).*

In 2019, Environment America, an advocate for green issues, sent interns door to door to promote their "No Bees, No Food" campaign: "We're here to save the bees."

Given the saturation of public conversation with concerns about honey bee collapse, it is reasonable to ask: what is fact and what is fiction? And to ask what *are* the implications of bee health for the food supply?

What We Know About Overwinter Mortality

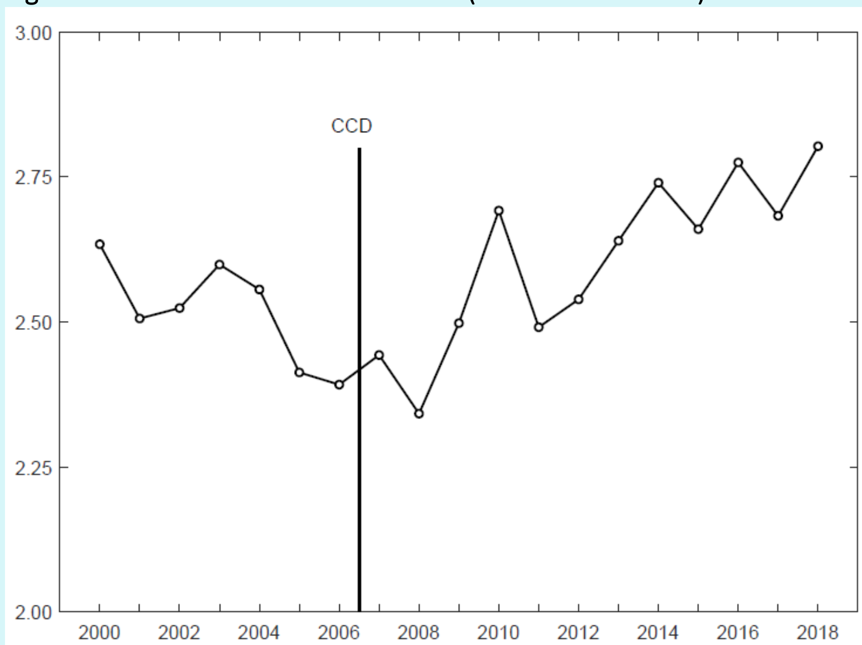
Systematic data on beekeeper's loss rates were not compiled prior to 2007. However, Burgett, Rucker, and Thurman (2009), Pernal (2008), and vanEngelsdorp et al. (2007) all report pre-CCD or "normal" mortality rates of about 15%, though this number is approximate and should not be taken to deny the substantial variability across beekeepers and over time. In 2007, the Apiary Inspectors of American began a telephone survey—now conducted online by the Bee Informed Partnership—compiling answers from hobbyists and commercial beekeepers. Among the questions asked of beekeepers are what percentage of their colonies failed to survive the winter. Figure 1 displays the annual averages of the response to this question along with the pre-2007, pre-CCD approximate normal level of 15% overwinter loss.

Figure 1 shows mean loss rates since 2007 to be about 30%, with considerable variability around the mean. The most recent of these values, reflecting loss rates over the winter of 2018/2019, is 38%. This is the highest loss rate reported since 2007. Whether it signals a shift in the distribution or a realization of loss rates from essentially the same distribution remains to be seen.

What We Know About Bee Numbers

Figure 2 displays a different reflection of the bee economy: counts of bee colonies conducted annually by the U.S. Department of Agriculture. Data are plotted since 2000; the most recent available observation is for 2018. Given the high colony loss rates since the advent of CCD, it is perhaps surprising that the trend in colony numbers in recent years is upward (albeit moderate). In fact, the 2018 U.S. population of bees—2.8 million colonies—is higher than any observation in the past 25 years.

Figure 2. U.S. Bee Numbers: 2000-2018 (millions of colonies)



Figures 1 and 2 seem contradictory on their face: Colony numbers rise during the same period that overwinter mortality rates have reached historic highs. Recent work by Rucker, Thurman, and Burgett (2019) analyzes other data from the beekeeping industry (honey production, pollination fees, and queen and package bee prices) and finds similar results: little or no detectable deleterious effect after the 2007 increase in loss rates. The one possible exception to this conclusion is the fact that fees for pollinating almonds rose substantially in 2005 and 2006 (prior to CCD proper) and have plateaued at approximately $170 per hive.

The explanation for the apparent disconnect between high recent colony loss rates and the (moderate) upward trend in colony numbers is that commercial beekeepers are able to replace collapsed hives quickly and relatively inexpensively. We discuss the details of this process below.

The important point apparent in the data is that changes in colony mortality do not translate directly into changes in colony numbers. Observed colony numbers are an economic outcome, not simply a biological or environmental condition. Beekeepers and input suppliers respond to market signals in determining the number of colonies maintained (see Cheung, 1973; Rucker, Thurman, and Burgett, 2012) and, as Champetier, Sumner, and Wilen (2015) point out, colony loss and replacement result, in part, from beekeepers' management strategies.

Bee Diseases: CCD and Its Predecessors

Honey bees have long suffered from diseases and parasites. Underwood and vanEngelsdorp (2007) document 23 episodes of major colony loss between 1868 and 2003. The most recent major predecessors to CCD are two species of mites (*Varroa destructor* and *Acarapis woodi*—tracheal mites), which first appeared in North America in the mid- to late 1980s. *Varroa* mites are ectoparasites that attach themselves to bees and feed on their blood (see Nordhaus, 2011, chapter 3). Tracheal mites are endoparasites that attack bees' breathing tubes. Diseases that currently affect honey bees include American foulbrood, a bacterial infection that attacks bee larvae and pupae; *Nosema*, a fungus that invades the intestinal tracts of adult bees; and chalkbrood, a fungus that infests the guts of honey bee larvae. Over time, commercial beekeepers have developed methods to combat each of these parasites and diseases. That said, such methods are costly, and bee diseases and parasites have periodically devastated nonmanaged feral colonies.

Following the appearance of CCD in the fall of 2006, scientists began searching for its causes (see Rucker, Thurman, and Burgett, 2019). Bee scientists and regulators concluded early on that bees from CCD-afflicted colonies were infected with a broad range of known pathogens as well as with pathogens not reported before in the United States. Since these initial efforts, research has proceeded. Early speculation that cell phone signals may have been a cause of CCD were supplanted by alternative explanations with more longevity, including CCD being a new disease (possibly brought in by foreign bees), a response to malnutrition as a result of drought or habitat loss, resulting from exposure to stress (possibly induced by traveling long distances for pollination), or exposure to toxins and pesticides (in particular a class of insecticides called neonicotinoids that has seen increased use in recent years). A recent theme from the bee research community is that CCD is multifactorial and, as such, is not the result of a single causal agent.

In the past few years, some researchers have concluded that CCD is an overly broad label and have attributed higher winter mortality rates of the past decade to increasing resistance to treatments for *Varroa* and *Nosema*, to new strains of fungal parasites, and to the decreasing availability of forage for honey bees, in addition to the possible causal agents listed above.

How Beekeepers Exploit Honey Bee Biology

Since the winter of 2006/2007, although the over-winter mortality rate of honey bees has increased substantially, U.S. colony numbers have grown. To make sense of this seeming incongruity, we briefly discuss aspects of honey bee biology, commercial beekeeping, and pollination markets. Our argument at the end of the discussion is that pollination markets function well and that commercial beekeepers have responded quickly and effectively to increased winter mortality rates. In the process, market responses have largely mitigated the impacts of CCD. Additional detail can be found in Rucker, Thurman, and Burgett (2012, 2019) and Burgett et al. (2010).

Honey bees collect nectar and pollen from flowering plants and, in the process of moving from flower to flower, enable plant reproduction. They are but one of thousands of animal species that pollinate about 90% of flowering plants, with the remaining 10% reproducing through pollination by wind and water. In the hive, bees transform the nectar into honey for later consumption (or extraction by beekeepers) and store the gathered pollen as a future protein source for the hive. Honey bees forage on almost anything that blooms, and this flexibility enhances their value to beekeepers.

A typical, full-strength colony of honey bees consists of a single queen and 25,000 to 40,000 worker bees. Queens usually live for about two years and, during that period, lay all the eggs in the hive. When a queen becomes less productive, the beekeeper replaces her with a newly fertilized queen, and the activities of the hive continue, largely uninterrupted. All the worker bees are sterile females with life spans of about six weeks in the summer. The colony also contains a small number of males, or drones, whose sole function is to mate with fledgling queens from other colonies.

Modern commercial beekeeping in the United States is highly migratory. Hives are moved by truck from crop to crop for pollination in the spring and, later in the year, to bee pasture for honey production. The U.S. crop that engages by far the most honey bees is almonds, all of which are grown in California. Rapidly expanding acreage in almond orchards, combined with rising almond pollination fees, have induced beekeepers from as far away as Florida and North Carolina to transport their colonies to California in the early spring, thereby further increasing the importance of migration. After early-season employment in almond orchards, bees are moved into fruit tree orchards and berry, melon, and vegetable fields to augment yield and fruit set.

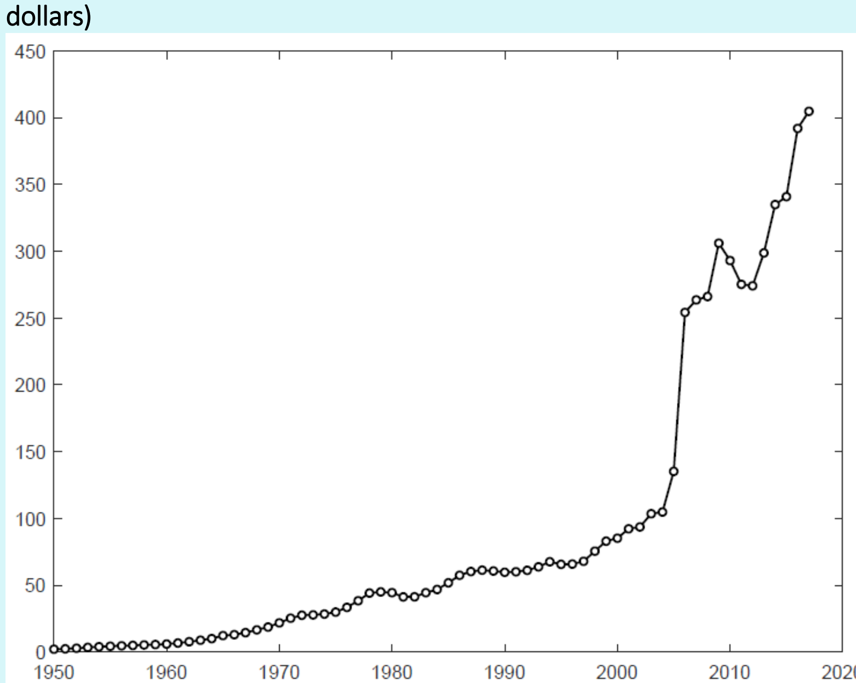
Over the course of a season, individual worker bees die and the colony replaces them. At the super-organism level, some whole colonies die every year as well, with higher frequency in the winter. When a beekeeper walks into his bee yard and discovers a dead colony, he has several options for replacement. Surveys of Washington and Oregon beekeepers in the winters following the appearance of CCD suggest that the method used most frequently is “making increase” or “splitting” (see Burgett, Rucker, and Thurman, 2009; Caron et al., 2010; Caron and Sagili, 2011). The process requires the beekeeper to move approximately half of the brood and adult bees from a healthy hive to an empty hive. The new hives—known as nuclei colonies (or nucs, or splits)—require a fertilized queen. Newly mated queens are often purchased for this purpose from commercial queen breeders, who in aggregate produce and sell hundreds of thousands of queens per year. Following a successful split, the beekeeper will have two full-strength hives in about six weeks. The splitting process takes an experienced beekeeper about 20 minutes, and new queens bought in bulk by commercial beekeepers can be purchased for about $18. Beekeepers can split hives preemptively, in anticipation of future losses, or after colony loss early in the pollinating season.

Pollination Markets

Until the early twentieth century, beekeepers collected revenues primarily from honey sales. Pollination markets began to develop not long after the turn of the twentieth century. Few details are available regarding early pollination markets, but by the time Steven Cheung studied them in Washington state in the early 1970s, they were sufficiently well developed that pollination service providers could be located in the local yellow pages. (Yellow pages were listings of businesses found in large bound volumes known at the time as “telephone books.” See Rucker and Thurman (2010) for discussion and analysis of early U.S. pollination markets.) Cheung (1973) concludes that the 1970s pollination markets he investigated operated efficiently, and Rucker, Thurman, and Burgett (2012)–using more current and much more extensive data than Cheung–reinforce that conclusion.

Observed pollination fees result from the interactions among a variety of supply and demand factors (see Burgett, Rucker, and Thurman, 2010.) On the supply side, a primary determinant is the number of honey bee colonies managed by commercial beekeepers. The fact that U.S. colony numbers have fallen over time, from roughly 5.5 million in the mid-1960s to about 2.5 million in the early 2000s suggests that, *ceteris paribus*, the supply of pollination services has fallen (see Muth et al. 2003). However, the supply of pollination generated by a given number of colonies will also be affected by the price of honey; at the margin, beekeepers make trade-offs between honey production and providing pollination services.

Figure 3. Almond Pollination Revenues: 1950-2017 (millions of 2017 dollars)



Other factors that have reduced the costs of commercial beekeeping include the development of the interstate highway system and flatbed trucks. Winter mortality rates also affect the supply of pollination services, although increased splitting of colonies in the late summer and fall can mitigate the reductions in colony numbers that accompany higher winter mortality rates.

Regarding the demand for pollination services, various crops employ bees, and they stock bees at different densities. Using data on Pacific Northwest beekeepers, Rucker, Thurman, and Burgett (2012) conclude that the average number of colonies used per acre ranges from less than 1.0 for cucumbers and squash and pumpkins to more than 2.0 for almonds and blueberries. The most important factor driving demand for bee pollination is almond production. Demand for pollination from almonds has increased dramatically over time as almond acreage has increased from 90,000 acres in 1950 to over 1,000,000 acres in 2018. Figure 3 displays the increase in almond pollination revenues between 1950 and 2016. The increase is due not only to the ten-fold increase in almond acres but also to increases in almond pollination fees, from roughly $1 per colony in 1950 to about $185 in 2016. As a result of this growth, in recent years, over 70% of U.S. colonies have been used to pollinate almonds in California in February. The tremendous importance of almonds in pollination markets is reflected in the fact that in 2016, 82% of all revenues from pollination services were from almonds (see Ferrier et al., 2018).

An important insight into the net effects of changing demand and supply conditions for pollination services over time can be seen by comparing past and present proportions of beekeeper incomes from honey and pollination services. In 1988, 11% of U.S. beekeeper revenue came from the provision of pollination services. By 2016, pollination revenues had increased to 41% of beekeeper revenues (Ferrier et al., 2018).

The preceding discussion suggests that (i) beekeepers respond to incentives transmitted through pollination markets and (ii) the relative and absolute magnitudes of the revenues from these markets have increased dramatically over time. Further, the increasingly migratory nature of commercial beekeeping is what allows markets to coordinate the narrow windows for providing pollination to crops that bloom only briefly, at different times each year, and in locations that span the United States.

Conclusions

Dramatically increased winter mortality rates over the last decade have been attributed to the appearance of Colony Collapse Disorder and in the past several years to a broader range of honey bee afflictions. Increased mortality has attracted unprecedented attention to the honey bee and the importance of the services it provides. Yet the number of honey bee colonies in the United States in recent years has risen, not fallen, even though colony numbers had fallen consistently for several decades prior to the appearance of CCD.

Why have colony numbers not fallen in concert with rising mortality rates? We conclude that the answer is found in an understanding of markets and the incentives they provide, combined with able deployment of beekeeping technology by beekeepers—factors overlooked by most researchers who investigate the seemingly precarious condition of honey bees. Beekeepers have always lost hives during the winter, and sustainable beekeeping requires them to replace dead and weak colonies using the splitting process and other methods. Since the onset of CCD, beekeepers have had to replace more hives to maintain colony numbers, and the time path of colony numbers shown in Figure 2 suggests they have succeeded in doing so.

The lesson we draw is that even in the face of a dramatic negative biological shock (i.e., the appearance of CCD and high mortality rates), well-functioning pollination markets combined with effective adaptation by commercial beekeepers have mitigated the impacts of the shock to such an extent that economic effects are hardly observable.

To conclude, consider the following questions that frame the public discussion and concern for bees, each followed by our response:

Question: Should we worry about the disappearance of managed honey bees?
Answer: No. Bees are managed livestock and beekeepers face appropriate incentives to manage honey bee disease problems.

Question: Should we worry that our food supply will be dramatically reduced?
Answer: No, and for similar reasons.

Question: Should we worry about the livelihoods of commercial beekeepers?
Answer: Costs of operating have increased as a result of CCD and other bee health problems. This causes beekeeper profits to fall. At roughly the same time, however, almond pollination fees have more than doubled, which makes beekeeping more profitable. Rucker, Thurman, and Burgett (2019) suggest that the latter effect outweighs the former, at least for commercial beekeepers whose bees pollinate almonds.

Question: Should we worry about the plight of nonmanaged pollinators?
Answer: From a biodiversity perspective, plausibly. Unlike honey bees, the services provided by unowned, nonmanaged pollinators are not transacted directly in markets and there are few market incentives promoting their conservation. It is useful to keep in mind here that data from managed honey bees have little direct relevance to the status or value of wild pollinators.

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Contracting for Pollination Services: Overview and Emerging Issues

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Keywords: Almonds, Beekeeping, Contracts, Ecosystem services, Honey bees, Pollination services

Introduction

For the last decade, growing attention has been focused on the "plight of the honey bees," referring to concerns about honey bee colony health and abnormally high mortality rates. Far less attention has been paid to the "plight of the beekeepers," who face the challenge of maintaining those struggling colonies. Honey bee colony health is often thought of as symbolic of the health of the natural environment, when in reality most honey bee colonies in the United States are managed as livestock by commercial beekeepers (Daberkow, Korb, and Hoff, 2009). Beekeepers all over the world have faced ever-increasing challenges with honey bee colony health, all while demand for honey bee pollination services has increased (Aizen and Harder, 2009).

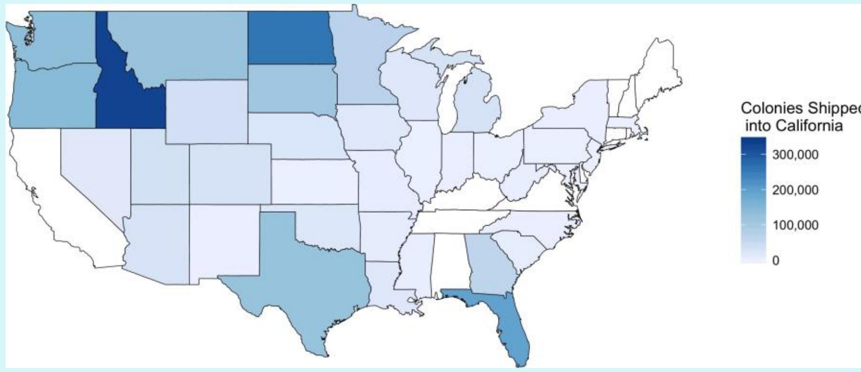
In the United States, California almond production is the largest user of pollination services. This one-month pollination event beginning in mid-February has been called the "Super Bowl of beekeeping" (Lowe, 2018) and utilized an estimated 82% of the total U.S. population of honey bee colonies as of January 1, 2018 (USDA, 2018; CDFA and USDA, 2019). According to the U.S. Department of Agriculture (USDA), almond pollination revenues in 2016 made up roughly one-third of U.S. beekeeping income and is therefore one of the key influences on the economic sustainability of U.S. commercial beekeeping operations. Contractual arrangements determine the profitability of a beekeeper's decision to partake in almond pollination. Specific contractual components for pollination services have been discussed anecdotally by prior research on pollination services (Cheung, 1973; Rucker, Thurman, and Burgett, 2012); until recently, the extent of contracting practices has remained unknown. This article discusses the results of a 2015 survey of almond growers, the first survey to outline basic components of pollination contracts. Many almond growers diversify their sources of pollination services using multiple beekeepers, often in addition to contracting through a pollination broker (Goodrich, 2017). Most almond pollination agreements include minimum requirements on the approximate number of bees in the colony (the colony's strength). These requirements are included as a quality control to ensure adequate pollination, and almond growers are willing to pay higher fees per colony for those with higher strength guarantees (Goodrich, 2019); premiums for high-strength colonies range from 5.7% to 8.6% (Goodrich and Goodhue, 2016). Other important components of almond pollination agreements include those regarding pesticide use, colony thefts, late placement of colonies, and beekeeper access to colonies after placement (Goodrich, 2017).

Due to its scale and corresponding value of fees per colony, the California almond pollination market has become one of the most structured markets for pollination services in the world. If almond pollination fees continue to rise, formal contracting practices will likely increase due to increasing risk on both sides of the almond pollination agreement. Pollination services markets are developing and becoming more formal worldwide due to the increasing demand for managed pollination services. Beekeepers, growers, and brokers in these developing markets can utilize information and lessons learned from contracting practices in the California almond pollination market to ease the transition toward more formal transactions.

Overview of the California Almond Pollination Market

In 2018, there were over a million productive acres of almonds in California (CDFA and USDA, 2019). This acreage has more than doubled since 2000 (CDFA and USDA, 2001). Most almond varieties require cross-pollination, so to facilitate adequate pollination almond growers have traditionally used a rule of thumb of two honey bee colonies per acre of almonds. Consequently, the number of productive almond acres in 2018 required roughly 2 million colonies for adequate pollination.

Figure 1. Honey bee Colony Shipments into California by State of Origin, Season 2018



Source: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services (California Department of Food and Agriculture, 2018). Figure originally published in Goodrich, Williams, and Goodhue (2019).

The number of colonies required for almond pollination outnumbered the supply of colonies in California and the Pacific Northwest states by the late 1970s (Rucker, Thurman, and Burgett, 2012). Thus, the supply of colonies for California almond pollination relies heavily on out-of-state shipments, which steadily increased along with almond acreage. According to the California Department of Food and Agriculture (CDFA), colony shipments into California increased by 64% between 2008 and 2018. For the 2018 almond pollination season, 1.8 million colonies (of the 2.6 million the U.S. total on January 1, 2018) were shipped into California (USDA, 2018; CDFA, 2018).

A beekeeper must take into account many costs when deciding whether to contract for almond pollination services. Shipping costs alone can make up 25% of the almond pollination fee when coming from the eastern United States (Goodrich, Williams, and Goodhue, 2019). Additionally, in southern states such as Florida and Texas, there may be opportunities for honey production at the same time as almond bloom. Forgone honey revenue must be covered by the almond pollination fee. There are also costs to preparing colonies for the almond bloom, costs to bee health through the spread of pests and disease, potential pesticide exposure, and the stress of shipment (Agnew, 2007; Oliver, 2010; Krupke et al., 2012; Simone-Finstrom et al., 2016). A beekeeper must be reassured that all anticipated costs and forgone revenues will be covered by the almond pollination fee before she will agree to participate (see Cheung, 1973; Rucker, Thurman, and Burgett, 2012; Champetier, Sumner, and Wilen, 2015).

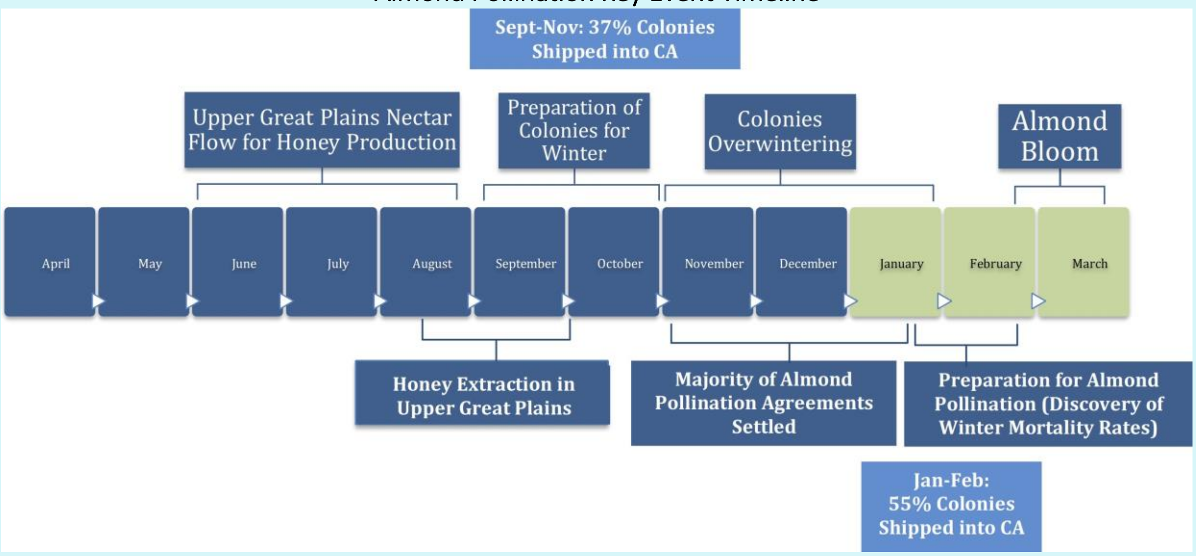
The reliance on out-of-state shipments means that colony populations throughout the United States are a major influence on the supply of available colonies for almond pollination. Figure 1 shows a heat map of the number of colonies shipped into California for 2018 almond pollination from each state. The top five states shipping colonies into California were North Dakota, Idaho, Florida, Oregon, and Texas.

Box 1 presents a timeline of events important for almond pollination compared to the population dynamics of honey bee colonies. Industry participants indicate that many almond pollination agreements are settled well before almond bloom. Contracting in advance provides advantages for both beekeepers and growers; beekeepers can lock in a price that they expect will cover transportation and preparation costs, while almond growers guarantee they will receive colonies for adequate pollination. By locking in a price, beekeepers and growers risk missing out on advantageous price movements closer to bloom. However, the tendency for forward contracting in the industry suggests the benefits of forward contracting outweigh the potential costs.

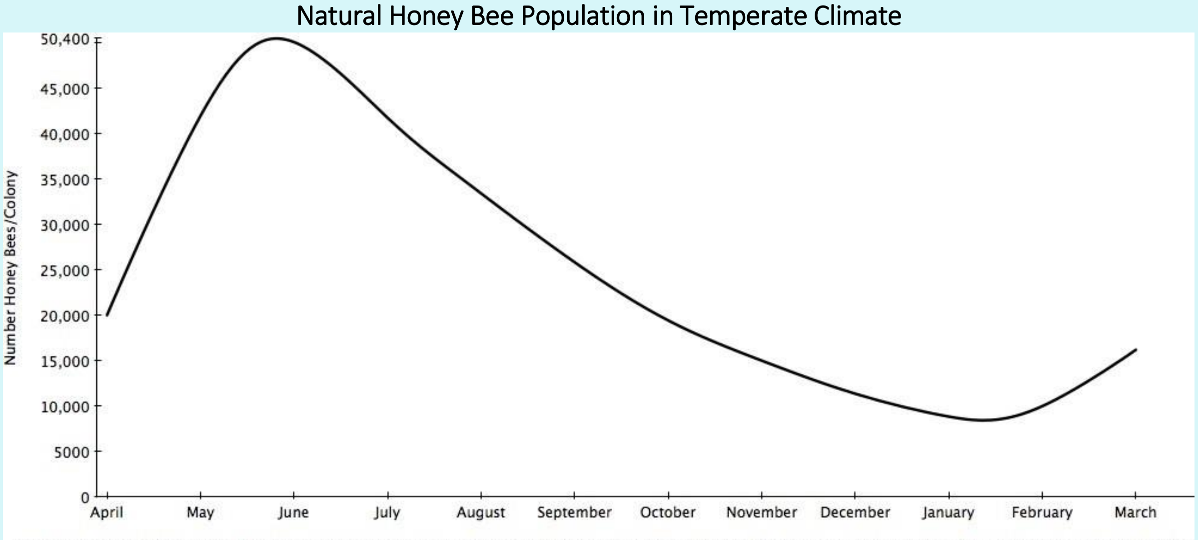
Box 1. Timeline of Almond Pollination Events and Honey Bee Colony Population Dynamics

The figures below present a timeline and natural population dynamics representative of a large portion of colonies contracted for almond bloom (specific beekeepers' practices may diverge from this). Bond, Plattner, and Hunt (2014) estimate that well over half of the commercial honey bee colonies in the United States spend the summer producing honey in the Upper Great Plains region (Minnesota, Montana, North Dakota, South Dakota). During late fall, colder weather and shortening days trigger colonies to shrink in size (Winston, 1992). This is because blooming forage is scarce and temperatures are too low for bee foraging to take place during winter across most of the United States (Gary, 1992). Beekeepers prepare colonies for overwinter dormancy by making management decisions in the fall, such as the amount of honey to extract and pest treatments, to help minimize losses over the winter months (Furgala and McCutcheon, 1992). After preparing for winter, most colonies are left untouched in their dormant state until early spring, when forage becomes available or colonies are prepared for almond pollination.

Almond Pollination Key Event Timeline



Natural Honey Bee Population in Temperate Climate



Source: Adapted from Oliver (2006).

Almond Pollination Agreements

The following section discusses the basics of almond pollination agreements interspersed with results from a 2015 survey of 114 almond growers conducted at the 2015 Almond Conference (Goodrich, 2017). This was the first survey to explore almond pollination agreements, so it provides baseline knowledge regarding pollination agreements and the extent to which contract components are used. The survey represents approximately 2% of almond operations in the industry.

Pollination Provider

Almond growers and beekeepers have many choices when it comes to their almond pollination agreements. One of the first is deciding whether to contract directly with the opposite party or to contract with a pollination broker, an intermediary who will facilitate the transaction. Brokers ensure that a grower gets adequate pollination services by guaranteeing a certain level of quality. Additionally, a broker contracts with many beekeepers, so if one comes up short due to high mortality rates, colonies from another beekeeper can usually be substituted easily. On the beekeeper side, brokers guarantee timely payments, so the broker takes on the risk of an almond grower not paying on time (or at all). Sometimes a broker (or beekeeper playing the role of broker) may even manage colonies in California while the beekeeper remains in their home state. Of course, these benefits come with a fee; brokers tend to charge the almond grower a higher fee than they pay the beekeeper and take the difference as payment for facilitating the transaction. Depending on the specific arrangement, brokerage fees can range from $2 to $20 per contracted colony.

In 2015, 53% of growers rented directly from a beekeeper, while 44% rented colonies directly from a beekeeper and also from an independent pollination broker; 3% of respondents rented colonies from an independent pollination broker only. The use of pollination brokers seems to be prevalent within almond pollination transactions: The Almond Board of California (2019) lists over 40 pollination brokers on their pollination directory.

Almond growers were also asked the number of beekeepers from which they received pollination services. While 44% of almond growers received colonies from only one source, 56% received colonies from two or more beekeepers. These findings suggest that many almond growers diversify their pollination sources. Another interesting finding was that of the respondents who contracted through a broker in 2015, 33% were unsure of the number of beekeepers utilized through that broker. This implies that the independent pollination broker incurs some of the logistical costs that a grower bears when contracting with a beekeeper directly.

Formality of Agreement

Pollination brokers will typically have a formal written contract separately with each the beekeeper and almond grower. If an almond grower and beekeeper choose to contract directly, each must then decide whether they want to engage in a formal written agreement or a more informal, “handshake” agreement. From conversations with industry participants, it became clear that repeated handshake agreements are the norm in the market for almond pollination services, and oftentimes the suggestion of a written agreement can actually be seen as offensive, especially in long-term relationships. In economics, these repeated informal agreements are referred to as relational contracts, which can take the place of formal written contracts when the value of the relationship going forward exceeds the value of breaking the agreement in the current period (Levin, 2003).

Almond growers reported whether they used written, oral (handshake), or both types of almond pollination agreements in 2015. Formal

Table 1. Average Respondent Characteristics by Pollination Agreement Form Used in 2015

Agreement Form	Years Experience	Yield (lbs/acre)	Acreage
Written	24	2,151	716
Oral	15	1,927	346
Both	23	2,282	1,694

Note: Using ANOVA methods, differences are statistically significant at the 10% level.

written and informal oral agreements were used to about the same extent; 43% of growers used pollination agreements in a formal written form, 42% of growers used pollination agreements that were informal oral agreements, and 12% of growers used a combination of written and oral agreements during 2015. Table 1 displays the relationships between the form of pollination agreement used and various respondent characteristics. Based on analysis of variance (ANOVA) methods, users of written agreements or combination of written and oral agreements had on average significantly more experience in almond production, higher yields, and more almond acreage than users of oral agreements.

The finding of similar formal and informal contract use was surprising giving the seemingly widespread use of relational contracts in the industry. Survey responses were likely biased toward relatively large operations (Goodrich, 2017). The disproportionate representation of contracts used by large operations likely overstates the formality of contracts used across all growers because large growers are more likely to use formal, written agreements. However, the representation of many large growers means the survey illustrates how a relatively large share of all colonies are contracted for almond pollination services.

Box 2. Colony Strength Inspections

A hive is the physical container in which a honey bee colony resides. A hive for almond pollination typically consists of two stacked boxes, each filled with ten removable frames on which bees construct comb to store honey and brood.

Honey bees' tendency to cluster allows industry members to visually inspect frames within a hive to estimate a colony's strength, or the number of bees in a colony. Colony strength definitions can vary slightly (see Sagili and Burgett (2011); Spivak (2011)), but a standard definition is that an "active" frame meets one of two criteria: Bees cover at least 75% of both sides of a standard frame of comb, or there are at least four bees per square inch of comb. The photos shown below display examples of an active frame compared with a nonactive frame of bees.

Growers can pay for a colony strength inspection by a trained inspector. Growers who hired one of the largest third-party inspection operations paid on average $1.50–$2.00 per inspected hive in 2016, which corresponds to roughly 1% of current pollination fees. The inspector opens some (typically 10%–25%) of the hives provided to an orchard and counts the number of active frames in each hive. The number of active frames per hive is averaged to estimate the beekeeper's average colony strength for all of the hives in that orchard.

(a) Active Frame

(b) Non Active Frame

Length of Pollination Relationship

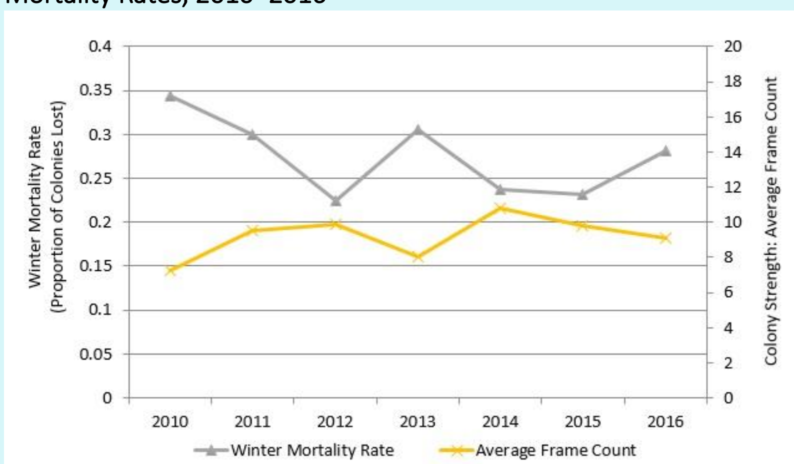
Nearly 80% of almond growers worked with the same beekeeper (or broker) for at least four pollination seasons, and 29% had worked with the same beekeeper (or broker) for at least 11 pollination seasons. The preference for repeated working relationships is supported by growers' stated preferences for selecting beekeepers each year. Nearly 80% stated that the prior contractual relationship with a beekeeper was the most important factor in selecting beekeepers each year. The second most common answer was that colony strength guarantees made by the beekeeper are the most important factor when selecting a beekeeper (11%). While another factor may be influential on their pollination provider decisions, many growers seemed to value repeated contractual relationships in almond pollination.

Growers find many benefits to working with the same pollination provider for multiple years. For example, time and effort savings occur because there is no need to search for a new pollination provider, and negotiating pollination contracts becomes easier due to the prior established agreement. In addition to these benefits, another factor—honey bee colony strength, or the approximate number of bees in a colony—is key in pollination transactions. Using the same pollination provider year after year can help a grower ensure access to reliable colonies for almond pollination each year. The following section discusses the role of colony strength in almond pollination contracts.

Colony Strength Requirements

In almost any market for agricultural products, some measure of quality exists. Everything from feeder cattle to wine grapes has some sort of agreed-upon quality measures, many of which are regulated by the USDA Agricultural Marketing Service (e.g., USDA Prime Beef, USDA Grade AA Eggs, U.S. Extra Fancy Apples). The almond pollination industry is no different. The industry uses colony strength as an approximation of the quality of pollination services performed by a colony. The idea is that the more bees in the colony, the more pollination services it performs, ultimately resulting in more almonds. Box 2 outlines the industry definition of colony strength and the basics of a colony strength inspection.

Figure 2. Almond Pollination Colony Strength and U.S. Winter Mortality Rates, 2010–2016



Source: The Pollination Connection (2016); vanEngelsdorp et al. (2011, 2012); Spleen et al. (2013); Steinhauer (2013); Lee et al. (2015); Seitz et al. (2016); and Kulhanek et al. (2017). Figure originally published in Goodrich (2019).

Higher colony strength can result in a higher value of almond production, especially in the weather that commonly occurs during bloom. Bees will not leave the hive to pollinate in temperatures below 55°F or if it is raining or windy (Gary, 1992). Almond growers tend to pay higher fees for higher delivered colony strength to ensure proper pollination in suboptimal weather (Goodrich, 2017, 2019). Colony strength is crucial in almond pollination transactions because almonds bloom in mid-February, when colonies are naturally at their smallest size (see Box 1). Beekeepers must feed colonies supplemental food in early winter so that colonies will begin increasing in population before almonds begin to bloom (Furgala and McCutcheon, 1992; Winston, 1992). Over the winter, aging bees within the colony are under considerable stress and additional factors such as winter weather, pests, and diseases, can cause colonies to decrease in strength over this period and, in extreme cases, completely perish (Oliver, 2013). When a beekeeper's winter mortality rate is high, it is likely that the surviving colonies are also stressed, so their populations would be low. As seen in Figure 2, U.S. average winter mortality rates are highly (negatively) correlated with average colony strength as reported by third-party inspections.

Almond pollination agreements can contain provisions specifying a minimum average level of colony strength across all colonies or a minimum colony strength for each individual colony as well as enforcement mechanisms, such as monetary penalties, that may be used in the case that colony strength requirements are not met. Approximately 78% of growers required a minimum average frame count in their pollination agreement, ranging from fewer than 5 to more than 10 active frames (See Box 2 for active frame definition). Nearly half of all growers indicated their minimum average frame count was eight active frames—the current industry standard—and 20% of growers said they offered a per frame bonus to incentivize beekeepers to provide high-strength colonies. For example, a per frame bonus contract would give a base pollination fee per colony for an eight-frame average and if the beekeeper provides colonies of more than an eight-frame average the beekeeper would receive a bonus per colony for the number of frames above the eight-frame average.

Table 2. Mean and Standard Deviation of Per Colony Almond Pollination Fees by Colony Strength

Category	Average	Standard Deviation
High colony strength	$179.36	12.36
Low colony strength	$169.66	14.71
No colony strength	$165.22	15.22

Note: High colony strength: Contracts with minimum average colony strength > 8 frames. Low colony strength: Contracts with minimum average colony strength ≤ 8 frames. No colony strength: Contracts with no colony strength requirement.

Because pollination markets have historically been small and therefore relatively informal, there is a lack of data in this sector. Even though there is a well-known correspondence between almond pollination fees and colony strength within the industry, the direct relationship is difficult to pin down by researchers and policy makers. Past research has explored this relationship, though more robust data is necessary to further explore the issue. Using the California State Beekeeper's Association (CSBA) pollination fee survey for 2008–2016, Goodrich (2019) finds that this relationship holds true: For a beekeeper, a decrease in the delivered colony strength decreases the per colony almond pollination fee she collects. Additionally, Table 2 displays average fees reported by almond growers in the 2015 survey by colony strength category. At the 5% level, there is a statistically significant difference in mean pollination fees between colonies contracted with a minimum average frame count of more than eight frames and colonies contracted with a lower or no minimum average frame count (Goodrich and Goodhue, 2016). It is clear that respondents requiring minimum average frame counts higher than the industry standard pay a premium compared to others with lower colony strength requirements. On average respondents paid a 5.7% premium for colonies contracted at strengths above an eight-frame minimum average compared to colonies contracted at an eight-frame minimum average or below. Similarly, respondents paid an 8.6% premium on average for colonies contracted at strengths above the industry standard compared to colonies contracted with no colony strength requirement.

Cheung (1973) noted that the standard colony strength for colonies rented for almond pollination in 1973 was four active frames, while the current standard is eight active frames. Supporting this conclusion, University of California Co-operative Extension recommended that each hive should contain at least five active frames of bees in 1998 and recommended at least eight active frames per hive in 2016 (Hendricks et al., 1998; Duncan et al., 2016). This is important to consider when comparing almond pollination fees over time. Either gradually over the last four decades or within a shorter interval during that period, the standard colony strength for almond pollination has doubled, suggesting that—all else equal—pollination fees should also have increased given the findings of Goodrich (2019) and Goodrich and Goodhue (2016). Prior economic analyses have not captured this change over time and consequently have not been able to fully explain substantial per colony fee increases for almond pollination.

Other Important Clauses

Additional clauses in pollination agreements other than colony strength requirements can outline conditions that may be beneficial during almond pollination for reducing risks or costs to growers, beekeepers and pollination brokers. The Almond Board of California (2018) highlights that in addition to the number and strength of colonies provided, the following should be included in the almond pollination agreement: dates for placement and removal of colonies, temperature and time of day of the colony strength inspection, payment terms, and the beekeeper's access to colonies. The survey asked almond growers to select various other clauses that were included in their pollination agreements. Table 3 reports the percentage of respondents, with both written and oral agreements, who indicated that their agreement contained a specific clause. A "clause" is assumed to be included in an oral pollination agreement if the respondent and beekeeper had made arrangements for dealing with any of the issues

Table 3. Percentage of Respondents Whose Contracts Included Various Clauses (N = 95)

Clause	Percentage
Pesticide application	29.6
Colony theft	18.4
Colony collapse disorder (CCD)	7.1
Late colony placement	28.6
Bloom percentages for approximate colony placement and removal dates	23.5
Beekeeper access after colony placement	33.7
Inspection specifics (inspecting party, time of day, etc.)	25.5
Unpaid balances	14.3
Minimum number of colonies per drop[a]	23.5
None of the above	36.7

Note: [a]"Drop" refers to the number of colonies placed together within an orchard. Logistically, it is easier for beekeepers to place many colonies next to one another rather than spreading them out.

listed prior to almond pollination. The three most common clauses used in respondents' pollination agreements related to (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. Over one-third of respondents did not have any of the listed contract clauses in their pollination agreements.

Clauses regarding the placement of colonies in orchards can be important on both sides of the agreement. Almond growers want colonies to be in the orchards shortly before or at the beginning of bloom to guarantee adequate pollination. Consequently, agreements may include penalties to deter late placement. Additionally, beekeepers want easy access to colonies in the orchards for regular maintenance and colony health checks.

Pesticide exposure poses a risk for any colony located on or near agricultural land, so beekeepers and almond growers may want to lay out specifics to mitigate some of this risk. For example, the contract may include statements regarding the time of day pesticides may be applied, which pesticides should be avoided, or what happens if colonies are harmed by pesticides applied by the grower. The Almond Board of California (2018) has outlined best management practices for when honey bees are in almonds in an effort to reduce the risk of pesticide exposure.

Colony thefts seem to be a growing issue for beekeepers, especially when colonies are in close proximity in remote almond orchards during bloom (Souza, 2019; Ebersole, 2019). Nearly 20% of respondents in 2015 had clauses related to colony theft in their almond pollination agreements. For example, a beekeeper may be willing to provide a discount on the pollination fee to locate colonies in an almond orchard that contains a locked gate. Due to increasing pollination fees, clauses regarding bee thefts may become common in almond agreements going forward.

The Future of Almond Pollination Contracts

Because the demand for almond pollination services continues to grow while already utilizing most U.S. colonies, many are concerned about where additional colonies will come from. Goodrich, Williams, and Goodhue (2019) find that beekeepers in the eastern United States have been more responsive to almond pollination fee increases than those in regions near California. Based on the number of colonies that are still available to participate in almond pollination, it is likely that Florida, Texas, Georgia, and Louisiana will provide additional colonies as almond acreage increases going forward (Goodrich, Williams, and Goodhue, 2019).

As the demand for almond pollination services creeps closer to the point of exceeding the total number of available U.S. colonies, it is unclear what market adjustments will take place to accommodate the additional demand. On the supply side, the number of colonies could increase if beekeepers are properly incentivized. So far, beekeeping operations have not expanded substantially, even in areas close to California almond orchards (Goodrich, Williams, and Goodhue, 2019). This is likely due to the lack of year-round forage on which to expand operations (Durant, 2019).

On the demand side, almond growers may start decreasing the number of colonies per acre of almonds in response to increasing pollination expenses, which are currently around 20% of annual operating costs (Duncan et al., 2016). One way to decrease the number of colonies per acre is for growers to plant self-fertile almond varieties that do not require cross pollination. Many almond growers with traditional varieties have stuck to using the rule of thumb of two colonies per acre, even though colony strength can be used as a substitute for the number of colonies per acre. Many in the industry hold the opinion that the rule of thumb has remained in use because federal crop insurance required two colonies per acre. Beginning in 2013, USDA Risk Management Agency changed the appraisal policy to incorporate colony strength into pollination requirements (U.S. Department of Agriculture, 2012). This change gives almond growers some flexibility. If per colony fees continue to rise, almond growers may begin to seriously consider renting fewer colonies per acre at a higher strength to cut down on pollination costs. If this takes place, it would likely place more emphasis on colony strength requirements in almond pollination agreements.

As the demand for colonies for almond pollination services continues to grow, risk likely increases on both sides of almond pollination agreements. Increased emphasis on colony strength requirements means that colony health issues become an even bigger risk for beekeepers in their almond pollination transactions. When a beekeeper's winter mortality rate is high, revenue losses compound through a decreased quantity (fewer colonies to rent out for almond pollination) in addition to a decreased price (remaining colonies do not meet colony strength requirements). Goodrich (2019) finds that a 10% increase in winter mortality rates can decrease a commercial beekeeper's revenue from almond pollination by 15%. Higher fees mean the beekeeper's current value of breaking a long-term informal agreement may outweigh its value going forward, thus it may become more advantageous for growers to engage in formal contracts. It is well established in economics that contracts are often used to transfer risk (Hudson and Lusk, 2004; Gillespie and Eidman, 1998; Kliebenstein and Lawrence, 1995; Knoeber and Thurman, 1995; Goodhue, 2000); raising the stakes on both sides of almond pollination agreements therefore likely means a trend toward more formal contracts and away from relational contract use. Additionally, the finding that growers with more experience tend to use more formal agreements suggests that as the industry progresses and growers gain more experience, formal contracts may gain in popularity among growers.

Conclusions

This article discussed contracting practices in the largest market for pollination services in the United States: California almonds. Contracting decisions in the almond pollination market will grow more valuable for beekeepers and growers as the demand approaches the total number of available U.S. colonies. Similarly, global demand for managed honey bee pollination has been increasing faster than the population of colonies (Aizen and Harder, 2009), so these conclusions reach further than the United States. For example, Australia's almond pollination industry is also growing and has struggled to get participation from beekeepers for pollination services (Le Feuvre, 2017). In the years to come, continued research on pollination services agreements will be helpful for beekeepers, growers, and others involved with developing pollination services markets all over the world.

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Are the Almond and Beekeeping Industries Gaining Independence?

Antoine Champetier, Hyunok Lee, and Daniel A. Sumner

JEL Classifications: Q13, Q12, Q57
Keywords: Almonds, Beekeeping, Pollination, Self-fertile varieties

Introduction

The almond and beekeeping industries are bound together by the strict dependence of almond trees on insect pollination for the production of a nut harvest. Through this dependence, the extraordinary growth of almond production in California has reshaped commercial beekeeping in the United States from a declining honey-producing industry into a growing pollination service provider. Opportunities for large pollination revenues have encouraged beekeepers to shift to rearing many colonies to satisfy pollination demands in late winter rather than preparing hives for honey production in spring and summer. Thus, prior to the almond bloom season, many beehives are readied for pollination activity, contracted for delivery, and moved into the orchards.

For the best part of the last four decades of almond expansion, growth in global demand for U.S. almonds has provided growers with sufficiently high revenues to support growing demand for pollination services. The draw of honey bees to almonds, at first only present among California beekeepers, spread to beekeepers across the nation (Rucker, Thuman, and Burgett, 2012). For the past dozen years, the beekeeping industry has been able to supply expanding numbers of hives for almond pollination with little increase in real rental rates (per unit of active bee services). There are good reasons to think that this elastic response could continue in coming years (Champetier and Sumner, 2019).

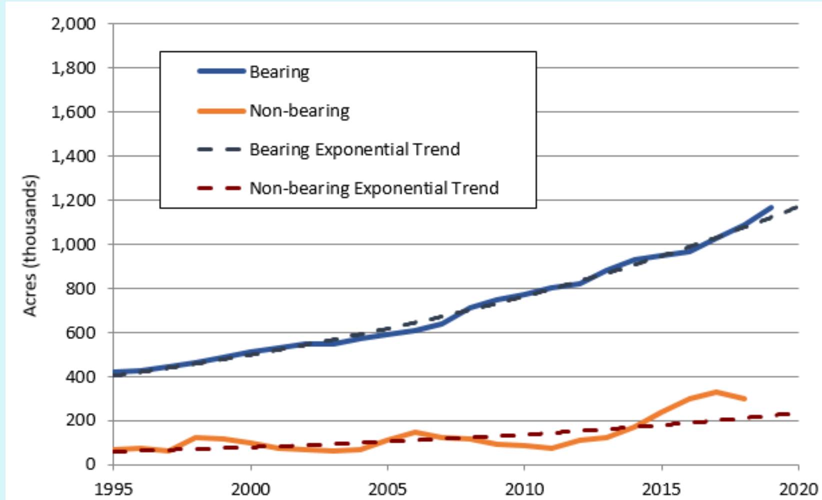
Yet the ability of the beekeeping industry to keep pace with rapid expansion of almond acreage has not always been self-evident. Concerns over pollination services becoming excessively expensive reached a peak in 2006 after almond pollination costs suddenly grew from about $150 per acre to $350 per acre, or $75 to $175 per hive at two hives per acre, in 2018 dollars (Ferrier et al., 2018). Concern about the supply of colonies for pollination services not keeping pace with the growth in acreage of pollinator-dependent crops became widespread around that time (Aizen and Harder, 2009). Economists, in contrast, argued that market forces would convey almonds growers' pollination needs to the beekeeping industry (Sumner and Boriss, 2006). Since then, a relatively calm decade of pollination market activity and only gradual change in fees have supported the notion of progressive adjustments of supply and demand for pollination services (Lee et al., 2017). Rucker, Thurman, and Burgett (2019) explain in detail how pollination markets have adapted to changes in bee health.

Despite only moderate recent fee increases, growers and researchers have pursued efforts to reduce almond pollination costs. Such efforts include both improved pollination practices and technological innovation. The rest of this article explores the adoption of self-fertile almond varieties, which require much smaller pollinator densities than varieties conventionally grown in California. We describe varietal planting trends and discuss economic issues surrounding the adoption of self-fertile varieties. We highlight an important economic trade-off between savings in pollination and other cultivation costs and quality-related price premiums for almond nuts.

Overview of Almond Acreage Growth

The growth of the California almond industry has been impressive. Figure 1 illustrates this growth by showing the exponential increase in bearing almond acreage from 1995 to 2018 (almond trees start bearing a commercial harvest after 3–4 years). According to the latest *California Almond Acreage Report* (California Department of Food and Agriculture, 2019), 1,090,000 acres were bearing in 2018. While the acreage of nonbearing orchards has ebbed and flowed following almond price fluctuations, the upward trend of nonbearing acres reflects a sustained pace of long-term expansion. While planting of new orchards seems to have slowed recently, nonbearing acreage has for several years been above what is needed for replacement of old orchards. As a result of this planting activity, almond acreage is likely to reach 1.4 million acres within a few years.

Figure 1. Bearing and Non-Bearing Acreages for Almonds with Simple Trend Projections



Source: California Department of Food and Agriculture (2019). Trends are authors' calculations.

Understanding the impact of almond acreage expansion on the demand for pollination services is straightforward if current patterns continue. Honey bees are placed at a stocking density of about two hives per acre of almond trees. The number of honey bee colonies in the United States, as measured by the Census of Agriculture in December 2017, was 2.9 million hives. Therefore, pollinating 1.1 million bearing acres required about 76% of U.S. honey bees. Pollinating 1.4 million acres would require 97% of the hives measured in the 2017 Census at the current stocking density.

Demand for almond pollination outgrew supply from California and West Coast–based beekeepers years ago and now draws three out of four colonies from across the U.S. (Rucker, Thurman, and Burgett, 2012). The trend seems set to continue and may include additional hives located in regions that are not currently major honey bee suppliers (Champetier and Sumner, 2019). Goodrich, Williams, and Goodhue (2019) argue that Florida, Georgia, and Texas will likely contribute to further expansion of almond pollination service provision.

Pollination Costs Are as High as Irrigation and Harvest Costs

Before 2005, pollination costs were a relatively small share of total almond production costs. Following the sudden increase in pollination fees from 2004 to 2006, and with the number of colonies per acre of almonds unchanged, the cost share of pollination has risen significantly. This pattern is clearly visible in Table 1, which reports sample cost shares of pollination in California from 1998 through 2019. The share of pollination costs varied between 6% and 8% from 1997 to 2003. The cost rose to nearly 10% in 2008 and 20% by 2016. The other major operating cost components for almonds are irrigation costs—which differ by region and vary from year to year—and harvest costs, which are more stable.

Table 1. Sample of Cost Shares for Pollination, Harvest and Irrigation in Total Operating Costs in Micro-Sprinkler Irrigation in North and South San Joaquin Valley

Year	Pollination Cost Share (%)	Harvest Cost Share (%)	Irrigation Cost share (%)	San Joaquin Valley Location
1998	6.7	19.2	13.1	North
2002	7.7	22.7	22.7	North
2003	7.6	18.7	30.8	South
2008	10.1	15.9	27.7	South
2011	13.0	16.0	10.8	North
2012	15.6	23.8	10.3	North
2016	20.0	17.7	22.1	North
2019	15.8	20.1	15.8	North

Note: The dashed line delineates the periods before and after the almond pollination fee hike for 2004–2006. The grey shadings highlight the high irrigation cost shares for the Southern San Joaquin Valley relative to the North.
Source: University of California Co-Operative Extension and UC Agricultural Issues Center Sample Cost and Returns Studies, years and locations indicated, all micro-sprinkler irrigated and not organic. Shares are authors' calculations.

Potential Responses to High Pollination Fees per Colony

High pollination costs caused increased attention to tracking and managing pollination services. Because pollination activity may differ greatly across hives, growers have adopted new standards for hive strength in pollination contracts. Goodrich, Williams, and Goodhue (2019) describe in detail how frame counts have become common practice in almond pollination contracts, with six and eight bee-covered frames being the reference standards. Unfortunately, the lack of historical record for frame counts limits our ability to fully assess how almond growers have increased active bee densities per hive while hive densities remain constant.

Almond growers have also attempted to reduce reliance on honey bees by experimenting with other insect pollinators. Given the early bloom of almonds, wild pollinators cannot be relied upon for the large expanses of almond areas and the high pollinator densities required. However, other managed species have been explored. For instance, the blue orchard bee can be successfully managed for cherry and apple pollination (Bosch and Kemp, 2001) and was the focus of large research and development efforts for almond pollination. Integrated pollination management, which combines honey bees with other species like the blue orchard bee, has also received significant attention (Koh et al., 2017). So far, however, blue orchard bees have not been cost-effective for almonds. After a decade of searching for alternative pollinators, using honey bees remain the only widespread practice among commercial almond growers.

A third approach to reducing the number of honey bee colonies needed in almond production is through the development of almond varieties (or cultivars) that require much less insect pollination. Most almond trees planted in California in the last several decades have been self-sterile varieties and thus require pollen to be moved across trees of different varieties to obtain a commercial harvest. The strict dependence of Californian varieties of almond trees on insect pollination is idiosyncratic. Many varieties traditionally cultivated outside the United States, in Spain for instance, are much less pollinator-dependent.

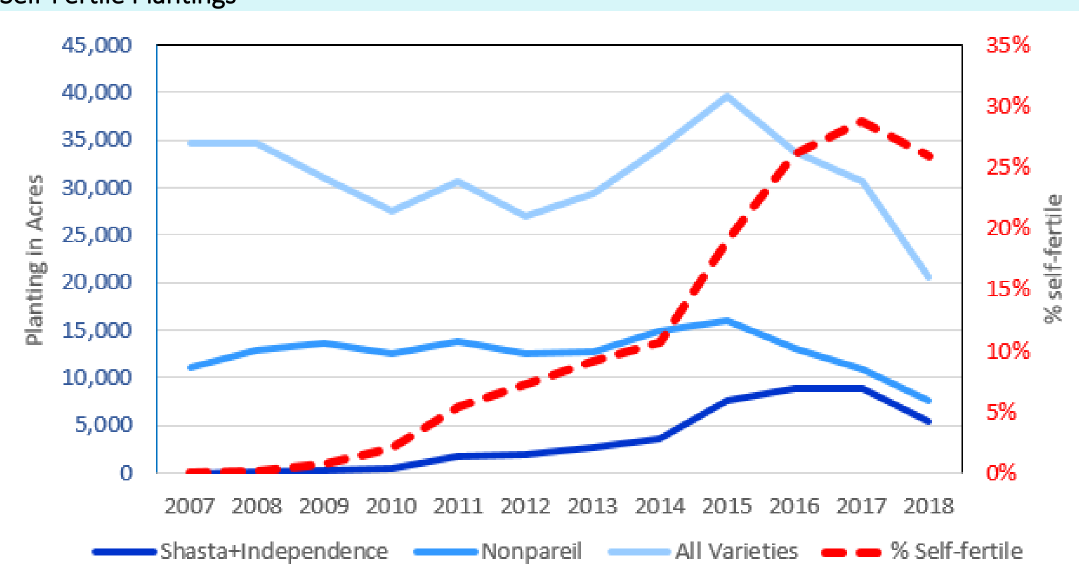
To reduce dependence on honey bees, plant breeding programs in California have developed two commercial varieties, 'Independence' and 'Shasta', that produce relatively high yields with hive-stocking rates of less than half the conventional two hives per acre used for standard varieties. The new varieties are self-fertile, meaning that they can be pollinated from the same variety to bear fruit. A low stocking density of around one honey bee hive for two acres is recommended for commercial yields with self-fertile varieties (Parsons, 2017). At the current rental rate of nearly $200 per hive, this may represent savings of up to $300 per acre (from 2 hives per acre to 0.5 hive per acre).

The potential cost savings of using self-fertile varieties are not limited to reduced stocking densities of honey bees. Planting these varieties eliminates the need to manage rows of "pollinator" or pollen donor varieties in between rows of the main variety. The mix of varieties in alternate rows complicates orchard cultivation practices such as spraying or fertilizing. Harvest is also complicated by planting patterns, especially when varieties must be kept segregated. Self-fertile varieties can be planted in uniform blocks with homogeneous management. Based on the almond cost studies published by the University of California Agricultural Issues Center, initial investments for orchard establishment are similar for self-sterile and self-fertile varieties, which means that operating costs and revenues are the main drivers of adoption (Duncan et al., 2016).

Increasing Acreage Planted to Self-Fertile Varieties

The potential for pollination and other cost savings is reflected in a growing portion of almond acreage in California planted with 'Independence' or 'Shasta' varieties. Adoption rates for these and other varieties can be tracked with data on plantings by variety provided in the *California Almond Acreage Reports* published by the California Department of Food and Agriculture. Figure 2 shows the acres in new plantings for which variety is known (covering about 70% of bearing acreage) from 2007 through 2018 along with plantings of self-sterile varieties as well as 'Nonpareil', the most popular self-sterile variety.

Figure 2. Plantings of Nonpareil, Independence and Shasta Varieties (acres) and Percentage of Self-Fertile Plantings



Source: California Department of Food and Agriculture (2019). Percentages of self-fertile varieties are calculated as the percentage of 'Independence' and 'Shasta' plantings in total state (all varieties) plantings.

The adoption of self-fertile varieties began to grow around 2010, with a rapid acceleration in 2015 and continued growth in 2016. In eight years, self-fertile varieties reached more than 25% of new plantings, second to 'Nonpareil'. The small dip in the share of self-fertile plantings from 2017 to 2018 might be indicative of a future slow-down in adoption. However, it is too soon to know whether adoption has peaked.

Despite the recent importance of self-fertile varieties in new plantings, the effect on total demand for honey bee pollination services for almonds remains small. As of 2018, of the almond acres for which a variety was known, about 5% were planted with self-fertile varieties (California Department of Food and Agriculture, 2019), and much of that was still nonbearing acreage planted within the last three years. Lee et al. (2018) simulated the impacts of the continuing adoption of self-fertile varieties in the long run. The scenario simulating a widespread adoption that reached 11% of bearing acreage, caused a 13% decline in pollination fees per hive. However, with a productive lifespan of almond trees of 25 years, the transition to self-fertile varieties would be a matter of decades rather than years.

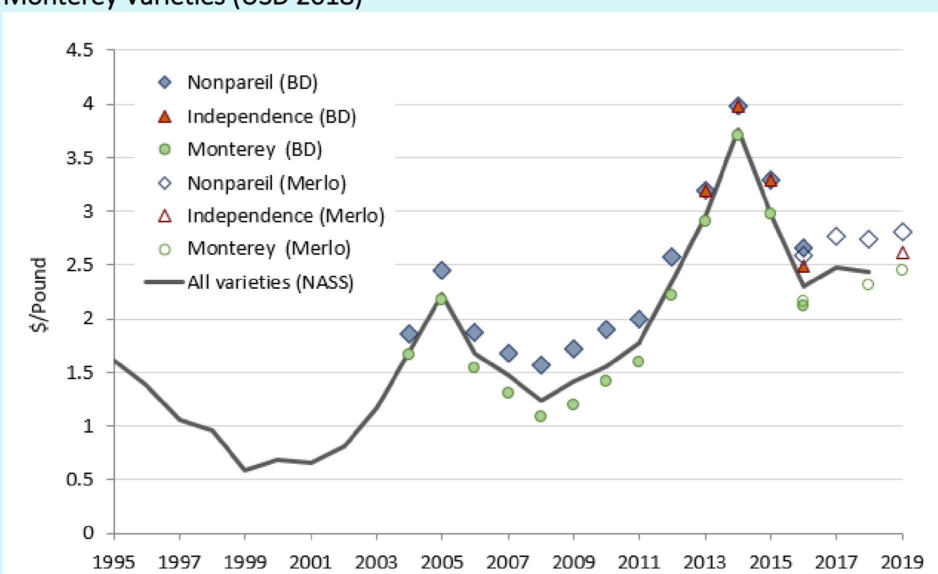
Clearly, adoption of self-fertile varieties can contribute to slowing the growth in demand for pollination services from the almond industry. The planting of self-fertile almond varieties is relatively new, however, and the costs and returns of adopting self-fertile varieties are only starting to become better understood. On the revenue side, variety-specific prices per pound of self-fertile almonds, a key driver for adoption rates, are just becoming available.

Relative Prices of Self-Fertile Varieties

Quality attributes of almonds are crucial determinants of market prices. Larger kernels generally garner higher prices, but characteristics related to taste and color also receive price premiums. Easily observable nut characteristics may indicate a likely price range, but pricing by variety is complex and prices for new varieties only become known after sufficient quantities have been in the market.

Figure 3 shows the average price of almonds (in 2018 dollars) as well as prices for three specific varieties—'Nonpareil', 'Independence', and 'Monterey'—from two industry sources for crop years 2007–2018. While the average market price varied from year to year, price differences between almond varieties were more stable. The price of 'Nonpareil' almonds was consistently above prices of other varieties. 'Monterey', considered a mid-range variety, sold for an average of 40 cents per pound below 'Nonpareil', with the difference ranging between 30 and 50 cents per pound. The average price across all varieties has remained between these two

Figure 3. Prices for All Almond Varieties and for Nonpareil, Independence, and Monterey Varieties (USD 2018)



Source: California Department of Food and Agriculture (2019), Blue Diamond (BD) Payment History in filled markers (2004–2016), Merlo Farming Group (Merlo), Almond Price Overview in hollow markers (2016–present). GDP deflator for United States from World Bank database.

variety-specific prices. Other varieties, such as 'Mission', have lower prices than 'Monterey'. Relative prices for these established varieties are well known to growers and buyers.

Market prices for 'Independence' almonds were available starting in 2013, when the crop was still very small. The red triangles in Figure 3, representing 'Independence', start in 2013 and coincide with 'Nonpareil' for the first three years. Due to the large size of their kernels, 'Independence' prices were initially listed as a premium nut, along with 'Nonpareil'. In 2016, Blue Diamond, the large almond marketing co-operative, bought 'Independence' almonds for prices about 6% less than 'Nonpareil' prices and about 18% more than 'Monterey' prices (Blue Diamond, 2018a). In 2019, an almond broker listed the price of 'Independence' almonds at about 6% below 'Nonpareil' and about 7% above 'Monterey' almonds. 'Independence' is now considered a distinct category from 'Nonpareil' as reflected in handler's requirement that growers segregate and deliver the two varieties separately (Blue Diamond Growers, 2018b).

Some observers note that 'Independence' has relatively high yields, so a loss in price per pound may be partially or entirely offset by a higher yield (Parsons, 2017). Using the 2018 average yield of 2,280 pounds per acre, a loss of $0.18 in price premium between 'Independence' and 'Nonpareil' (year 2018 in Figure 3) amounts to forgone revenue of $410 per acre (or 7% of revenue). This potential loss in revenue is above the $300 per acre of cost savings on pollination calculated above. However, the average prices per acre should account for the fact that some rows of lower-priced varieties must be planted as pollination donors in 'Nonpareil' orchards. Moreover, operation costs will also likely be slightly higher when the block is not of a uniform variety. Therefore, the economic gain from 'Independence' has been compelling for some growers. Overall, the largest impediment to planting the 'Independence' variety may simply be the relatively little evidence about how relative prices, yields, and costs may persist over the life of an orchard.

Concluding Remarks

Almond pollination demands services from most commercial honey bees in the United States. As almond acreage continues to expand, the demand for pollination services from honey bees will continue to grow unless the number of hives per acre falls. The relatively high cost of pollination, between 15% and 20% of almond operating costs, provides an incentive to reduce the use of honey bees. One of the few promising ways to accomplish this may be through further adoption of self-fertile almond varieties, such as 'Independence'. However, the economics of adoption of self-fertile almonds remains uncertain and, even if planting continues to be significant, its impact on pollination demand will be gradual and take decades to be fully realized.

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Honey, Forage and Almond-Pollinating Honey Bees

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Keywords: Almonds, Bee forage, Beekeeping, Honey, Pollination

Introduction

The pollination of almonds in February and March attracts more than two million honey bee hives to California each year (Champetier and Sumner, 2019). Almond pollination fees—the price for the rental of a hive for the duration of the bloom—depend on the marginal cost of supplying the hives and the demand for pollination services as an input to almond production. Observed pollination fees and hive rental numbers reflect the shapes and positions of the supply and demand of pollination services in late winter. This article focuses on the supply side of pollination services and discusses important drivers that affect the supply of pollination services. We argue that the availability of forage in the entire United States may become a limiting factor in the further expansion of pollination services to almonds. While other inputs—such as labor, equipment, and feed—can be provided to the beekeeping industry at nearly constant costs per unit, bee forage from crops and natural landscapes is a limited resource. We review the role and importance of forage in the economics of beekeeping and consider whether the quantity of honey bee pollination services to almonds can continue to expand and, if so, at what price.

The demand for almond pollination services can be represented by an inelastic demand curve (i.e., with a quantity demanded not responding much to price changes) that has been shifting right (out) by around 5% per year (Champetier and Sumner, 2019). As we discuss in our companion article in this issue of *Choices*, the demand for pollination services is inelastic because all but a few, still minor, almond varieties strictly depend on insect pollination. This demand is largely satisfied by hired honey bees. Given sustained growth in almond acreage, further expansion in the demand for bees for almond pollination is likely on the horizon.

Our discussion of the supply side of the pollination and honey markets must begin with a few observations that are well-known to specialists but sometimes misunderstood more broadly:

1. Beehives are mobile and the supply of hives for pollination (and honey) is thus determined by the economic behavior of beekeepers across the nation. This is especially true for pollination of California's almond crop, which requires such a large share of all commercial beehives; almond pollination revenue is a substantial share of annual revenue for beekeepers.
2. Bees are a livestock whose population follows a seasonal cycle. The number of hives available in the late winter is determined by the cost and returns of beekeeping operations throughout the year.
3. U.S. beekeeping is a relatively small livestock industry with total revenue (including pollination, honey, and other bee products) of less than $700 million in 2016 (Ferrier et al., 2018).
4. U.S. beekeeping comprises heterogeneous enterprises and practices. Some commercial operations move thousands of hives several times a year and generate millions of dollars in revenue, while additional thousands of backyard hives never move and specialize in local honey markets.
5. Honey bees provide nonmarket benefits in terms of ecosystem services and pleasure from beekeeping as a recreational activity. Services and products for recreational beekeepers generate significant revenue, but, in general, these benefits are hard to quantify given limited data and are not the subject of this article.

Improved data collection by the U.S. Department of Agriculture National Agricultural Statistics Service, the Bee Informed Partnership, and others, are contributing to a more detailed and accurate picture of the commercial beekeeping industry. In this article, we use some of these data as well as information we collected from beekeepers to characterize the costs and supply conditions of commercial beekeepers that supply pollination services to almonds.

Overview of Economics of Supply of Hives for Almond Pollination

Recent data show that pollination fees for almonds have changed little in real terms for more than a decade (Ferrier et al., 2018). Improvements in hive quality and the expansion of pollination contract features that monitor hive quality reinforce the observation that there has been little if any increase in cost of pollination services since 2006 or 2007 (Lee, Sumner, and Champetier, 2019). This relative stability of the cost of pollination in the face of rapidly growing almond acreage is consistent with a very elastic long-run pollination supply curve (Champetier and Sumner, 2019; Ferrier et al., 2018). Whether the beekeeping industry will be able to supply increasing numbers of hives for almond pollination without large increases in pollination fees in the coming decade (an elastic supply response) is critical for both the almond and beekeeping industries as well as consumers of almonds and honey and those who like the idea of more honey bees in general.

Recent data gathered from a representative group of California beekeepers who participate in almond pollination documents costs by category for beekeeping operations (Champetier and Sumner, 2019). Most major inputs for beekeeping are not specialized and other inputs, such as queens, hive boxes, and frames, can be readily expanded as well (see Figure 1). These conditions for beekeeping inputs suggest that pollination services may expand with relatively modest increase in marginal costs in these categories. However, two additional and important factors to supply expansion must be considered.

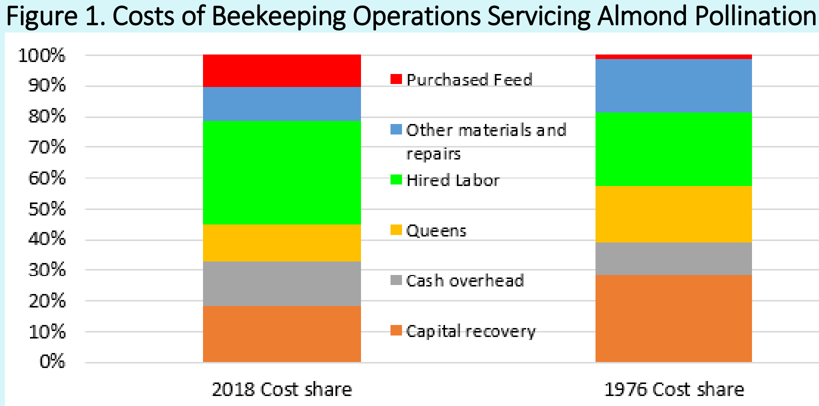
First, the availability of bee forage provided by crops and other vegetated landscapes may limit expansion in the number of hives available for late winter pollination (Champetier, Sumner, and Wilen, 2015). Forage inventory based on the ecological notion of carrying capacity may be helpful in quantifying these limits. Hellerstein et al. (2017) provide a first estimate of such forage suitability for the entire continental United States and find indications of possible declines in forage availability from 2002 to 2012. Such accounting must be updated and refined. Climate change also has the potential to increase or decrease availability and costs of honey bee forage.

Second, potential increases in forgone income from honey production could increase the opportunity costs of supplying hives to almond pollination, if forage is limited and a trade-off exists between these two revenue sources (Rucker, Thurman, and Burgett, 2012).

Costs of Commercial Beekeepers and the Importance of Forage

Figure 1 compares recently collected beekeeper cost information (2018) to costs of a comparable operation four decades earlier (1976). In both years, the costs apply to a moderate-sized (1,000 hives) California beekeeping operation that received revenue from both pollination services and sales of honey into the wholesale market (Champetier and Sumner, 2019). California had about 0.5 million hives in 1976. In 2018, USDA data report that California had about 0.34 million "honey-producing" hives, but other USDA data report that, over the course of the year, the total number of hives in California, including those

Figure 1. Costs of Beekeeping Operations Servicing Almond Pollination



Source: From data in Champetier and Sumner (2019), based on University of California Cost and Returns Studies.

usually based elsewhere, ranged from about 1.5 million hives in the late winter to about 0.6 million hives in early summer.

Figure 1 shows that fixed costs, defined as annualized capital costs plus cash overhead, were about one-third of costs in 2018 but close to 40% in 1976. Annualized capital costs alone were about 30% of costs in 1976, in part due to high interest rates that year relative to 2018. Costs for queen replacement were also a higher share of total costs in 1976 (about 18% compared to 12% in 2018). Hired labor costs, which were not quite one-quarter of costs in 1976, grew to more than one-third of costs by 2018. The costs in equipment repairs and materials (including pest control costs) were about 18% in 1976 and 11% in 2018. Overall, the most informative difference is that the cost of purchased feed for bees has risen from almost nothing (1%) in 1976 to 10% of costs in 2018. Note that management is not listed as a separate cost category, because net returns to the operation are considered the compensation of the manager for the 1,000-colony firm.

Two reasons account for high use of purchased feed recently. First, bees need to be aroused earlier from hibernation when little natural forage is available to get them ready for almonds early in the winter. Second, after almond pollination is completed, there is intense competition for forage locations among the massive number of hives in California. Almond blossoms provide excellent bee nutrition but only last three to six weeks. Before and after the almond bloom, beekeepers have two options: Find a source of forage from flowering plants from which bees can make their own nutrition (basically pollen and a healthy nectar that they consume within the hive) or feed a cheap and less nutritious substitute mostly made from sugar and plant proteins. In some circumstances, the need to feed bees can be reduced by holding the hives in cold storage before the almond season, during which time they will shut down most activity and essentially hibernate.

Natural forage is an important input for most honey bee operations but does not appear as a distinct category in the list of input costs in Figure 1 because, even with forage becoming more scarce, relatively few beekeepers pay an explicit rental fee to put their bees on pastures or in a crop field. The costs show up in budgets as added labor, capital, and materials used for moving bees.

Forage availability in most places is highly seasonal and depends on the flowering timing of plants. For example, natural habitats in California are dry in the summer and few flowers are in bloom. In places such as North Dakota, adequate spring and summer rainfall make pastures and extensive crops such as rapeseed or clover excellent summer forage. In contrast, winter in California may see early blooms, whereas North Dakota is months away from supplying any forage for honey bees.

Supply of pollination services cannot be expanded much in the very short run. In a period of only a few weeks, there is little a beekeeper can do to expand the number of hives and pollination services they provide. For example, consider a beekeeper that has contracted to deliver 1,200 hives for almond pollination on February 1. If that beekeeper found on January 1 that its hives had suffered unusually high winter losses and therefore the beekeeper only had 1,000 suitable hives, it could not create new active hives by applying more labor or feed inputs. The beekeeper would need to get hives from another operation or fail to deliver on its contractual obligations and suffer the consequences. If many beekeepers had the same problem in the same year, the search for new hives to meet contracted numbers would become more expansive and more expensive. During more favorable periods of the year, such as late spring and early summer, one colony can be split into two, providing beekeepers with a method to replace lost colonies or expand their operation. However, even split hives are not immediately productive for pollination or commercial honey and require a month or two before becoming fully productive units (Oliver, 2018).

Over a horizon of a year or more, most beekeeping inputs that are also used outside the bee keeping industry—such as general materials, general equipment, and labor—can be readily expanded. Similar to other livestock industries, the supply of some more specialized inputs, such as new queens and building new hive boxes and frames, can also be expanded, although it may require more time and may only be possible during certain periods of the year. The specialized services of beekeeping managers and technical specialists may also be attracted and trained within a few years.

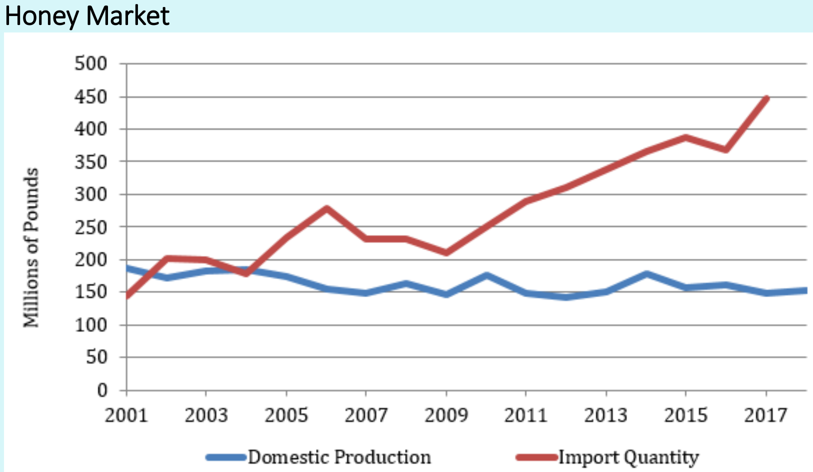
In contrast, natural forage can be a limiting factor for the beekeeping industry. As noted, several of the cost items in Figure 1 reflect the costs of accessing forage and the consequences of using the less healthy feeding alternative. These include costs of trucks, fuel, and hired labor for moving bees from place to place as forage becomes exhausted in each location. Moreover, one of the consequences of too much feeding of sugar and protein substitutes rather than natural forage is hives that are less healthy and therefore require costly replacement of dead or dying colonies.

Long-distance migration is an important strategy used by beekeepers to overcome forage scarcity. The most visible outcome of this strategy is the increasing number of hives moved to the large forage sources in the Dakotas in spring and summer (Goodrich, Williams, and Goodhue, 2019). As colony density in the best forage locations increases, however, beekeepers report that they seek other locations such as forests and other vegetated landscapes that provide some forage. Beekeepers adjust hive density to the perceived size and quality of forage resources, accounting for weather conditions. Potential hazards to bees, in the form of predators, parasites, and the possibility of pesticide exposure, can reduce the suitability of otherwise healthy forage. Hellerstein, et al. (2017) provide the only available forage inventory for the continental United States and develop a forage suitability index that accounts for forage nutrition value and pesticide exposure. The study finds that after an increase from 1982 to 2002, the index declined slightly from 2002 to 2012 across the nation, with a more pronounced decline in the Dakotas. Aside from the need for an update, additional forage inventory efforts would help anticipate the potential impact of forage scarcity on the beekeeping industry. Champetier and Sumner (2019) further discuss how beekeepers have responded to scarcity of forage, but much more research is needed to assess where forage might be most available and how much marginal cost may rise as more hives access new forage locations. Better understanding of bee nutrition and health may allow innovations in increasing bee benefits from each acre of forage and in economizing on costs of improving honey bee hive health.

Increased Honey Demand, Growth of Imported Honey and Supply of Pollination Service

The relationship between honey market conditions and supply of pollination services is complex because of seasonality in forage and bee numbers and the trade-off between extracting and selling honey versus allowing the hive to consume honey that could otherwise be sold. For a given amount of forage, the more a beekeeper focuses on preparing healthy, well-nourished hives for almond-pollinating season, the less honey can be extracted for sale. In this section, we review data on honey production to assess the role that this trade-off may have played in shaping the response of the beekeeping industry to changes in demands for honey and pollination. Let us first characterize the demand for honey facing the U.S. beekeeping industry.

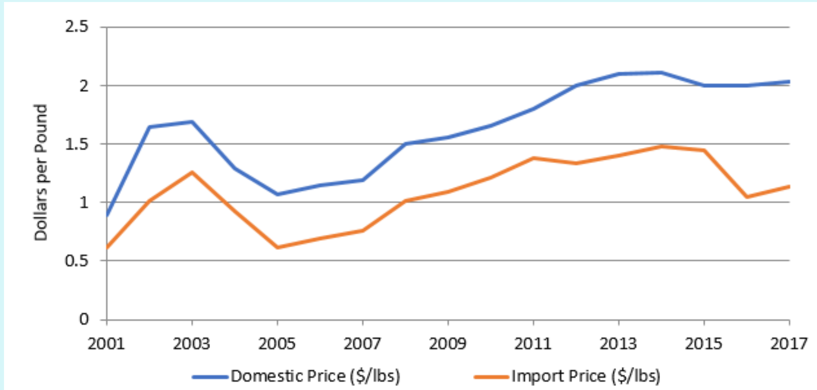
Figure 2. Domestic Production and Import Quantities for the U.S. Honey Market



Source: U.S. Department of Agriculture (1999–2018) and U.S. International Trade Commission.

U.S. honey consumption has increased rapidly over the last two decades, but this growth has been for imported honey only. Figure 2 shows U.S. production and imports of honey for 2001–2018. Domestic honey production (and consumption of domestic honey, since exports are almost 0) has fallen by 18% since 2001, whereas honey import quantity has almost tripled. The difference in trends between imported and domestic honey consumption is explained by a difference in price. Figure 3 shows that the price of domestic honey has remained much higher than imported honey and the price premium has grown recently as total honey consumption has continued to rise. This price differential suggests a clear difference in the characteristics of domestic and imported honey. However, the consonant movement in prices over time (with the exception of 2016 and 2017) indicates that the markets have been well integrated with substitution at the margin.

Figure 3. Domestic and Import Prices for the U.S. Honey Market (USD 2012)

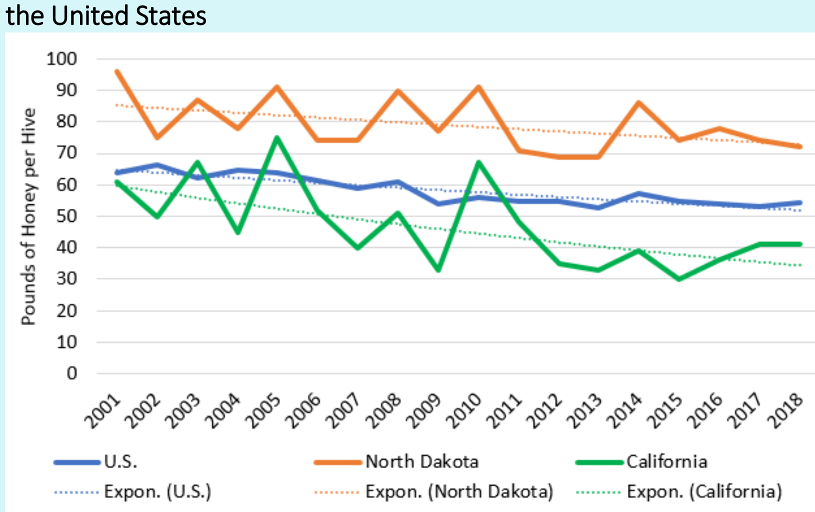


Source: U.S. Department of Agriculture (1999–2018), and U.S. International Trade Commission, and GDP deflator World Bank.

The real price of domestic honey has doubled since 2001. Domestic honey revenue has grown substantially based on higher prices for smaller quantities. The price and quantity changes for U.S.-produced honey are consistent with a relatively stable and inelastic demand for domestic honey and a shift up in the marginal cost of production of domestic honey. While total demand for honey is shifting out, most of the shift may be concentrated in the lower market segment, where imports are competitive.

Now let us turn to the evolution of honey production since 2001. Figure 4 shows the average honey production per hive each year in the United States as a whole and in North Dakota and California, the states with the most honey-producing hives. The U.S. honey yield per hive has clearly declined over time. North Dakota honey production per hive has fallen gradually, from over 80 pounds per hive in 2001 to about 70 pounds per hive in 2018. Honey per hive in California fell from more than 60 pounds to less than 40 pounds during the 2012–2016 drought before climbing to 41 pounds per hive in 2018.

Figure 4. Honey Production per Hive in California, North Dakota, and the United States

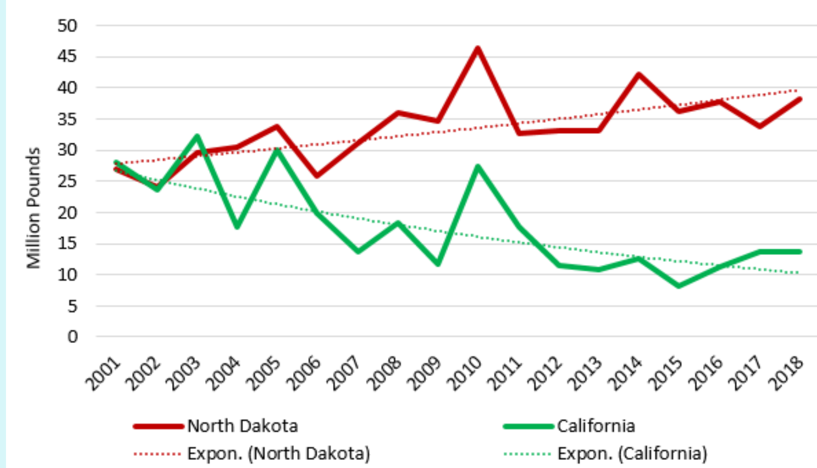


Source: U.S. Department of Agriculture (1999–2018).

The number of honey-producing hives in North Dakota has grown by enough that total honey production has risen, even though honey per hive has fallen (Figure 5). Indeed, more hives competing for the same or less forage is one cause of lower honey production per hive. The expansion of hives that migrate to

North Dakota after pollinating almonds is consistent with the observed declines in honey per hive there, even though the available forage is used to produce more honey in total. The trend has been different in California, where the number of hives producing honey has declined along with honey per hive, so total honey production has fallen faster (about 5.6% per year) than has honey per hive (about 3.2% per year). In both states, the pattern of honey production per hive is consistent with less available forage for honey production and illustrates how the forage trade-off between honey and pollination shapes the supply responses of the beekeeping industry. While the effect of this trade-off may have been moderate so far, several factors could increase its importance in the future.

Figure 5. Honey Production in California and North Dakota



Source: U.S. Department of Agriculture (1999–2018).
Note: Dotted lines are linear trends.

One scenario to consider for its implications for supply of almond pollination services is a substantial shift out in demand for domestic honey, say because of positive health information or negative information about quality or safety of imported honey. A higher price for domestic honey would increase the opportunity cost of feed needed within the hive to maintain large populations of healthy bees for almond pollination in late winter. The honey price increase, or equivalent demand shift, would need to be large, as almond pollination is a large source of revenue, equivalent to selling 90 pounds of honey per hive (assuming, for example, an almond pollination fee of $180 per hive and a price of honey of around $2 per pound). It requires a lot of marketable honey, more than average production per hive in all major honey states, to offset a loss of almond pollination revenue.

While this first-order effect is straightforward, there are offsetting factors. Almonds supply additional forage to hives that can then turn to production of marketable honey during the rest of the year. Without almonds, many more hives would be left dormant later into spring and thus start the productive honey season later and with smaller bee populations. If sufficient forage is available in the post-almond seasons, the nutrition provided during almond pollination likely contributes to lower the marginal costs of honey production (Lee, Sumner and Champetier, 2019).

Final Remarks

Forage availability is the significant potential limiting factor that could cause almond pollination fees to rise substantially as demand expands. In the past decade, fees have risen only slightly as more locations are drawn into honey bee forage supply. But it remains unclear how much more forage is available and what beekeepers may do to find it.

Honey demand is another unknown that affects pollination supply. At this stage, the data do not support the hypothesis that honey demand is a major factor in almond pollination supply. However, the research question remains: Would a large increase in the demand for domestic honey shift enough hives away from almond pollination in situations where access to natural forage for honey production is limited, such that the cost of pollination would rise?

Other factors could increase the prominence of the honey–pollination trade-off stemming from forage limitations. Changes in cropping and pesticide patterns, climate change, and pest pressures may contribute to shrinking available forage (Hellerstein et al. 2017). The net effect of such changes will depend on seasonality, while pest and disease pressures on bee health have the potential to increase the benefits of natural forage relative to sugar and other feed.

Beekeepers may find opportunities to improve forage availability. As foraging needs and patterns become better understood, we may see the adoption of more developed bee forage property rights and markets with consequent efficiencies. The rapid increase in almond pollination demand has also created incentives for innovation in feed and pest management offering the prospect of improvements in bee health at lower costs. As in other parts of agriculture, innovation may be the driving force in the evolution of beekeeping economics.

Additional Information

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For More Information

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The Evolution of Federal Programs for Beekeepers and Pollinator Data

Peyton Ferrier

JEL Classifications: Q13, Q12, Q57

Keywords: Apicultural insurance, Beekeeping, Colony loss, Honey, Pollination

Introduction

Will there be enough pollinators to sustain the needs of agriculture into the near future? This straightforward question exposes critical gaps in the data on how farms obtain pollination services, how much they pay for them, and what factors affect pollination service supply. Prior to the emergence of Colony Collapse Disorder (CCD) in 2006, no systematic survey data tracked honey bee colony loss rates. Prior to 2015, no national-level data tracked either the cost and use of pollination services to farms or the movement of managed honey bees by beekeepers. This knowledge gap mainly reflects the complicated and localized structure of markets of pollination markets, the historically small contribution of pollination service fees to beekeeper revenue, and the fact that farms sometimes receive pollination services—from either managed honey bees or native pollinators—for free.

In the absence of national data on pollination services fees or colony loss, researchers have extrapolated from either regional data on pollination fees or changes in the number of honey-producing bee colonies (as measured in the long-standing U.S. Department of Agriculture *Honey* report (2018b)) as a way to gauge whether agriculture potentially faced pollination shortfalls. As we describe later, both approaches have shortcomings. Regional data may give an unbalanced picture on how much the typical farm utilizes and pays for colony rentals because the two main previous surveys had been from regions (the Pacific Northwest and California) where pollination service demand was the highest. The *Honey* report's colony figure, on the other hand, captures honey market conditions (rather than pollination market conditions) by omitting colonies not producing honey. Since 2015, new data from the National Agricultural Statistics Service (NASS) in the *Honey Bee Colony Report* and *Cost of Pollination Report* have provided much more detail on how pollination service markets have responded to colony loss and how pollination service utilization and fees have varied by region and crop.

This article describes how the federal support programs and data reporting surrounding beekeeping have historically focused on the industry's production of honey as a sweetener. The rise of pollination fees for almonds in 2004, the designation of CCD in 2006, and the recording of elevated colony loss rates since 2007 spurred a change of focus for support programs to address, in part, the risk of colony loss to beekeepers and to collect better data. These data have shown that, despite winter loss rates remaining high, honey bee colony numbers have been relatively stable since the 1990s and that large pollination fee increases have been mostly constrained to almonds, a crop that provides 82% of the pollination service revenue collected by beekeepers. Despite the creation of these new data sources, the extent to which farms rely on wild versus managed pollinators outside of formal honey bee colony rental agreements needs greater research; the development and implementation of surveys of wild pollinators also remains a challenge (U.S. Government Accountability Office, 2016).

The Historical Focus on Honey Production rather than Pollination Markets

Throughout most of the twentieth century, data on beekeeping measured the production quantity and value of honey and, to a lesser degree, beeswax. Since the 1870s, the USDA's Census of Agriculture recorded the number of “swarms of bees” owned by farms, along with their honey yields, the number of pounds of honey produced per colony. In 1900, 4.1 million colonies were maintained on 12.8% of the 5.9 million U.S. farms. Pre-twentieth-century honey yields at the national level were far lower than modern ones with 23.8 pounds per colony (in 1870) being the maximum recorded before 1900. In contrast, the maximum between 1900 and 1949 was 46.3 pounds (in 1940) and 83.7 pounds between 1950 and 1999 (in 1998).

In 1939, NASS began surveying beekeepers annually on honey production and yields, reporting 4.5 million U.S. colonies in its yearly *Honey* report (U.S. Department of Agriculture, 2017). Then, World War II vastly increased demand for both honey as a substitute for rationed sugar and beeswax as a sealant used in various armaments, leading various federal departments to encourage beekeeping on the home front (Hoff, 1995). Colony numbers rose from 4.4 million in 1940 to 5.9 million in 1947, the year after real honey prices had reached their historic peak.

The sharp falloff in post-war honey prices led to the creation of the Honey Program in 1949, justified in part by the needs of farms for crop pollination (Hoff, 1995; Muth et al., 2003). Under this program, producers could either sell their honey directly to the government at a support price or borrow against their honey in a loan based on the honey’s support price value. Because borrowing producers could later forfeit their honey to the government if they could not find a higher market price, these loans obligated the government to acquire the honey when prices fell below the support price.

For the first 30 years of the program, support prices were set well below market prices. Even as demand fell sharply with the end of sugar rationing, government acquisitions were insignificant. Between 1947 and 1972, colony numbers fell in all but two years, eventually reaching 4.1 million. Improved honey prices in the 1970s helped stabilize and expand colony numbers through the remainder of the decade. Then, double-digit inflation in combination with adjustments to the formulas used to set support prices caused the support price to exceed the market price after 1979 (Muth et al., 2003). Beekeepers selling or forfeiting honey to the federal government led to program acquisition as high as 65% of domestically produced honey, even as imports surged into the United States. The Food Security Act of 1985 scheduled gradual reductions in support levels and restructured the program to make loan deficiency payments rather that purchases or forfeiture acquisitions, which eliminated government acquisitions. Program utilization fell sharply. In 1993, the Honey Program was denied appropriation from the federal budget, and it was finally eliminated in 1996 legislation. Between 1985 and 1996, U.S. colony numbers fell from 4.3 to 2.6 million, although a statistical adjustment in 1986 to exclude small beekeepers from the *Honey* report survey obscures the exact size of this decline (see Muth et al., 2003, on this issue). Since 1996, colony numbers in the *Honey* report have largely stabilized. Colony numbers dipped to 2.3 million by 2008 but recovered and increased to 2.8 million in 2017.

Federal support since the Honey Program’s demise has taken three main forms: trade protection from honey imports, compensation for colony losses, and weather-based insurance. On trade protection, China agreed to voluntarily restrict its honey exports to the United States from 1995 to 2000. After the agreement’s expiration, an antidumping tariff was imposed on imports from China (which is still in place) and Argentina (which was smaller and removed in the mid-2000s). Moreover, from 2001 to 2008, revenue collected under the anti-dumping tariff was to be redistributed back to U.S. producers under the Continued Dumping and Subsidy Offset Act (CDSOA) of 2000 (also known as the Byrd Amendment after its sponsor). Legal issues delayed actual distribution of funds well beyond 2008 so that total CDSOA honey producer payments averaged $7 million between 2007 and 2019 (U.S. Customs and Border Protection, 2018).

On colony loss compensation, in 2010, the Emergency Livestock Assistance Program (ELAP) began compensating beekeepers for colony losses exceeding a normal (annual) mortality rate of 15% of all colonies resulting from disaster events or CCD. Until 2017, ELAP payments were capped, which caused payments for individual claims to be pro-rated by the available amount across all claims. For 2017, payment caps were removed, but in 2018 the normal mortality rate for claims purposes was raised to 22% (U.S. Department of Agriculture, 2018a). In fiscal year 2018, ELAP payments to beekeepers totaled approximately $38 million (Stubbs, 2018). Concerning apicultural insurance, in 2017, the USDA expanded a pilot program that subsidized beekeeper premiums for insurance, where payments are made if a weather index indicates the presence of drought conditions, an event that lowers honey yield. In 2019, about 57% of all colonies were insured, with subsidies totaling $25 million (U.S. Department of Agriculture, 2019). For perspective, total beekeeper income in 2017 was $695 million (U.S, Department of Agriculture, 2017).

Since the inception of the Honey Program, supporters had emphasized the important role honey bees played in crop pollination and linked supporting the honey price to supporting crop pollination (Hoff and Willett, 1994; Muth et al., 2003; Muth and Thurman, 1995). Despite Cheung (1973) showing that, despite common misconceptions, beekeepers can and did charge farms for pollination services, scant data quantified how much pollination income beekeepers earned on average. Amid the Honey Program's curtailment, a federally financed survey in 1988 showed that pollination services income made up only 10.9% of beekeeper revenue, while honey sales and government payments (tied to honey production) comprised 52.7% and 27.7% (Hoff and Willett, 1994). Moreover, only 22% of beekeepers reported any pollination service income, and the pollination share of beekeeper revenue was much higher in the West (18.3%) and Northwest (15.4%) than in the Northeast (4.8%), Southeast (3.6%) and Midwest (1.8%).

As with pollination services fees, colony loss rates showed a similar knowledge gap (at least for latter researchers) because, at the time, no systematic data on colony loss rates were being collected. The same survey analyzed by Hoff and Willett (1994, p. 25) addresses this gap somewhat, reporting:

> *Beekeepers experiencing winter kill reported that about 20 percent of their colonies were affected in 1988. Of the affected colonies, 35 percent incurred 50 percent or more loss of bees.*

The fact that the survey's "winter kill" rate does not necessarily indicate that those colonies experienced a complete loss of the population illustrates how definitional concerns can create difficulties in interpreting isolated colony loss reports. Although colonies are found by beekeepers that are completely nonviable (i.e., "dead outs"), existing colonies in a state of imminent collapse without intervention or newly split colonies failing to establish themselves may also potentially be classified as losses within some frameworks.

The 2006 discovery of CCD spurred the Bee Informed Partnership (BIP) to collect continuous, systematic, and well-documented data on winter loss rates beginning the following year. While loss rates were nontrivial in earlier periods, they had not been regularly surveyed. Based on the knowledge of industry experts, a 15% rate of winter loss became accepted as the "historically typical" rate of colony loss rate as new BIP survey data showed winter loss rates exceeding 30% in three of the first four years of collection. BIP later added summer loss rates to its surveys in 2011 and, while these rates also seem high, a comparable historic baseline loss rate has not emerged in the literature.

Given the greater importance of pollination service revenue to West Coast beekeepers, it should be unsurprising that the first surveys of pollination service fees through colony rentals occurred in the Pacific Northwest (PNW) in 1989 and then in California in 1993 (Burgett, Rucker, and Thurman, 2009). The PNW survey showed that a beekeeper rented out an individual colony 2.4 times each year, on average, serviced 5.5 different crops, and operated in 6.8 counties. Certain crops—almonds, plums, and early cherries—paid considerably more for colony rentals throughout the survey's timespan, reflecting differences in both the seasonality of the crop's bloom and its honey-making potential. For instance, in every year between 2002 and 2008, early-blooming cherries paid at least 2.3 times more per colony than late-blooming cherries. Because beekeepers and their colonies are capable of moving thousands of miles if the colony rental price is high enough (as it has become with almonds), extrapolating whether colony loss could increase the scarcity of pollination service is difficult with only regional surveys. National measures of bee utilization were needed: What share of farms rented bees for pollination services and at what cost? Did farms ever adjust stocking rates in response to colony rental prices? Did farm practices that affected pollinator health ever influence the prices beekeepers charged for colony rentals?

Between 2004 and 2008, three events further exposed the need for better data. First, between 2004 and 2006, average pollination fees rose sharply for almonds. Second, CCD was identified in 2006 as a specific set of symptoms associated with the otherwise unexplained colony losses and quickly gained media attention. Third, BIP surveys stated winter colony loss rates of 31.8% and 36% in 2007 and 2008. Subsequent media reports worried that high colony loss rates might threaten the survival of honey bees generally and, with it, the production of pollinator-dependent crops (Walsh, 2013). Rising pollination service fees were cited as evidence of a looming pollination shortage, despite large fee increases being limited mostly to almonds. Little data detailed which farms used managed pollinators, either owning or renting honey bees or relying on native pollinators (which have also showed worrying signs of decline). Estimates of the potential effects of pollinator loss often included considerable extrapolation. Despite lacking clear data on whether existing honey bee colonies were being fully utilized for pollination services, some authors worried that the growth of honey bee stocks were not keeping up with agricultural demand for pollination (Aizen and Harder, 2009).

Crops rely vitally on pollinators, but this reliance is not uniform. Pollinator dependency is a statistic measuring a crop's reduction in yield in the absence of all insect-facilitated pollination. Many estimates of the value of pollinators to crop production use this metric to extrapolate the total loss of agricultural production associated with a total loss of pollinators. By construction, however, a crop's pollinator dependency says little about the effect of marginal losses in pollinators, the stocking rate crops need to achieve full pollination, the differences in their pollination requirements across crop varieties (i.e., recommended blueberry stocking densities range from 0.5 to 2.5), or the cost of renting pollination services (Muth and Thurman, 1995; Melhim, Daly, and Weersink, 2016; Pritts and Hancock, 1992). As an economic identity, colony rental costs paid by farmers are equal to pollination revenue earned by beekeepers. Higher pollination fees, particularly for almonds since 2004, seemed likely to at least partially offset the higher costs beekeepers bore from having to replace lost colonies or move them further distances.

New USDA Data on Pollination Markets

Following a coordinated 2014 initiative across federal agencies to address pollinator health problems, NASS began collecting three new surveys describing conditions in pollination service markets. Two honey bee colony surveys of beekeepers record their loss rates, causes of colony stress, and colony replacement rates as well as tracking the location of colonies. The large beekeeper survey occurs quarterly; the small beekeeper survey annually. The third, cost of pollination survey recorded the number of paid and unpaid managed honey bee colonies used for pollination, acreage requiring pollination, and expenditures on honey bees, alternative pollinators, and habitat improvement. From these data, one could also infer stocking densities (the number of colonies placed per acre) and price differences across locations. Two public reports released key summary data. Researchers, however, could potentially access and link the underlying survey responses for individual farms and beekeepers to other NASS data, including the Census of Agriculture, which itself added questions for beekeepers on aggregate pollination service revenue, and the *Honey* report, which also added questions on beekeeper production costs (mite treatments, feed cost), colony replacement stock (queens, package bees and "nucs," i.e., nucleus colonies), and pollination service revenue.

These surveys filled some critical knowledge gaps. First, the estimate of total farm expenditures on honey bee colony rentals from the surveys was considerably less than a previous estimate made by multiplying available estimates of crop pollination costs (typically conducted by co-operative extension services at the state level) by total acreage of that crop (Bond, Plattner, and Hunt, 2014; Ferrier et al., 2018). Since crop budgets are undertaken on an ad hoc basis and are specific to a crop's region and variety, the underlying budgets themselves may only record a crop's pollination costs where their costs and utilization is highest. When first measuring farm costs of pollination in 2015, NASS comprehensively surveyed 31 crops types but only obtained sufficient data to report on 20.

Second, almonds drive pollination service revenue, making up 82% of all beekeeper revenue from pollination services. Because pollination service revenue now comprises 41.1% of beekeeper revenue, a full third of all beekeeper revenue comes from almonds alone. Pollination services fees for almonds ($165 per colony in 2015) have been about three times higher than the average of fees charged to all other crops ($54.8 per colony). However, this large revenue share is not attributable solely to high fees. Almonds account for 61% of all colony rentals and 52% of all crop acres renting honey bee colonies (Ferrier et al., 2018). The almond bloom drives patterns of colony movement and forces crops with similar bloom times to pay similarly high fees. Relatedly, in 2015, California contained 60% of U.S. colonies during the first quarter but only 26% in the third quarter (U.S.

Department of Agriculture, 2016). In 2015, outside of almonds, colony rental costs represent only 1% or 2% of farm production costs (Ferrier et al., 2018).

Third, while colony loss rates remain elevated, the number of honey bee colonies varies seasonally and does not show clear signs of declining numbers on a year-to-year basis. This finding stems from the close correlation of colony losses with colony additions, typically made through splitting existing colonies (Ferrier et al., 2018). By splitting existing colonies, beekeepers seem to be able to rebuild colony stocks following high loss rates within the course of a year. Splitting, in the context of the bee's life cycle, causes colony numbers to vary seasonally. As one might expect, summer is the peak colony season; from 2015 to 2017, July colony counts averaged 15% higher than January colony counts.

While these new public reports have been informative unto themselves, the underlying survey data also shows great promise for further analysis because the underlying NASS data can be merged so long as confidentiality is maintained. For example, both the cost of pollination survey (of crop producers) and the honey bee colony survey (of beekeepers) can be merged with Census of Agriculture survey data (of all farm operations) in years (like 2017) when they overlap. These merged data may potentially inform questions such as whether mixed-use or organic farms are less likely to contract for pollination services or whether levels of colony loss are higher for different types of beekeepers. Unfortunately, NASS suspended the cost of pollination survey in 2018; further inquiries on pollination services markets may be forced to rely on regional studies and have limited ability to address how pollination market utilization changes in response to economic and environmental factors.

Conclusion

Honey bee colony loss rates remain high. Understanding and reducing colony loss will remain a priority for beekeepers, entomologists, and the biological sciences community generally. New NASS datasets provided the first national-level view of pollination service fees, colony movements, and beekeeper costs of replacing lost colonies. In showing stable pollination fees and restocking costs, these data paint a less dire picture of the effects of honey bee health problems on agricultural production than some alarmists have portrayed. Moreover, the data show how the almond industry's continually growing need for the pollination services has reshaped the entire revenue structure of beekeeping.

Additional Information

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