COLONY COLLAPSE

AND

THE ECONOMIC IMPLICATIONS OF BEE DISEASE

by

Randal R. Rucker
Montana State University

Walter N. Thurman
North Carolina State University

and

Michael Burgett
Oregon State University

February 25, 2011

I. Introduction

In October 2006 David Hackenberg, a Pennsylvania beekeeper, took almost 3,000 honey bee (*Apis mellifera*) colonies to Florida for the winter. In mid-November, he checked on the hives he had left in a Tampa location and discovered that many (roughly 360 out of 400) were essentially empty—there were no adult bees in the hives–and there were no dead bees in or near the hives. Upon further investigation, he found that roughly 2,000 of the hives he had taken to Florida had been wiped out. Hackenberg began making phone calls describing his losses, and within a week other beekeepers were calling him to report similar experiences.

In February 2007, reports of this new bee affliction began making the national news. The affliction was christened Colony Collapse Disorder (or CCD) and a survey of beekeepers in 15 states indicated a 31.8 percent loss rate during the winter of 2006/2007 (vanEngelsdorp, et al. 2007). Since then, thousands of news articles have reported on the status and consequences of CCD. Most of the media discussion has focused on the high winter mortality rates since the appearance of CCD. Possible causes of CCD are often discussed in the media reports, and estimates of the value of pollination services frequently are cited.[1] Although it usually is left to the reader to speculate on the relationship between CCD and the supply of pollination services, the link is occasionally made explicit. In 2007, then-Secretary of Agriculture Mike Johanns warned that "if left unchecked, CCD has the potential to cause a $15 billion direct loss of crop production and $75 billion in indirect losses."[2]

---

[1] One of the more commonly cited estimates of the value of pollination services in the United States is $15 billion. This estimate comes from the study by Morse and Calderone (2000), which represents an update of an earlier estimate of $9 billion from Robinson et al. (1989). A recent study pegged the world-wide value of pollination at $217 billion (ScienceDaily, 2008). For a critique of the logic used to obtain these estimates, see Muth and Thurman (1995).

[2] See Stipp (2007). The source of the multiplier that would inflate the $15 to $75 billion is unclear.

Based on information provided in the media, attentive readers who have tracked the annual reports since 2006 might infer that managed U.S. honey bee populations are nearly gone. They might also believe that the collective is incurring billions of dollars in damages. Particularly astute readers might, however, look at the prices of apples, pears, cherries and blueberries and wonder why—in the face of impending doom—they can still afford to put these items in their children's lunches and on their breakfast tables.

There is an important component missing from, as best we can tell, all published discussions: defensible, objective estimates of the costs of CCD. The objective of this paper is to fill the gap. Toward this end, below we provide brief primers on honey bee biology and on the managed pollinator industry in the United States. We then discuss the available evidence on winter bee mortality rates from 2006/07 to the present and the current state of knowledge on the causes of CCD.

We conclude with an empirical examination of the impacts of CCD. For this purpose, we examine three data series that might be expected to display substantial reactions to the advent of CCD. First, we analyze annual USDA estimates of colony numbers at the aggregate (United States) level, as well as at the state level, to determine whether the managed honey bee population has been affected by the onset of CCD. Next, we analyze the prices of an input to beekeeping–packaged bees and queens–which might be expected to rise as the industry adjusts to higher mortality rates. Finally, we investigate pollination fees paid by farmers using annual survey data from both the Pacific Northwest and from California for evidence that these have been affected by CCD. To conclude, we develop estimates of the impacts of CCD on beekeepers' income and on consumer prices. Our results suggest that there has been no discernible impacts of CCD on either colony numbers or on the prices of packaged bees and queens. We find it plausible that CCD has caused a portion of recent increases in almond pollination fees (but not in the pollination fees for other crops). We estimate the impacts of CCD-induced increase in pollination fees on U.S. consumers to be small. We estimate the impacts on beekeeper costs to be modest, and possibly less than their increased revenue due to CCD-induced increases in pollination fees.

II. Honey Bees and Bee Diseases

Honey bees collect nectar and pollen from flowering plants. In the process of moving from bloom to bloom to collect nectar, grains of pollen (which contain male gametes or sperm) become attached to the bees bodies and are transferred to the pistil (essentially the female reproductive organ) of other flowers. This pollination process enables the fertilization and reproduction of flowering plants.[3] Nectar, which is a sugar-rich liquid produced by flowering plants, attracts worker bees. The nectar that is carried back to the hive is transformed into honey for later consumption (or extraction by beekeepers) and the pollen is stored for future use as a source of protein for the hive. The honey bee is polylectic, which means it is a floral generalist, feeding on just about anything that blooms.

A typical full strength colony of honey bees consists of a single queen and 15,000 to 30,000 worker bees. The queen usually lives for about two years and lays all the eggs in the hive. All the worker bees are sterile females, with life spans of about six weeks. The colony also contains a few thousand males, or drones, whose sole function is to mate with fledgling

[3] Honey bees are but one of thousands of different animal species that pollinate about 90 percent of flowering plants. The remaining plants reproduce through abiotic pollination, most of which is accomplished by wind, with the remainder pollinated by water.

queens from other colonies.

Honey bees have long suffered from a variety of diseases. A recent study documents about 20 episodes of major colony losses since the late 1860s (Underwood and vanEngelsdorp, 2007). In the last twenty years, the spread of Africanized honey bees is perhaps, the challenge facing beekeepers that is best known to the general public. More important from an economic standpoint, however, are the series of bee diseases and parasites that have infected commercial colonies. The most recent major predecessors to CCD were two important species of honey bee mite parasites (*Varroa destructor* and *Acarapis woodi*—or tracheal mites), which first appeared in North America in the mid- to late-1980s. Varroa mites are tiny ectoparasites that attach themselves to bees and feed on their blood.[4] Tracheal mites are minute endoparasites that attack bees' breathing tubes. Other diseases that currently affect honey bees include American foulbrood, a bacterial infection that attacks the bee larva and pupae and ultimately causes the death of the infected immature bees; nosema, a virus that invades the intestinal tracts of adult bees; and chalkbrood, a fungus that infests the guts of honey bee larva, competes with the larva for food, and ultimately causes it to starve.[5] It is notable that, over time, methods have been developed to battle each of these bee diseases and commercial beekeepers have managed to survive. That said, such methods are costly and cannot feasibly be applied to feral bees.[6]

---

[4] Varroa mites are tiny from the perspective of humans, but are quite large from the perspective of their host bees. One source likened varroa mites on a bee to "crawling, bloodsucking frisbees©" on a human (Maryland Invasive Species Council 2007).

[5] See Morse and Flottum (1997) for additional information on bee diseases.

[6] In their analysis of pollination fees, Rucker et al. (2010) find that pollination fees increased following the advent of the Varroa mite and that their estimated increase in fees was roughly equal to the costs of treating Varroa. There is little reliable information on the status of feral bees.

III. Beekeeping, Supply Response, and Pollination Markets

Human relations with honey bees go back thousands of years. At least 5,000 years ago ancient Egyptians were practicing beekeeping *per se* (DeGrandi-Hoffman 2003, Fraser 1950). During most of the time humans "kept" honey bees, it was under what is termed fixed-comb beekeeping: colonies were kept in a variety of cavity types where the natural wax combs were fixed to the cavity top and side walls. Harvesting honey required the destruction of the colonies. This all changed in the mid-19th century with the development of the top-opening, moveable comb hive, invented by the American Rev. Lorenzo Langstroth. The Langstroth hive induced a revolution in beekeeping and was adopted around the world. Beekeeping, as practiced today, is based on the foundation of Langstroth's hive design, which incorporates frames that can be easily removed without enraging the bees or destroying the hive, can be expanded as healthy colony populations grow, and allows beekeepers to reuse wax combs.

No honey bees are native to the western hemisphere. The western, or European, honey bee (*Apis mellifera*) was introduced to North America in 1607 by English settlers (Pellett 1938, DeGrandi-Hoffman 2003). Today it is the primary bee kept by beekeepers in both Europe and North America. Most environments in North America are amenable to the natural and human-assisted spread of honey bees, and by the mid-18th century, honey bees were found throughout America, both under human managed conditions and in the feral state.

Today, supplemental pollination by European honey bees is an important input into the production of many crops. While grains and staple crops typically are not pollinated by honey bees, a wide variety of fruits, vegetables, and nuts are. In North America, crops that rely (either partially or completely) on the services of honey bees include almonds, pears, apples, cucumbers, blueberries, and vegetable seed crops. Pollination services in modern North American agriculture are supplied by mobile beekeepers, many of whom truck their bees hundreds of miles, traveling along migratory routes that "follow the bloom." A typical large-scale North American pollinator drives a tractor-trailer combination that carries 400 hives of bees. Transportation of the bees is facilitated by traveling at night with nets covering the hives–bees fly out of their hives only during the day.

Once the truck arrives at a field or orchard for pollination, fork lifts move the hives to strategic points to spread bees throughout the flowering area. When placed in a pollen and nectar-rich flowering field, bees typically stay relatively close to home. They will, however, fly considerable distances when pollen and nectar sources are more difficult to find.[7] In the case of tree fruit and nuts, an important role played by bees is cross-pollination—the transfer of pollen between trees of one variety and those of another variety, strategically planted in adjacent rows.[8] The hybrid vigor that results from inter-variety pollen transfer promotes fruit set and ultimately fruit quality and uniformity.

Bees typically are moved into an orchard or field for just the flowering period, which lasts about three weeks for almonds and most tree crops, but can vary with the weather. A typical mobile beekeeper will pollinate several crops during the spring, collecting pollination fees from the growers of each. In recent years, a majority of the commercial bees in the United

---

[7] Seeley (1995, pp. 46 - 50) discusses the results of studies of the foraging range of honey bee colonies. He states that " . . . the median distance was 1.6 km, the mean distance was 2.2 km, and the maximum distance was 10.9 km. Perhaps the most important property of this distribution is the location of the 95th percentile, which falls at 6.0 km. This indicates that a circle large enough to enclose 95 percent of the colony's forage sites would have a radius of 6 km, hence an area greater than 100 km^2 ."

[8] See, for example, Degrandi-Hoffman, Thorp, Loper, and Eisikowitch (1992) on bee foraging behavior in almond orchards and its implications for optimal planting of trees and varieties.

States have begun their pollination seasons in California almond orchards in February and March.[9] From there, beekeepers transport their bees back to their home bases to pollinate nearby blooming crops.

Migratory routes vary by region. One major migratory route is that followed by western U.S. beekeepers. Evidence suggests that virtually all commercial Washington and Oregon beekeepers transport colonies to California in the early spring to pollinate almonds (Burgett et al., 2010). After that, they load their hives on flatbeds and return to their home bases and pollinate local crops. Depending on the local demand for pollination services, some beekeepers then move their hives to honey production areas. For example, Pacific Northwest beekeepers whose home bases are west of the Cascade Mountains pollinate tree fruits (apples, pears, and cherries), then soft fruits (strawberries, raspberries, and blueberries), then seed crops (e.g., onions and carrots), and then cucumbers, pumpkins, squash, and some legume seeds (e.g., clovers) and occasionally alfalfa seed.

Beekeepers whose home bases are on the east side of the Cascades, which is much richer in honey sources than the west side, have a somewhat different annual schedule. After returning to their home bases from California, they typically pollinate tree fruits, then spend the rest of the season using their bee colonies to produce honey. Industry participants say that many Montana beekeepers currently take their colonies to California to pollinate almonds then return home to produce honey, with no pollination activities in between. On the east coast of the United States there are similar migratory routes that move up the Atlantic coast, from fruit and vegetable crops

[9] See Rucker et al. (2011) for a discussion of the importance of almond pollination in today's U.S. pollination markets.

in Florida in winter and early spring to blueberry bushes in Maine in May and June.

The impact of CCD that is highlighted by the news media is high winter mortality of managed honeybee colonies. Over the last four winters (2006/2007 through 2009/2010), surveys estimate the annual average losses for the beekeepers who responded to the surveys at 32 percent, 36 percent, 29 percent, and 34 percent.[10] Independent surveys of Pacific Northwest beekeepers suggest annual losses of 30 percent for the winter of 2007-2008, 21 percent for the winter of 2008/2009, and 24.6 percent for the winter of 2009/2010.

A fact not often mentioned in news reports, however, is that some fraction of bees dies every winter, whether CCD is present or not. Using information from a survey of PNW beekeepers, Burgett et al. (June 2009) estimate that normal annual winter mortality rates for those (commercial) beekeepers was about 14 percent prior to the appearance of CCD.[11] Thus, colony replacement at some level is a standard part of beekeeping. (Moreover, and as we demonstrate below, aggregate U.S. colony numbers have not changed much since the appearance of CCD, which suggests that beekeepers are adapting increased mortality by increased replacement efforts.)

There are three methods commonly employed by beekeepers for maintaining and

---

[10] See vanEngelsdorp et al. 2007, 2008, 2010a, and 2010b for discussions of the methodology used for each of the annual national surveys conducted by the Apiary Inspectors of America in cooperation with the USDA.

[11] Similarly, Pernal (2008) estimates that prior to CCD, normal winter mortality was 15 percent, and vanEnglesdorp et al. (2007) reported that during the winter of 2006/2007, beekeepers experiencing normal losses had an average mortality rate of 15.9%. In the mid- to late- 1980s, colony losses for North American beekeepers were severely elevated following the arrival of two important species of honey bee mite parasites (*Acarapis woodi* and *Varroa destructor*). Prior to that time good beekeepers were able to keep their winter losses below 10 percent. After the arrival of the mites, for the ten year period from 1989 to 1998 the average annual colony loss for commercial beekeepers was found to be 22.6 percent (Burgett, 1998).

rebuilding hive numbers. Understanding these methods is important to understanding how the beekeeping industry responds to bee disease. The three methods are discussed below, along with the limited information available on the relative frequency with which the methods are used.

The first method used to replace weak hives or hives lost over the winter involves a beekeeper splitting a healthy, full strength, hive into two parts. This process, known in the industry as "making increase," has been employed for many years. The process requires the beekeeper to move a portion of the brood and adult bees (typically less than 50 percent) from a healthy hive to a new hive. The new hives are known as nuclei colonies (or nucs, or splits). For a nuc to be viable, a fertilized queen is required. Newly mated queens for this purpose typically are purchased from specialized commercial queen breeders, who produce hundreds of thousands of queens annually for sale.[12] Sometimes the nucs are not given newly mated queens, but instead are allowed to produce their own queens from the eggs and/or young larvae that provisioned the unit. In this instance they are referred to as "egg" nucs. Most commercial beekeepers produce nucs from their own base of healthy colonies, although there are times when beekeepers will purchase nucs from other beekeepers.

The original hive from the split has a near-uniform age distribution, from egg to mature foraging worker bee. Thus, the original hive can continually replace its cadre of pollinators and the hive is strong enough to pollinate crops shortly after the split. The new hive, on the other hand, contains only adults and will not be sufficiently strong to pollinate crops for about six weeks, the time it takes newly produced brood to mature. In California, beekeepers typically

---

[12] The current average price of a fertilized queen bee is near $12. Queen prices are discussed in more detail below.

make increase for the season in March, after almond pollination is complete. In Oregon and Washington, where winters last longer than in California, beekeepers typically make increase in April. Astute commercial beekeepers will anticipate colony losses and regularly produce nucs in mid-summer for the purpose of maintaining total colony numbers for next year's pollination season.[13]

The second method used to build or replenish hive numbers is to buy packaged bees. There are a number of companies who sell packaged bees for this purpose, typically the same companies that sell queens. The current average price of a three pound package of bees, which includes roughly 12,000 working bees and a fertilized queen, is about $50.[14] If an empty hive is stocked with a package of bees it might be productive immediately. Soon, however, there will be a drop-off in production due to the time lag between the placement of the package of workers in the hive and the time that a new generation of worker bees is hatched and matured to the point of leaving the hive to collect nectar, pollen, and water. Even if the new queen begins laying fertilized eggs immediately upon her placement in the empty hive, it will take 21-25 days before worker bees hatch. If a hive in Oregon or Washington is stocked with packaged bees on, say April 10, the hive will probably not produce any surplus honey until the following year.

The third method, which is used to maintain (rather than increase) the number of hives, is to replace the queen. A fertilized queen typically lays eggs for about two seasons. As the old

---

[13] It is noteworthy that the three mortality surveys of PNW beekeepers reveal that commercial beekeepers have replaced more bees than they have lost. In the past three winters, the commercial beekeepers who responded to the survey reported that 20.7 percent more colonies were started than were lost in 2008 (Burgett et al. 2009), 26.5 percent more colonies were started in 2009 (Caron et al. 2010), and 6 percent more colonies were started than were lost in 2010 (Caron and Sagili 2010).

[14] Package prices are discussed in more detail in section V below

queen becomes less productive, beekeepers replace her with a new fertilized queen. Assuming the new queen is accepted and begins laying fertilized eggs immediately, the hive will remain strong, healthy, and productive.[15] Insofar as the productivity of the old queen had diminished prior to replacement, the productivity of the new hive will increase with the addition of the new queen.

To what extent are the three replacement processes used by beekeepers? This question was asked in the three recent mortality surveys of PNW beekeepers. Results are reported in table III.1. Over the three years of the survey, PNW beekeepers reported that 80 percent of replacement colonies were obtained through making increase (or creating splits/nucs). About 10 percent of the colonies replaced were nucs purchased from other beekeepers, and 2 percent were mature colonies obtained from other beekeepers. Survey respondents reported using packaged bees for about 8 percent of their replacements.[16] Because no systematic information is available regarding replacement methods used by beekeepers outside the PNW, it is not known whether splits are the predominant method used elsewhere in the United States.

At the aggregate level, the "making increase" approach could conceivably result in a doubling of the number of healthy hives in six weeks, although it is doubtful that in the short run there are sufficient queens available to accomplish such an increase. There would also likely be

[15] For experienced beekeepers, the expected acceptance rate of new queens is reported to be between 80 and 95 percent. Beekeepers often prefer to replace the old queen with a purchased new queen (rather than letting the colony replace the queen on its own) because it allows them to better control the genetic makeup of the colony.

[16] It is notable that in the winter of 2009/2010 beekeepers reported replacing substantially fewer colonies with their own splits than in the two previous winters. On the other hand, they also indicated that they replaced substantially more lost colonies with packaged bees in 2009/2010 than in the previous two winters. Whether these changes represent permanent shifts in beekeepers approaches to replacing lost colonies remains to be seen.

other constraints to such a large short-term increase. For example, in Langstroth hives, the bottom box of frames in the hive is referred to as a "deep." These are larger and deeper than the other boxes in the hive. The process of making increase involves the beekeeper moving a portion of the population of a colony to another physical colony. This requires an extra deep for every colony that he wants to expand to two colonies, as well as several additional non-deep frames. Whether there are sufficient additional frames and deeps to double the number of colonies instantaneously is doubtful. It is clear, however, that beekeepers are capable of replenishing substantial numbers of hives lost to winter kill. Moreover, insofar as a beekeeper does splits for the purpose of replacing colonies lost over the winter, he will have sufficient colonies and deeps available to replace winter losses up to 50 percent.

IV. Current Scientific Thinking on the Causes of CCD

In fall 2006, when beekeeper David Hackenberg started describing his experience with lost hives in Florida, one of the people he contacted was Pennsylvania's state apiary inspector, Dennis vanEngelsdorp.   After receiving more reports of problems, vanEnglesdorp started collecting samples of diseased bees from around the country. When he took some of his samples to entomologists at Penn State University, the molecular tests they performed indicated that the bees were infected with a broad range of known viruses and also with pathogens not seen before. The researchers concluded that the immune systems of the bees had collapsed.

In December 2006, Dr. Ian Lipkin, a molecular biologist who is head of an infectious disease laboratory at Columbia University was contacted by Diana Cox-Foster, an entomologist from Penn State asking him for help in solving the mystery of CCD. Lipkin subjected the bees to metagenomic analysis–a process that extracts all the genetic information from the bees, as well as from any other organisms living in them. Lipkin's analysis revealed that the bees were infected with a variety of pathogens, but one in particular (Israeli Acute Paralysis Virus or IAPV) seemed to be highly associated with CCD. The researchers cautioned, however, that their work did not show IAPV to be the cause of CCD.[17]

Since these initial efforts, a number of other investigations into the causes of CCD have been carried out. A variety of possible causes have been hypothesized. Early speculation was that cell phone signals may have caused honey bees to lose their bearings and become lost from their hives. Alternative explanations with more longevity include CCD being a new disease (possibly brought in by foreign bees), a response to drought-related malnutrition, stress (possibly induced by increased traveling for pollination), toxins, and a new class of insecticides, called neonicotinoids.[18]

The current consensus of the bee research community is that the CCD phenomenon is multi-factorial and, as such, cannot be explained by any single causal agent. What has been revealed is the presence in the United States of several previously unrecognized pathogens—for example, IAPV and a new species of the adult honey microsporidian parasite, *Nosema ceranae*. Previous to the discovery of *N. ceranae* in the late 1990s, only one species of *Nosema* attacking honey bees was known, *Nosema apis*. This new parasite, as the species name implies, utilizes the Asian honey bee *Apis cerana* as its natural host. *Nosema cerana* has now reached cosmopolitan proportions certainly throughout Europe and North America. The circumstances

[17] Subsequent research, in fact, failed to confirm a link between CCD and IAPV and found that although IAPV can result in honey bee mortality, the symptoms are not consistent with those of bees dying from CCD. See Bromenshenk et al. (2010), vanEngelsdorp et al. (2009), and Maori et al. (2007).

[18] See Mussen (July 2007) for an informative review of the then-current state of knowledge. See Bromenshenk et al. (2010) for a more recent overview of the research into the causes of CCD.

that brought about the spread of this parasite, which was previously believed to be confined to east and south Asia, are not known. That the parasite is capable of using *A. mellifera* as a host is not in doubt, and it is suspected that when infecting *A. mellifera*, it can be more pathogenic to its adapted host.

A recent collaboration among scientists at Montana State University and the University of Montana, and Army scientists in Maryland (Bromenshenk et al. 2010) concluded that CCD was characterized by a lethal combination of the virus *Iridoviridae* and microsporidian *N. ceranae*. The consensus among experts seems to be that although this is an important finding in the search for the causes of CCD, the exact nature of the relationship between the fungus and the virus is not understood. More research is needed to determine how additional outbreaks can be prevented, what role is played by such environmental factors as heat, cold and drought, and what causes the bees to fly away from their colonies to die.[19]

V. Economic Indicators of CCD and its Economic Impact

Ultimately, we are interested in how CCD is affecting consumers, farmers, and beekeepers. In this section we examine three indicators of such effects. We first turn to bee populations and examine the impacts of CCD on colony numbers at both the aggregate U.S. level and at the state level. Numbers of bee colonies are not, however, exogenous reflections of bee disease. Rather, they reflect disease along with whatever strategies beekeepers employ in response, moderated by whatever equilibrium changes in input and output prices that result from

[19] See Johnson (2010). A news release written by A. Sparrow and dated February 14, 2011 recounts an interview with the national director of the $4.1 million USDA-funded Managed Pollinator Coordinated Agriculture Project in which he discusses the results of research to date on his project. It seems noteworthy that the overlap between the set of possible causes that the director discusses and the factors identified by Bromenshenk et al. (2010) appears to be the null set.

disease and beekeepers' responses. Accordingly, our second and third economic indicators are input and output prices. For inputs, we examine prices for queen bees and packages of worker bees, inputs into producing hives of healthy bees. For outputs, we examine the price of pollination services, which should reflect any increase in the costs beekeepers face as a result of exposure to CCD.

V.A. The effects of CCD on honey bee colony numbers

The average rate of winter mortality over the past four years is 33 percent.[20] Although honey bees have always suffered winter mortality from a number of causes, recent mortality rates are higher than normal. A reasonable assessment derived from beekeeper surveys is that since the appearance of CCD, mortality rates have at least doubled.[21] Mortality represents an outflow from the population of bees, while the re-queening and splitting of hives and the creation of new colonies represents an inflow. The net result is the change in colony numbers, which we analyze at the national and state levels.

There are two sources of estimates of honey bee colony numbers, both generated by the USDA. Estimates from these two sources are displayed in figure 1. The first results from responses to questions asked in the U.S. Census of Agriculture, which is conducted every five years. The numbers in this series are interesting for a variety of reasons, but are not of much use for our purposes because of the five year lag between them. It is noteworthy, however, that there was a substantial increase in the estimated number of managed colonies in the 2007 census

[20] This number represents the simple average of the four years of mortality rates estimated by vanEnglesdorp et al. (2007, 2008, 2010a, and 2010b)

[21] Burgett et al. (2009), Pernal (2008) and vanEngelsdorp et al. (2007) all report pre-CCD or normal mortality rates as being about 15 percent.

relative to the 2002 census. This change is inconsistent with CCD causing reductions in colony numbers.

The second source, and the focus of our analysis, derives from annual surveys of beekeepers. Data from these surveys are generally available back to 1939 or 1940 at both the national and the state levels. The national data are plotted in figure 1 and labeled "U.S. Honey Report." The primary purpose of USDA's annual survey is to obtain estimates of the number of colonies used to produce honey. The questions from which the estimates are obtained ask beekeepers to list the states in which they had colonies in the year just completed, and then ask them from how many colonies they harvested honey in each of those states.[22]

The most obvious feature of the Honey Report estimates of colony numbers in figure 1 is their substantial decline since the mid- 20th century.[23] The fact that the USDA did not conduct its

---

[22] This approach can yield inaccurate estimates of the number of managed honey bee colonies for two reasons. First, insofar as beekeepers have bee colonies that are not used for honey production (e.g., they are used solely to provide pollination services), then the numbers reported by the USDA will underestimate the actual number of managed colonies. Second, to the extent that individual beekeepers use hives to produce honey in more than one state, those hives will be counted more than once, and the numbers reported by the USDA will overestimate the actual number of managed colonies.

We are aware of no research that assesses the magnitude of these two sources of bias. Champetier et al. (2010) suggest, however, that the USDA annual colony estimates are misleading, particularly in recent years. Their argument is that recent increases in almond pollination fees have dramatically increased both pollination revenues (per hive) and the fraction of (per hive) revenues from pollination relative to honey, thereby inducing beekeepers to focus more on pollination services. Insofar as there is an increase in the number of hives that are used for pollination only, the USDA numbers will not reflect the full extent of the additional hives (but the Census numbers should accurately account for these hives).

Assuming this argument is correct, what are its implications for our analysis below? A decrease in the number of hives not being used to produce honey will cause the recent USDA estimates to be biased downward. This phenomenon will make colony numbers appear to fall in recent years more than they have actually fallen, which could overstate losses due to recent events, including CCD.

[23] We are aware of no systematic economic analysis of the causes of this decline.

annual survey from 1982-1985, combined with a change in 1986 in the data collection procedures used by the USDA, suggests that comparisons between the pre- and post-1985 periods should be made with caution.[24] The figure includes two vertical lines, one at the year 1986 to indicate the change in data collection procedures of the USDA and one at 2007 to indicate the first year when CCD might have influenced colony numbers. Visual inspection of the figure does not reveal a notable decrease in U.S. colony numbers in the years since 2007. In fact, there were more colonies in 2009 than there were in 2006.

Figure 2 displays colony numbers from the Honey Report for the top ten colony number states, ranked by the average number of colonies over the five year period 2006-2010. Like the plot of aggregate U.S. colony numbers in figure 1, this figure contains two vertical lines—one at 1986 and one at 2007. As with total U.S. colony numbers, a visual examination of the plots in this figure reveals no dramatic reductions in colony numbers after 2006.

The results of a more formal statistical analysis of the possible impacts of CCD are reported in table 1. There, model 1 is a regression of U.S. Colony Numbers on a linear trend, calibrated so that 1939 is zero, a dummy variable that takes the value of 1 for all years after 1985, and a dummy variable that takes the value 1 after 2006, to represent CCD. The estimated coefficient on the latter variable indicates whether—given any pre-existing trend—there has been a decrease in colony numbers following the appearance of CCD. The model 1 estimates indicate that there has been a statistically significant downward trend in colony numbers of about 30,000 colonies per year, and that there was a significant downward shift in the trend line

[24] Estimates prior to 1982 included colony counts from all beekeepers, whereas estimates for years after 1985 included colony counts only from those beekeepers that maintained at least five colonies. Muth et al. (2003, pp. 497-498) estimate the one-time reduction in colony numbers from this change to be 863,000 colonies with a standard error of 195,000 colonies.

following 1985 of about 1 million colonies. Finally, the estimated coefficient on the CCD variable is a negative 35,000 colonies, but is not close to being statistically significant.

Models 2 and 3 correct for autocorrelation by fitting and AR1 error by maximum likelihood. A highly significant level of autocorrelation is found, and both the trend variable and the post-85 variable remain negative and significant.[25] The estimated coefficient on the CCD variable is now positive, but still not close to statistically significant.

Model 3 includes a multiplicative interactive term between Year and Post-85, while model 4 adds the squared value of Year to the earlier models. In model 5, which includes both of the additional variables, the estimated coefficients on both of these additional variables, as well as those on Year and Post-85 are statistically significant. In all three of these models the estimated coefficients on the CCD variable are positive and not statistically different from zero.

Apart from providing no strong evidence for CCD, how informative is the CCD dummy coefficient? A 95% confidence interval for the CCD effect, constructed from the model 5 estimates is (-197, 508). the lower end of the interval represents an 8% decline over 2009 predicted levels and the upper end represents a 19% increase. A strong leaning in the direction of the CCD explanation for colony numbers, then, allows at most (at the 95% level of confidence) for an 8% effect.

Overall, the consistent result from table 1 is that aggregate U.S. data provide no indication that CCD has resulted in reduced colony numbers. To investigate the possibility that the aggregate numbers mask CCD impacts in individual states, we examine the plots (see figure

[25] Note that the estimated coefficient on the post-85 variable in models 1 - 3 and 5 are quite close to the estimated impact of the change in the USDA's methodology for counting colonies estimated by Muth et al.

2) of colony numbers in the ten largest states (in terms of colony numbers), and then estimate the regression specifications in table 1 for all the individual states for which colony numbers are reported in recent years.[26] Visual examination of figure 2 suggests it is unlikely that the aggregate U.S. data are masking important state level CCD impacts, at least for the states with the most colonies.

Tables 2 and 3 report time series regressions estimated separately for each of the 50 states. Table VA.2 replicates model 1 and table VA.3 replicates model 5. Coefficient estimates, standard errors, t-statistics, and p-values for the CCD variable are shown. For all regression specifications in all states, significant autocorrelation is found. In table 2, twenty of the estimated CCD effects are negative and twenty are positive. If we view the null hypothesis as CCD having no impact on colony numbers and the alternative hypothesis as CCD having a negative impact on colony numbers, then a one-tailed test is appropriate. The final column of the table indicates there are only three states for which the null hypothesis is rejected in favor of the alternative hypothesis at the 10% level. Note that there also are two states for which the estimated coefficient is positive and significant at conventional levels. Finally, note that the total of the forty estimated CCD coefficients is positive and equal to about 30,000 colonies, which is well within the 90 percent confidence intervals for the coefficient on the CCD variable in table 2.

Table 3 displays the forty estimated state-level CCD coefficients from the regression specification in model 5 of table 1. The results are similar to those in table 1, albeit even less supportive of the notion that CCD has resulted in reduced colony numbers. Eleven of the forty

---

[26] The ten states for which the U.S. Honey Report does not report colony numbers in recent years are Alaska, Connecticut, Delaware, Kentucky, Maryland, Massachusetts, New Hampshire, Oklahoma, Rhode Island, and South Carolina.

estimated coefficients are negative, while twenty-nine are positive. There are no states for which the estimated CCD coefficient is negative and significant at the 0.10 level, although there are three states for which the estimated CCD coefficient is positive and significant. The sum of the forty estimated coefficients is about 152,000.

The analysis discussed in this section suggests that colony numbers at the aggregate level and in individual states have not fallen since CCD appeared. Given that an average of one-third of the honey bee colonies in the United States have died in each of the four winters since the onset of CCD, how can this be? Our favored interpretation rests on the fact that beekeepers have always lost hives during the winter. Sustainable beekeeping requires them to replace dead and weak colonies using the methods described in section III above. Since the onset of CCD, beekeepers have had to replace more hives to maintain their colony numbers, and the results in this section suggest they have done exactly that.

V.B. The effects of CCD on queen bee and package prices

Concluding that bee populations haven't changed dramatically, or at all, due to CCD doesn't identify the points of adjustment to the phenomenon. Our second approach looks specifically at factor markets for evidence of such adjustment. Two common methods for replacing lost colonies are by making splits and by purchasing packaged bees. In our survey of Pacific Northwest beekeepers, we found that few colonies were replaced by purchases of packages and most replacement colonies came from splits (see table 4). We do not know whether splitting hives is the predominant method used by beekeepers to replace lost colonies in other parts of the country.

The economic logic of the impacts of CCD on package and queen prices is straightforward. Newly split colonies require new queens, which typically are purchased. Packages of workers and queens can be used to start a colony from scratch. By all accounts, CCD has resulted in an increase in winter mortality of colonies which causes an increase in the demand for queens and packages. This increase in demand is expected to cause an increase in the prices of queens and packages.

The magnitude of the CCD-induced increase in costs of replacing lost bee colonies will depend (in part) on the elasticity of supply of queen and packaged bees. To our knowledge there are no available data series on either quantities or prices of queen and packaged bees. Moreover, there has been no analysis conducted of the determinants of queen and packaged bee prices. Therefore, to provide insights into the possible impacts of CCD on beekeeper costs, we constructed a data series on prices for packaged and queen bees from advertisements in the *American Bee Journal* (*ABJ*, published continuously since 1861) and then analyze the determinants of those prices.[27] A description of the procedure we use to collect these data follows.

First, because a common time of year to make increase (which typically employs purchased queens) and to replenish depleted hives with packaged bees is in the spring, we collected information on advertisements for queen and package prices in the March issues of the *ABJ*. We constructed a list of all the sellers who advertised in March *ABJ* issues by selecting

[27] The ABJ describes itself on its masthead as follows: "The American Bee Journal was established in 1861 by Samuel Wagner and has been published continuously since that time, except for a brief period during the Civil War. The Journal has the honor of being the oldest English language beekeeping publication in the world. ... Readership is concentrated among hobby and commercial beekeepers, bee supply dealers, queen breeders, package-bee shippers, honey packers, and entomologists."

roughly one year per decade going back to the 1960s. From this list we identified seven sellers who advertised in the *ABJ* for an extended period of time.[28] We then went through every March issue from 1964 to 2008 and recorded the packaged and queen bee prices for each of the seven sellers who advertised in that issue.

This procedure was complicated by a number of considerations. First, sellers often offer quantity discounts. For example, in March 2007, one seller offered the following schedule of prices:

3 Pound Packages		Queens	
Quantity	Price/Package	Quantity	Price/Queen
1-3	$55.00	1-3	$16.00
4-24	$48.00	4-24	$13.00
25-99	$47.00	25-99	$12.00
100-up	$46.00	100-up	$11.00

The quantity breaks differ across sellers. For example, one seller in the March 2007 ABJ had no quantity discounts, another had only two price categories (1-9 and 10 or more), and another had four price categories, but with different breaks than in the preceding table. Another complication is that payment of shipping costs is not uniform across sellers. Currently, it appears that most sellers do not cover shipping costs, whereas in the past sellers often did cover these costs. Some ads do not indicate whether shipping costs are covered or not.

To account for the different prices of sellers who offer quantity discounts, we construct a data set for our empirical analysis that includes—for each seller and year–the prices the seller

[28] The sellers we identified were Drew Apiaries, Hardeman Apiaries, Walter T. Kelley Co., Russell Apiaries, Weaver Apiaries, Wilbanks Apiaries, and York Bee Co.

charged for queen and package quantities of 1, 5, 25, 50 and 100.

Figure 3 displays the real (deflated) price per queen charged by the seven sellers (for quantities of 50) for whom we collected information from *ABJ's*.[29] The first observation to make regarding these prices is that over the full time span covered by our data any upward trend in real queen prices is moderate. Certainly from the mid-1970s to the present there is little visual evidence that average real queen prices trended upward.[30] The second observation is that from roughly 1977 until 2001 the prices of the seven queen producers moved closely together. This visual impression is supported by the pairwise correlations for the seven sellers—19 out of 21 of these are greater during the period 1977 - 2001 than during the entire span of our data. Since 2001, however, one seller has increased prices substantially relative to the other sellers, while another seller has reduced its prices substantially. The third observation regarding the plots of prices in figure 3 is that there is no obvious CCD-induced increase in queen prices in 2007 and 2008.[31] We have price observations for three sellers for 2006, 2007 and 2008. Two of these charged notably lower (inflation adjusted) prices in 2008 than in 2006, and the third charged roughly the same price in 2008 as in 2006. All four sellers for whom we have prices in both 2007 and 2008 sold queens for lower prices in 2008 than in 2007.

Generally speaking, the same observations can be made regarding the plots of real package prices displayed in figure 4. For the full span of our data any possible upward trend in package prices is moderate and from the mid-1970s to the present, any such trend is even

[29] Plots of prices for the other quantities on which we collected prices (1, 5, 25, and 100) look substantively the same as for the plots of quantities equal to 50.

[30] Plots of nominal prices, on the other hand, show a strong upward trend over time.

[31] We are in the process of updating our data set to include 2009, 2010, and 2011.

weaker. From 1977 to 2001 the prices of the seven package producers move together—17 out of the 21 pairwise correlation coefficients are higher during this period than for the entire sample period. As with queens, since 2001 one seller has increased prices substantially relative to the other sellers, while another seller has reduced its prices substantially.[32] Finally, figure 4 suggests that there is no apparent CCD-induced increase in package prices in 2007 and 2008. For the three sellers on whom we have prices for 2006, 2007 and 2008, all charged notably lower (inflation adjusted) prices in 2008 than in 2006. For the seller for whom we have prices for 2007 and 2008 (but not 2006), the price charged in 2008 is substantially lower than in 2007.

Figure 5 displays the average (for the sellers in our ABJ sample) queen and package prices for 1964 - 2008. Both of these series suggest a moderate upward trend in real prices. Estimated trend lines suggest that package prices increase by about \$0.35 per year (with a t-value of 4.17) and that queen prices increase by about \$0.07 per year (with a t-value of 2.95). It is also noteworthy, however, that over the period from 1974 - 2008, neither package nor queen prices have significant trends. Regarding possible impacts of CCD, both package and queen prices increased substantially from 2006 to 2007, but both also decreased even more substantially between 2007 and 2008. Again, this pattern of prices is not consistent with CCD having major impacts on input markets for honey bees.

To examine more formally the determinants of queen and package prices and the possible impacts of CCD on these prices, we estimate regressions for each of the price series (queen and package). The specification of the queen and package price regressions is as follows:

[32] The seller who increased queen prices also increased package prices and the seller who decreased queen prices also decreased package prices.

$$(1) \qquad \text{Price}_{ijt} = \alpha_0 + \alpha_1 \text{ Almond Acres}_t + \alpha_2 \text{ Year}_t + \sum_{i=1}^{7} \beta_i \text{ Seller } i_{ijt} + \sum_{j=1}^{5} \varphi_j \text{ Quantity } j_{ijt} + \delta_1 \text{ CCD\_DUM}_t + \varepsilon_{ijt},$$

where Price_{ijt} is the price per queen (or package, in 2008 \$s) charged by seller i, for quantity j, in year t; Almond Acres_t is the number of almond acres in California in year t; Seller i_{ijt} is a dichotomous variable that identifies each of the seven sellers in our sample; Quantity j_{ijt} is a dichotomous variable that distinguishes among the number of queens (or packages) purchased (1, 5, 25, 50 or 100) in year t (1964 - 2008); and CCD_DUM_t is a dichotomous variable that we assign a value of one for 2007 and 2008 observations, and zero otherwise.[33] An increase in the number of almond acres is expected to increase the demand for pollination services, which in turn results in an increase in the demand for queens and packaged bees.

We estimate equation (1) using OLS and examine alternative functional forms, including linear (as shown in equation 1 above), log-log (on Price and Almond Acres), semi-log and inverse semi-log. Box-Cox tests indicate that using the natural logarithm of Price (the dependent variable) is strongly preferred to using the raw Price.[34] Comparisons of R^2 values indicate that a log-log specification is preferred to a log-linear specification.

Table 5 presents results from three regression specifications for queen prices. Several insights are gained from Model A. First, although the correlation between the natural logarithm of Almond Acres and the Year trend variable are very high (0.94), there is sufficient independent information in the Almond Acres variable that the estimated coefficient on ln(Almond Acres) is

[33] We also estimate specifications with dichotomous variables to identify observations from 2007 and from 2008.

[34] See Box and Cox (1964).

highly significant.[35] Second, the null hypotheses that the estimated coefficients for the dichotomous Quantity variables are (1) jointly equal to zero and (2) equal to each other, are both convincingly rejected (the p-values for both of these tests are less than 0.01). Given that the quantity category for purchases of 100 queens is omitted, the rejection of the first hypothesis indicates that the per unit prices for the other four quantities are jointly significantly different from the per unit price for purchasing 100 queens. The rejection of the second hypothesis indicates that the per queen prices paid for quantities of 1, 5, 25, and 50 are significantly different from each other. Moreover, the estimated coefficients indicate that the price per queen increases as the quantity of queens purchased declines. With the omitted quantity category being Quantity = 100, the estimated coefficient on, e.g., the dichotomous variable for a quantity of 25 suggests that the price per queen for 25 queens is 6 percent higher than the price per queen for a quantity of 100.

Third, the null hypothesis that the estimated coefficients for the six dichotomous Seller variables are jointly equal to zero is soundly rejected (with a p-values less than 0.01). This implies that the per queen prices charged by sellers vary systematically by seller. Also, although several of the prices charged by individual sellers are significantly different from the prices of the omitted seller, five of the six other sellers charge prices within 11 percent of the prices charged by the omitted seller. Seller 5 charges prices about 23 percent higher than the omitted seller.

Models B and C include variables designed to measure the impact of CCD on queen

[35] None of the conclusions drawn from the regressions reported in tables 5 and 6 are altered by the exclusion of the YEAR trend variable from the reported models.

prices. As can be seen in table 5, the introduction of these variables has no substantive impact on other estimated coefficients, and the three insights (discussed above) gained from Model A apply for Models B and C as well. Model B includes all the variable in Model A, plus the dichotomous CCD variable mentioned above. The estimated coefficient on the CCD variable is insignificant, indicating that there is no support for a prediction that the advent of CCD has caused queen prices to increase. A 95% confidence interval for the queen price impact of CCD is (-9%, +3%). Model C includes separate dichotomous variables for the years 2007 and 2008. The estimated coefficient for the 2007 variable is positive, but not significantly different from zero, whereas the coefficient for 2008 is negative (and significantly different from zero at a 0.05 level). These coefficients further suggest that CCD has not resulted in increased prices for queens.

Table 6 presents results from three regression specifications for package prices. These specifications are essentially the same as for the analysis of queen prices. The dependent variable in table 6 is the price per package and the PACK_DUM_1 - PACK_DUM_50 variables are the per package prices for orders of 1, 5, 25, and 50 packages. The insights gained from the analysis of queen prices also apply to Models A, B, and C for package prices. First, the Almond Acres variable contains independent information beyond that contained in the Year trend variable. Second, the null hypotheses that the estimated coefficients for the dichotomous Quantity variables are (1) jointly equal to zero and (2) equal to each other are both convincingly rejected (the p-values for both of these hypotheses again are less than 0.01), and the interpretation of the rejection of these hypotheses is exactly analogous to the interpretation for the queen price analysis. Third, the null hypotheses that the estimated coefficients for the six dichotomous Seller variables are jointly equal to zero is rejected with a p-value less than 0.01. Five of the six sellers' prices are within 10 percent of the prices of the omitted seller.

The results regarding the impacts of CCD are also the same as for the queen price analysis. Neither the estimated coefficient on the dichotomous CCD variable (Model B), nor the estimated coefficients on the 2007 and 2008 Year variables (Model C) provide evidence that CCD has resulted in increased prices for packaged bees.

Prices of packaged bees and queens provide important information regarding the scarcity of these inputs into the provision of pollination services. If CCD-induced increases in winter mortality are having potentially disastrous impacts on the pollination industry, then one would expect to observe not only decreases in colony numbers and increases in pollination fees, but also increases in the prices of such important inputs as packaged bees and queens. Numerous studies suggest that CCD has resulted in substantially increased winter mortality.[36] Such increases likely result in substantial increases in the demand for packaged bees and queens as beekeepers replace greater numbers of lost colonies resulting from CCD. The preceding statistical analysis suggests there is no evidence that this increased demand has resulted in increased queen or packaged bee prices. We infer from these results that the supply (even in the short run) of packaged bees and queens is sufficiently elastic that any increases in demand have not resulted in measurable increases in prices.

V.C. The effects of CCD on pollination fees

Beekeepers supply the services of bees for two commercial purposes: to provide

[36] See, for example, Burgett et al. (2009), Caron et al. (2010), Pernal (2008), and vanEnglesdorp et al. (2007, 2008, 2010(a) and 2010(b)).

pollination services for farmers and to produce honey. Bee disease, such as CCD, that increases the costs of beekeeping should increase the price of the industry's outputs. Honey is traded internationally and domestic price effects seem less likely than do price effects on pollination services. In this section we examine the price of pollination services, a non-traded commodity, for signs of CCD.[37]

To look for evidence of increased pollination fees due to Colony Collapse Disorder, our empirical strategy is to analyze panel data on fees by crop for two distinct groups of beekeepers responding to two different surveys. The most comprehensive data on pollination fees comes from a survey that Michael Burgett has administered from the Oregon State University since 1987. Every year since then he has surveyed Oregon and Washington (PNW) beekeepers, asking them what fees they received and for which crops. His survey currently yields responses from beekeepers responsible for 70% of bees used for commercial pollination. The second data source is a similar beekeeper survey administered by the California State Beekeepers

---

[37] The jointness of supply of pollination services and honey has implications for the equilibrium pricing of pollination services. A formal model is developed and econometrically analyzed in Rucker, Thurman, and Burgett (2011). A summary of the implications for an empirical explanation of pollination fees is as follows.

Pollination fees for different crops will vary based on the volume and value of nectar provided by the crop for the purposes of making honey–better honey crops will pay smaller pollination fees. Pollination fees for individual crops will vary over time with the price of honey, but the sign of the effect is ambiguous. On the one hand, an increase in the price of honey increases the in-kind value of the honey harvest from a crop and so should reduce the equilibrium pollination fee; on the other hand, an increase in the price of honey makes it more attractive for beekeepers to specialize in honey production and not to transport their bees to crops for pollination. Either effect could dominate on net. Identifiable factors affecting the costs of beekeeping, especially fuel prices for migratory beekeepers, as well as costs of disease control should vary positively with pollination fees. Finally, aggregate pollinated acreage varies over the crop year, and to the extent that larger acreage represents increased seasonal demand for pollination, fees should *ceteris paribus* be positively related to pollinated acres, the largest employer of bees being almonds in late February and early March.

Association, modeled after the PNW survey and conducted annually since 1996.

A broad sense of the PNW fees can be gained from figure 6, which displays the annual averages for almonds fees and for an average of 11 other crops. Because almonds are important in their own right and because almond pollination fees have behaved differently from fees for other crops in recent years, we treat them separately.

Notable in figure 6 is that almond fees increased dramatically after 2004–behavior not seen for other surveyed crops. Almond fees rose from $59 to $89 between 2004 and 2005, and increased again to close to $140 in inflation-adjusted terms in 2006, 2007, 2008, and 2009. It is tempting to attribute these fees to Colony Collapse Disorder, and CCD may be partly to blame, but two facts argue against jumping to the conclusion that the post-2004 almond fee increases are entirely due to CCD. The first is that there is no similar dramatic rise in the pollination fees for other crops. If CCD raises the costs of beekeeping and thus reduces the supply of colonies, there is no obvious reason to expect it to raise only the costs of pollinating almonds. The second fact that should give pause before attributing recent high almond fees to CCD alone is that the timing is not right. The first reported instance of CCD was during the winter of 2006-2007, which could only have affected fees beginning in spring 2007. But as figure 6 shows, almond fees rose earlier: in 2005 and 2006.

Because recent changes in almond fees are a prominent part of the data we analyze, it is important to consider the time patterns of other possible explanations of recent high almond fees. Figure 7 displays two of them: the real price of diesel fuel (an important input into migratory beekeeping) and the numbers of nut-bearing almond trees. It is clear from figure 7 that there is a high degree of collinearity between these two series. Coupling that fact with the limited duration of the recent period of high almond fees should cause one from the outset to not be optimistic about the ability of the recent several annual observations to definitively disentangle these effects.

Data on pollination fees parallel to the PNW survey just described comes from a survey of California beekeepers conducted by the California State Beekeepers Association. The survey has less history than does the PNW survey, and covers a somewhat different set of crops. Still, there are large areas of overlap in terms of time and crop. Figure 8 displays the real (2009 dollar) pollination fees for almonds and the average across 18 other crops.

Table 7 imbeds our search for CCD effects in the more general setting of a reduced form regression for real pollination fees. It reports Generalized Least Squares regression estimates of a panel data model for the Pacific Northwest survey data. Twelve crops are represented over the years 1987-2009. The empirical model can be written as:

$$(2) \qquad y_{it} = \sum_{j=1}^{12} \mu_j d_{it}^j + \varphi V_{it} + x_{it}' d_{it}^A \beta_A + x_{it}'(1- d_{it}^A) \beta_N + \varepsilon_{it},$$

for i = 1, ..., 12 and t = 1987, ... , 2009 .

The variables are defined as follows:

y_{it} = real pollination fee for crop i in year t, measured by the average of responses across beekeepers,

d_{it}^j = crop dummy variables equaling 1 when i = j,

V_{it} = a dummy variable equaling 1 when $t \geq 1991$, the year in which *Varroa* began to cause large-scale losses in the Pacific Northwest,

x_{it} = a vector of explanatory variables, including subsets of the following: the log of one-step-ahead forecast honey price, the log of one-step-ahead forecast crop price, the log of diesel fuel price, the log of almond-bearing acres, a post-2004 dummy variable, and a post-2006 (CCD) dummy variable,

d_{it}^{A} = a dummy variable equaling 1 for observations on almond fees.

The disturbance terms are assumed heteroskedastic but uncorrelated across crops and over time:

$$\mathrm{Var}(\varepsilon_{it}) = \sigma_i^2,\ \mathrm{Cov}(\varepsilon_{it},\varepsilon_{is}) = 0 \text{ for } t \neq s, \text{ and } \mathrm{Cov}(\varepsilon_{it},\varepsilon_{jt}) = 0 \text{ for } i \neq j\,.$$

The semi-log specification in (2) allows for sensible aggregation across crops. For all crops, the left-hand side variable is measured in real dollars per colony of bees. On the right-hand side, prices of crops refer to different commodities and taking logarithms converts their changes into comparable percentage change magnitudes. Notice that in (2), crops are distinguished from one another by crop-specific intercepts and crop-specific variances. Almonds are further distinguished from non-almond crops by the almond dummy interaction terms.

The panel is nearly complete but contains holes due to survey nonresponse. Compared to a total potential number of observations of 12 crops x 23 years = 276, our data set comprises 252 usable observations. In table 1 we report Weighted Least Squares (WLS) estimates of equation 2, where first-stage Ordinary Least Squares residuals are used to estimate the crop-specific variances used in the second stage.

Table 7 reports three specifications of the panel model, each contains our primary variables of interest, a CCD (post-2006) dummy variable and a post-2004 dummy variable, along with other determinants of pollination fees. Crop-specific intercepts are estimated but not reported. The three specifications differ by including log diesel price (specification 1), log almond acres (specification 2), and both log diesel price and log almond acres (specification 3).

Focusing on the indicators of recent change in pollination fees, notice that the CCD coefficient is significant at the 10% or 5% level for almonds in the three specifications and that point estimates of the effect range between $14 and $22 per colony. Notice also that the CCD coefficient is statistically insignificant and the point estimate of $0.70 is small for fees other than almonds. Specification 3 provides the least weak evidence of a CCD effect for non-almond crops, with a 95% confidence interval for the effect of (-$3.13, $4.53).

There are also important time effects, seen visually in figure 6, for almonds, but not for other crops. The post-2004 effect for almonds has a 95% confidence interval of ($18.81, $54.61). The story for almonds is that fees rose by an estimated $36.71 after 2004 and another $14.58 after 2006 (specification 3). These results conform with the unconditional inference one might draw from figure VC.1. Further, non-almond crops saw a statistically significant rise in fees of $4.75 after 2004, but no subsequent increase after that wasn't accounted for by variation in the other covariates.

CCD was first reported late in 2006 – a dramatic finding of abandoned colonies by a migratory beekeeper in Florida. But our estimated CCD effect on almond fees was only modest after this event, and an effect for non-almond crops is not supported by the data. Our method attributes CCD as a residual time-related effect, and there may well be non-CCD explanations for the significant almond effect that we find. Further, it should be kept in mind that our estimates maintain a linear dependence of fees on the other covariates.

A parallel investigation of the other pollination data source, the California beekeepers survey, results in remarkably similar conclusions, at least for almonds. See table 8. The estimated CCD effect for almonds among the California beekeepers is $15.06 (compared to the

PNW estimate of \$14.58). The California effect is larger than its standard error but statistically insignificant by conventional standards. The CCD effect for non-almonds is statistically significant, modest, and negative (-\$2.53). As with the PNW data, both almonds and non-almonds showed statistically significant increases in fees post 2004. Interestingly, the non-almond effect for California beekeepers is a positive \$2.76 post 2004, which is just about exactly offset by a negative \$2.53 post 2006. The California data show no evidence of a CCD effect for non-almond crops.

Particularly in light of the difference in effects between almond and non-almond fees post 2006, we think that the evidence is weak for any increase in pollination fees due to CCD.

VI. Evaluating the Costs of CCD

In this section, we develop back-of-the-envelope estimates of the impacts of CCD on consumer prices and beekeeper income based on fixed coefficient technologies.

VI.A. CCD's effect on consumers

Tables 7 and 8 suggest point estimates of the effect of CCD on almond pollination fees near \$20. Current (2010) almond fees are near \$140, and the implied no-CCD almond fee would be \$140 - \$20 = \$120. The implied percentage increase in almond fees due to CCD is then (20/120) × 100 = 16.7%. Further, with a pollination fee for almonds of \$120 per colony and a stocking density of 2 colonies per acre, the cost per acre of pollinating almonds is 2 × \$120 = \$240. Suppose the yield of almonds is 2,000 pounds per acre and that the farm-gate price of almonds is \$2 per pound. Then revenue per acre is 2,000 × \$2 = \$4,000 and the cost share of pollination in almonds is \$240/\$4,000 = 0.06 or 6 percent.[38]

Next, suppose that Smokehouse Almonds at the retail level sell for \$7 per pound and that one pound of Smokehouse Almonds requires 1.429 pounds of raw almonds. Then the cost share of farm almonds in the production of Smokehouse Almonds is $(1.429 \times \$2)/\$7 = 0.41$.[39] Thus, the cost share of pollination services in retail Smokehouse Almonds is $0.06 \times 0.41 = 0.025$ or 2.5 percent.

The stipulated 16.7 percent increase in almond pollination fees due to CCD therefore causes the cost of Smokehouse Almonds to increase by $0.167 \times 0.025 = 0.004$. Four-tenths of one percent of the \$7/lb cost of Smokehouse Almonds is 2.8¢. Similar calculations could be made for other almond-containing products or products made from other pollinated crops.

VI.B. CCD's effect on beekeepers

Turning to the effects on beekeeper net income, consider first how CCD affects beekeeper costs. We obtain the relevant information from Burgett et al. (2009). In that study, the authors found that for all responding PNW beekeepers (commercial, as well as semi-commercial), the colony mortality rate for the 2007/2008 winter was 30 percent. This rate compares to reported pre-CCD losses of about 14 percent. Based on the reported number of living colonies as of Oct. 1 2007, this sixteen percentage point increase in mortality represents about 9,936 of the surveyed colonies. The PNW beekeepers who responded to the 2008 survey owned 70 percent of the estimated 90,000 colonies in Washington and Oregon. Assuming the

---

[38] In the absence of reliable data on economic costs, we assume a competitive equilibrium with zero profits. Thus, costs per acre are equal to the revenues per acre of \$4,000.

[39] As with the previous calculation, this calculation is based on the assumption of zero profits in the production of Smokehouse Almonds.

beekeepers who did not respond to the survey are similar to those who did respond, the total number of colonies lost to CCD in the PNW is was 4,400 over the 2007/2008 winter.

Responses to questions in the PNW survey about replacement methods indicated that beekeepers used the making increase (or splits) method for almost 80 percent of the colonies replaced. What are the costs associated with this replacement method? Suppose a beekeeper inspects his hives and finds that 100 of them are dead. To replace them, he must purchase 100 queens to place with the new splits produced from the healthy parent colonies. Recent advertisements in the *American Bee Journal* suggest these will cost about $15 each. In addition, about 20 minutes of labor will be required per colony to remove the four or five frames of brood, bees, and honey stores from the parent colony to stock the nuc colony. If labor costs are assumed to be $12 per hour, the labor cost per colony is $4 and the total cost of each split is $15 + $4 = $19.[40] To convert this cost estimate to a per pollination set basis, we can use data from the annual PNW survey, which indicate that on average, beekeepers use each colony for about 2.5 pollination sets per year. Dividing the $19 cost estimate from above by 2.5 implies that the cost per pollination set is $7.60.[41]

Burgett et al. (2009) estimate that PNW winter mortality rates increased from about 14

[40] Another possible cost of splits might be foregone income from pollination or honey production. Splitting by both California and PNW beekeepers usually takes place after almond pollination, so that source of income is not affected. Moreover, the initial healthy hive typically has enough of its bee population intact to pollinate the next scheduled crop (for example, tree fruit in the PNW). The splits themselves will likely be strong enough for later pollination sets such as berries. Thus, it does not appear that there are any additional costs from this source.

[41] A similar calculation suggests that replacing lost colonies by purchasing packaged bees would cost about $52 per colony (or $20.80 per pollination set). This higher cost estimate is consistent with the survey responses indicating that less than 3 percent of colony replacements were accomplished with packaged bees.

percent prior to the appearance of CCD to roughly 30 percent over the winter of 2007-08. Thus, assuming that CCD is responsible for all of this difference, about half the colony mortality in the 2007-08 winter is attributable to CCD. The beekeepers who responded to the survey owned 62,100 out of the USDA's estimated 90,000 colonies in the PNW. Assuming that the beekeepers responding to the survey are representative of the non-responding PNW beekeepers, the demise of about 13,500 (= 90,000*0.15) colonies is due to CCD. The product of the cost per lost colony and the number of colonies due to CCD, or $19×13,500 = $256,500, represents an estimate of the aggregate costs borne by PNW beekeepers as a result of CCD in the winter of 2007-08.

The 25 beekeepers who responded to the 2008 PNW survey owned a total of 62,100 colonies as of Oct.1, 2007, or an average of 2,484 colonies each. Assuming these beekeepers lost 15 percent of their bees to CCD on average, the estimated CCD cost per beekeeper is 0.15 × 2,484 × $19 = $7,079.

Offsetting these increased costs are increased beekeeper revenues from higher almond pollination fees, and 72 percent of the colonies in the 2008 survey were rented out for almond pollination. If, as in the previous subsection we take the almond fee increase due to CCD to be $20, then the average PNW beekeeper with 2,484 colonies, who uses 72% of them (0.72 × 2,484 = 1,788) to pollinate almonds, gains an increase in revenue of 1,788 × $20 = $35,760. The change in net revenue is $35,760 - $7,079 = $28,681, implying that the beekeeper benefits from the equilibrium effects of CCD. Whether these results will be bid down by expansion and entry depends on the elasticity of supply of beekeeping services. The factor in least elastic supply is almost certainly beekeepers' skill and management.

VII. Conclusions

Empirical analysis of honey bee colony numbers, beekeeping input prices, and pollination fees gives only modest support against a null hypothesis that CCD has no economic impact. Estimated effects on these indicators can be considered, at worst, economically modest.

REFERENCES

Box, G. E. P., and D. R. Cox, "An Analysis of Transformations," *Journal of the Royal Statistical Society, Series B,* 1964, 211-43.

Bromenshenk, Jerry J., Colin B Henderson, Charles H. Wick, Michael F. Stanford, Alan W. Zulich, et al. (2010). "Iridovirus and Microsporidian Linked to Honey Bee Colony Decline," PloS ONE 5(10) at http://www.plosone.org/article/info:doi/10.1371/journal.pone.0013181. Accessed February 10, 2011.

Burgett, Michael. "Pacific Northwest Pollination Survey." Various issues of *USDA Honey Market News*.

Burgett, Michael. 1998. "PNW Colony Mortality." *USDA National Honey Market News* No. 9.

Burgett, Michael, Stan Daberkow, Randal Rucker, and Walter Thurman. "U.S. Pollination Markets: Recent Changes and Historical Perspective." *American Bee Journal* (January 2010): 35-40.

Burgett, Michael, Randal R. Rucker, and Walter N. Thurman. "Economics and Honey Bee Pollination Markets." *American Bee Journal* (April 2004): 269-271.

Burgett, Michael, Randal Rucker and Walter Thurman (2009). Honey Bee Colony Mortality in the Pacific Northwest (USA), *American Bee Journal*, Vol. 149, No. 6, June 2009, pp. 573-575.

Caron, Dewey, Michael Burgett, Randal R. Rucker, and Walter N. Thurman, "Honey Bee Colony Mortality in the Pacific Northwest: Winter 2008/2009," *American Bee Journal* (March 2010): 265-269.

Caron, Dewey and Ramesh Sagili, ""Honey Bee Colony Mortality in the Pacific Northwest: Winter 2009/2010," unpublished manuscript, Department of Horticulture, Oregon State University, Corvallis, OR, 2010.

Cheung, Steven N.S. "The Fable of the Bees: An Economic Investigation." *Journal of Law and Economics* 16(1973):11-33.

Committee on the Status of Pollinators in North America, National Research Council of the National Academies. *Status of Pollinators in North America*. The National Academies Press: Washington, D.C. 2007.

Crane, Eva. *The World History of Beekeeping and Honey Hunting*. Routledge Press: New York. 1999.

Daberkow report. List under USDA or Stan D? One report or two?

DeGrandi-Hoffman, Gloria (2003). "Honey Bees in U.S. Agriculture: Past, Present, and Future," chapter 1 in *For Nonnative Crops, Whence Pollinators of the Future?*, Karen Strickler and James H. Cane editors, Entomology Society of America, Lanham, MD.

Flores, Alfredo, "Coordinated Research Aims to Improve Honey Bee Health," USDA/ARS, February 1, 2008, at http://www.ars.usda.gov/IS/pr/2008/080201.htm (accessed August 19, 2008).

Hoff, Frederic L. and Lois S. Willett. "The U.S. Beekeeping Industry." USDA. ERS. Agricultural Economic Report Number 680. Washington DC: May 1994.

Horn, Tammy. *Bees in America: How the Honey Bee Shaped a Nation*. The University Press of Kentucky: Lexington, Kentucky. 2005.

Johnson, Kirk. "Scientists and Soldiers Solve a Bee Mystery," New York Times, October 6, 2010 at .http://www.nytimes.com/2010/10/07/science/07bees.html. Accessed February 10, 2011.

Kolbert, Elizabeth, "Stung: Where have all the bees gone?" The New Yorker, August 6, 2007, pp. 52-59.

Mairson, Alan, "America's Beekeepers: Hives for Hire," *National Geographic*, May 1993: 73-93.

Maori, E., S. Lavi, R. Mozes-Koch, Y. Gantman, Y. Peretz et al. (2007) Isolation and characterization of Israeli acute paralysis virus, a dicistrovirus affecting honey bees in Israel: evidence for diversity due to intra- and inter-species recombination. *J Gen Virol* 88: 3428–3438 at http://vir.sgmjournals.org/cgi/reprint/88/12/3428

Maryland Invasive Species Council, "Varroa mite, Varroa destructor is the February Invader of the Month," February 6, 2007 at http://www.mda.state.md.us/article.php?i=5027 (accessed January 29, 2011)

Morse, Roger A. and Nicholas W. Calderone, "The Value of Honey Bees as Pollinators of U.S. Crops in 2000," *Bee Culture*, March 2000. http://bee.airoot.com/beeculture.

Morse, Roger A. and K. Flottum, *Honey Bee Pests, Predators, and Diseases*. A. I. Root Co., Medina, Ohio, 1997.

Mussen (2007).

Muth, Mary K. and Walter N. Thurman. "Why Support the Price of Honey?" *Choices* 2nd Quarter, 1995: 13-17.

Muth, Mary K., Randal R. Rucker, Walter N. Thurman, and Ching-Ta Chuang, "The Fable of the Bees Revisited: Causes and Consequences of the U.S. Honey Program," *Journal of Law and Economics*, 46(2003): 479-516.

Natural Resources Defense Council, "The Bees' Needs: Honey bees are mysteriously vanishing across the country, putting $15 billion worth of fruits, nuts and vegetables at risk," at http://www.nrdc.org/wildlife/animals/bees.asp (accessed August 19, 2008).

Pellett, Frank C. *History of American Beekeeping*. Ames, IA: Collegiate Press. 1938.

Pernal, S.F. 2008. CAPA statement on honey bee losses in Canada (spring 2008) – final revision. Canadian Assoc. of Professional Apiculturists.

Pollan, Michael. "Our Decrepit Food Factories," *New York Times*, December 16, 2007.

Robinson, W.S., R. Nowogrodzki, and R.A. Morse. "The Value of Honey Bees as Pollinators of U.S. Crops." *American Bee Journal* (June 1989):411-23 (Part I) and (July 1989):477-87 (Part II).

Rucker, R., W. Thurman, and M. Burgett (2010). *The Economics of Honeybee Pollination Markets*. Unpublished working paper, Department of Agricultural Economics and Economics, Montana State University, Bozeman, MT.

ScienceDaily, "Economic Value of Insect Pollination Worldwide Estimated at U.S. $217 Billion," Sept.15, 2008, http://www.sciencedaily.com/releases/2008/09/080915122725.htm (accessed January 12, 2009),

Seeley, Thomas D. *The Wisdom of the Hive : The Social Physiology of Honey Bee Colonies*. Harvard University Press: Cambridge, Massachusetts. 1995.

Sorrow, April Reese, "Researchers Honing in on Bee Colony Collapse Disorder," Southeast Farm Press, Feb. 14, 2011 at http://southeastfarmpress.com/print/government/researchers-honing-bee-colony-collapse-disorder?page=1. Accessed February 14, 2011.

Stipp, David, "As bees go missing a $9.3B crisis lurks," Fortune, August 28, 2007: 2:55 p.m. EDT. Accessed June 8, 2008 online at http://money.cnn.com/magazines/fortune/fortune_archive/2007/09/03/100202647/index.htm.

Underwood, Robyn M. and Dennis vanEngelsdorp 2007. "Colony Collapse Disorder: Have We Seen This Before?" *Bee Culture* 135(7):12-15.

United States Department of Agriculture, National Agricultural Statistics Service (NASS). February 2008. Honey." http:/usda.mannlib.cornell.edu/usda/current/Hone/Hone-02-29-2008 pdf.

vanEngelsdorp D, Evans JD, Saegerman C, Mullin C, Haubruge E, et al. (2009). "Colony Collapse Disorder: A Descriptive Study," PLoS ONE 4(8): e6481. at http://www.plosone.org/article/info:doi/10.1371/journal.pone.0006481. Accessed February 10, 2011.

vanEngelsdorp, D., Underwood, R., Caron, D. and J. Hayes. 2007. An estimate of managed colony losses in the winter of 2006-07: a report commissioned by the Apiary Inspectors of America. *American Bee Journal* 147: 599-603.

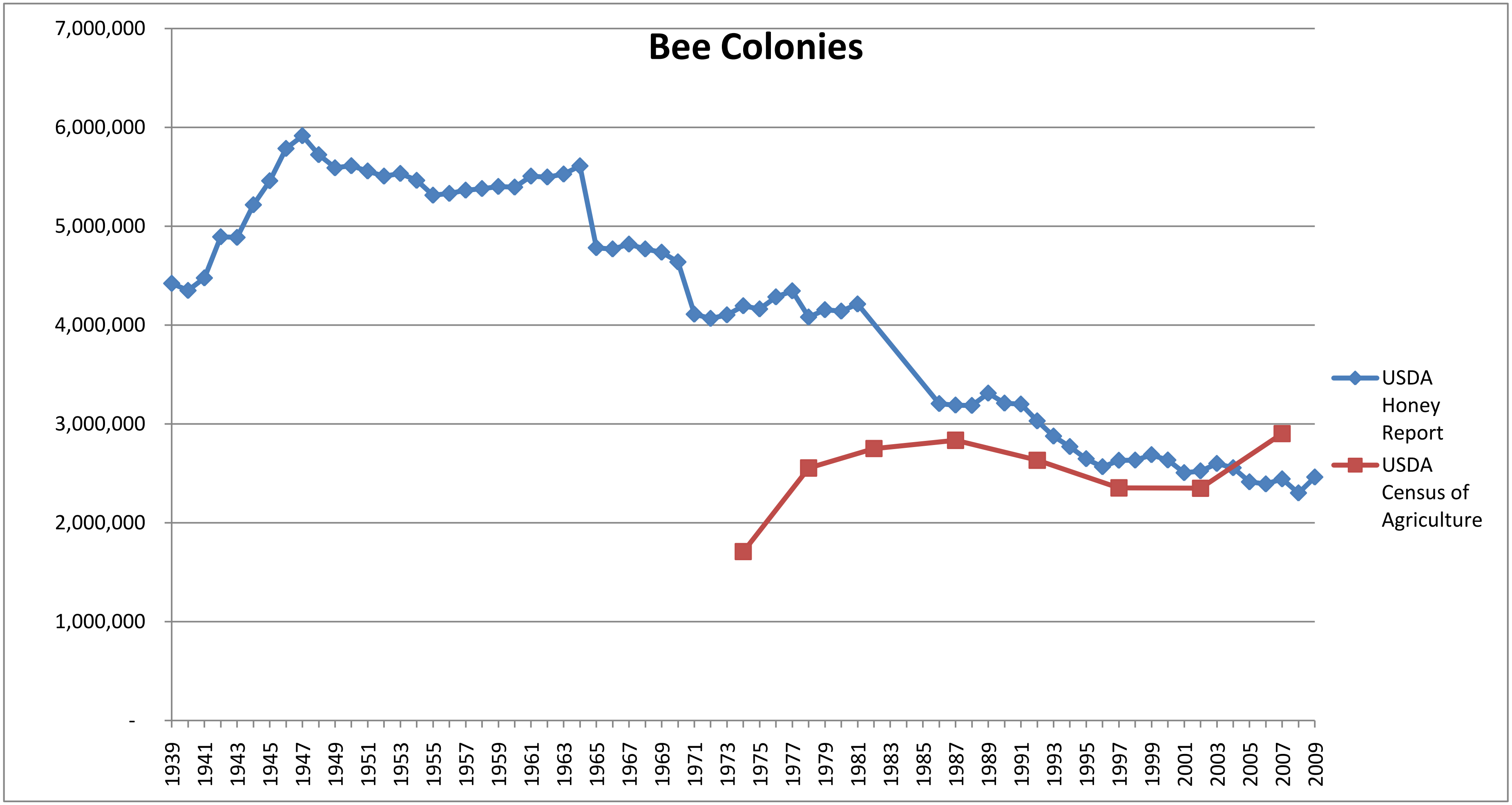
vanEngelsdorp, D., Hayes, J. and J. Pettis. 2008. A Survey of Honey Bee Colony Losses in the U.S., Fall 2007 to Spring 2008. PLoS ONE. 2008; 3(12): e4071. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2606032

vanEngelsdorp D; J. Hayes Jr., R. M. Underwood, and J. Pettis. 2010a. A survey of honey bee colony losses in the United States, fall 2008 to spring 2009. *Journal of Apicultural Research* 49: 7-14.

vanEngelsdorp, D, J Hayes Jr., R M. Underwood, D M. Caron, and J. Pettis. 2010b. A Survey of managed honey bee colony losses in the U.S., fall 2009 to winter 2010. *Journal of Apicultural Research*, forthcoming.

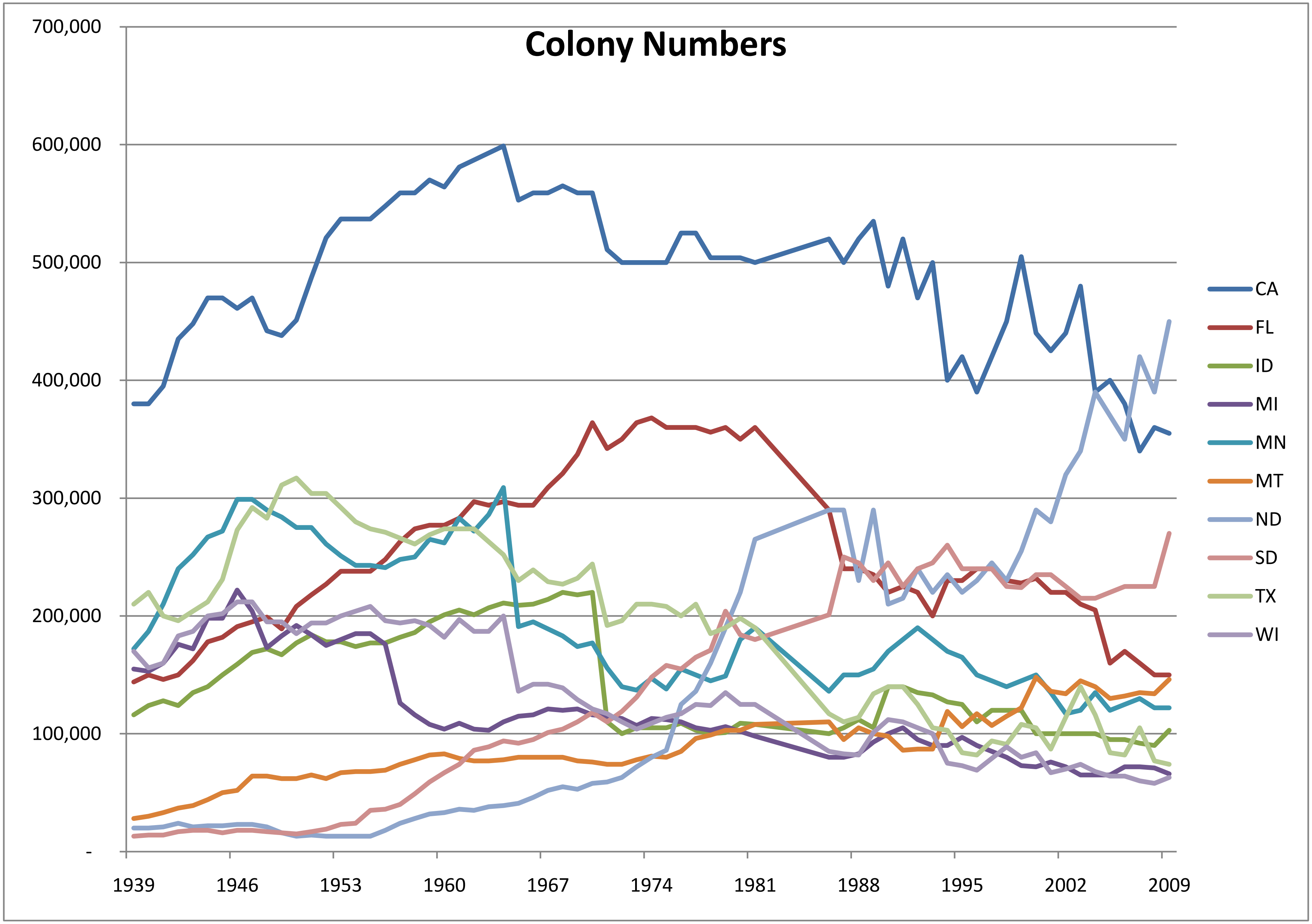
Whynott, Douglas. *Following the Bloom: Across America with the Migratory Beekeepers.* Harrisburg, PA: Stackpole Books. 1991.

Figure 1.



Bee Colonies
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
-
1939
1941
1943
1945
1947
1949
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
USDA Honey Report
USDA Census of Agriculture

Figure 2.



Colony Numbers
700,000
600,000
500,000
400,000
300,000
200,000
100,000
-
1939
1946
1953
1960
1967
1974
1981
1988
1995
2002
2009
CA
FL
ID
MI
MN
MT
ND
SD
TX
WI

Figure 3.

~~FIGURE X~~: PLOT OF REAL QUEEN PRICES, 1964-2008, QUANTITY=50:

SQ=SD1, CIRCLE=SD2, STAR=SD3,
PLUS=SD4, DIAMOND=SD5, TRIANGLE=SD6, DOT=SD7

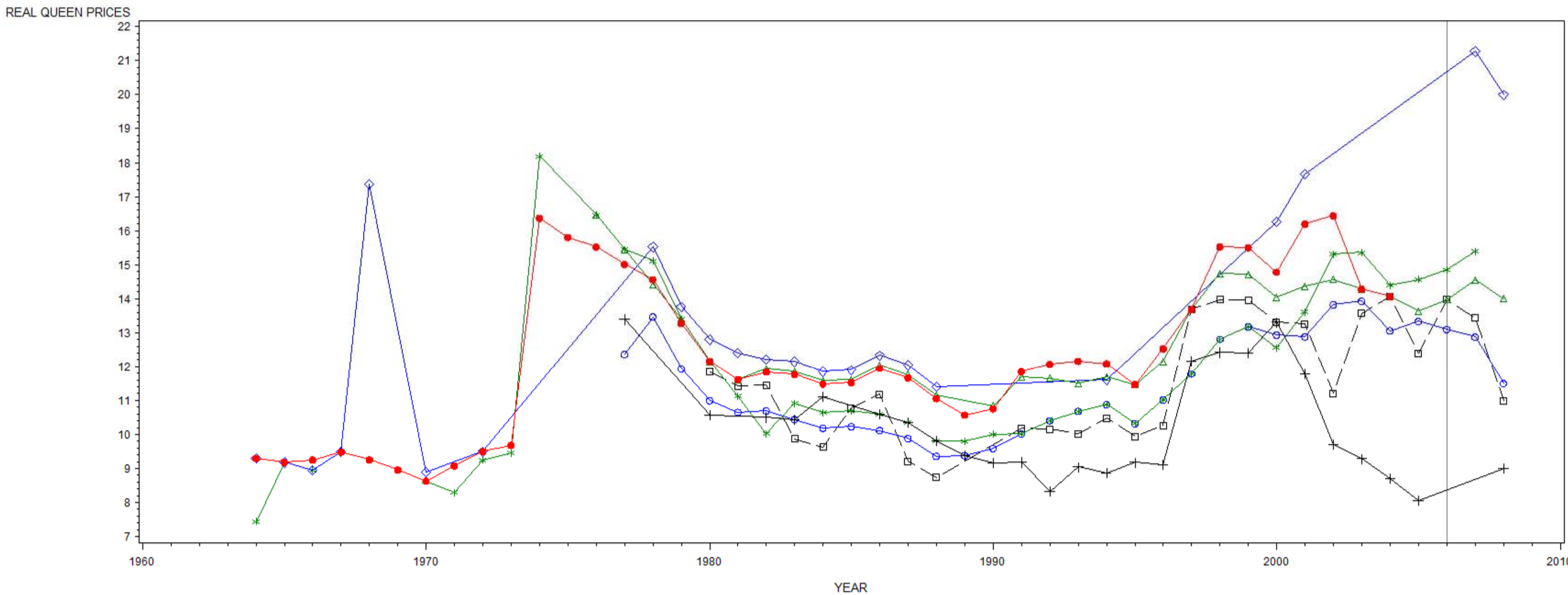


Figure 4.

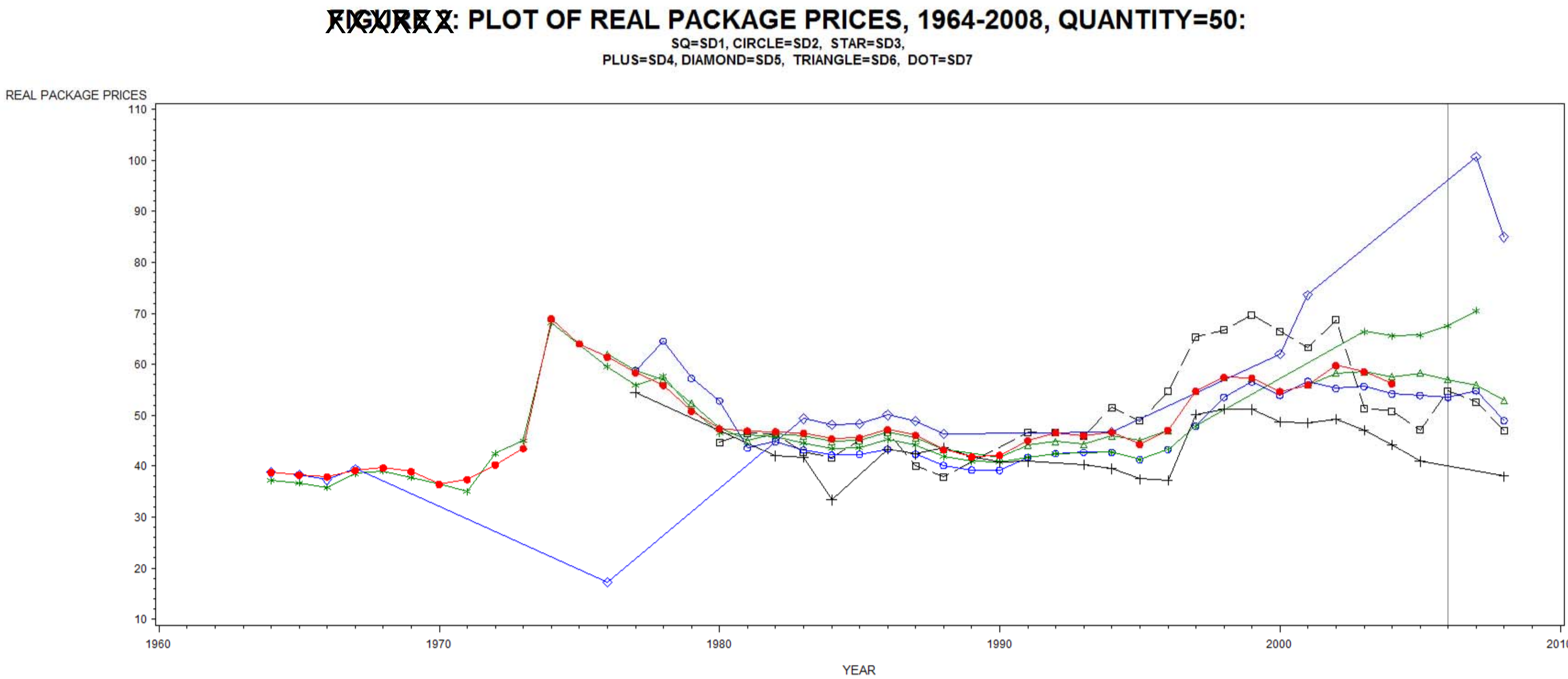


FIGURE X: PLOT OF REAL PACKAGE PRICES, 1964-2008, QUANTITY=50:
SQ=SD1, CIRCLE=SD2, STAR=SD3,
PLUS=SD4, DIAMOND=SD5, TRIANGLE=SD6, DOT=SD7
REAL PACKAGE PRICES
110
100
90
80
70
60
50
40
30
20
10
1960
1970
1980
1990
2000
2010
YEAR

Figure 5.

~~FIGURE 3:~~ AVERAGE REAL PACKAGE AND QUEEN PRICES, QUANTITY = 50

BLACK SQUARE=PACKAGE PRICE, BLUE DIAMOND=QUEEN PRICE

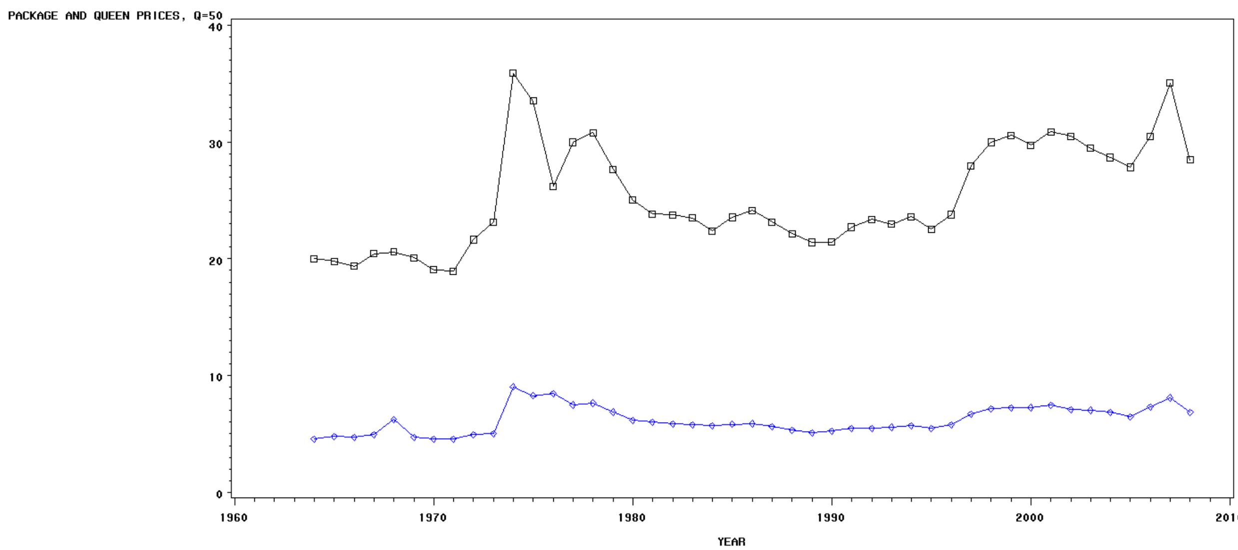


Figure 6.

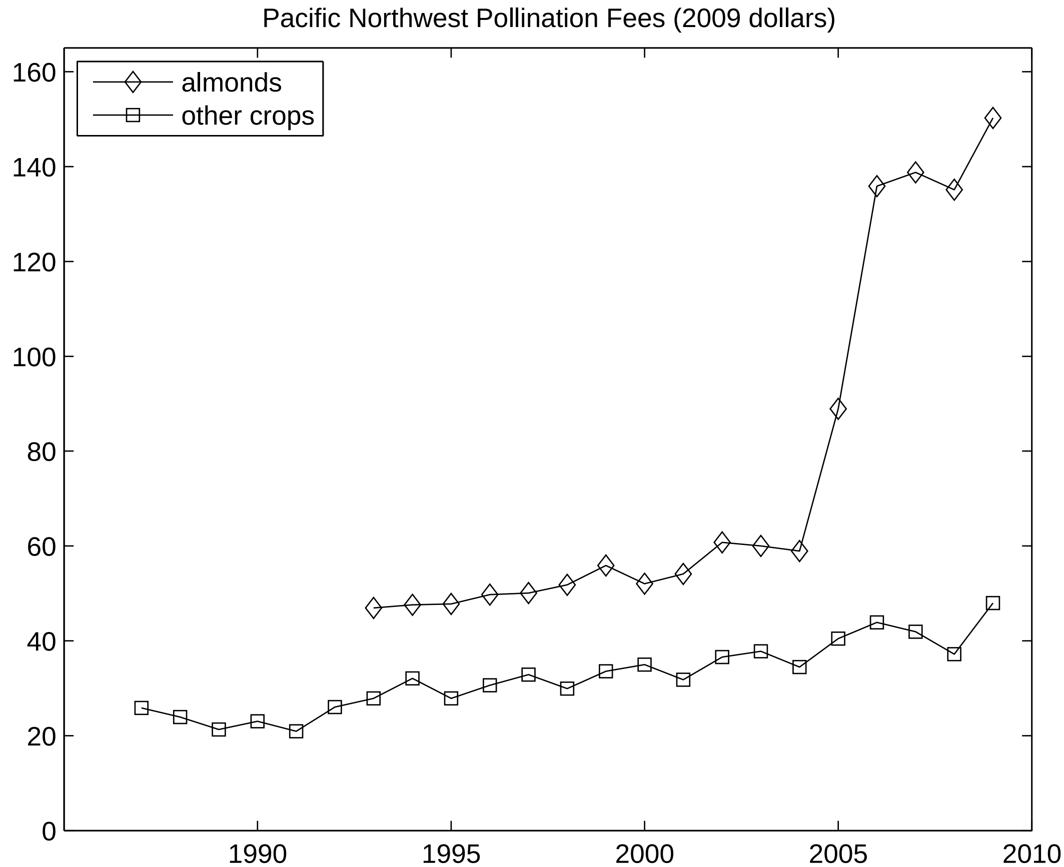

Pacific Northwest Pollination Fees (2009 dollars)
almonds
other crops
160
140
120
100
80
60
40
20
0
1990
1995
2000
2005
2010

Figure 7.

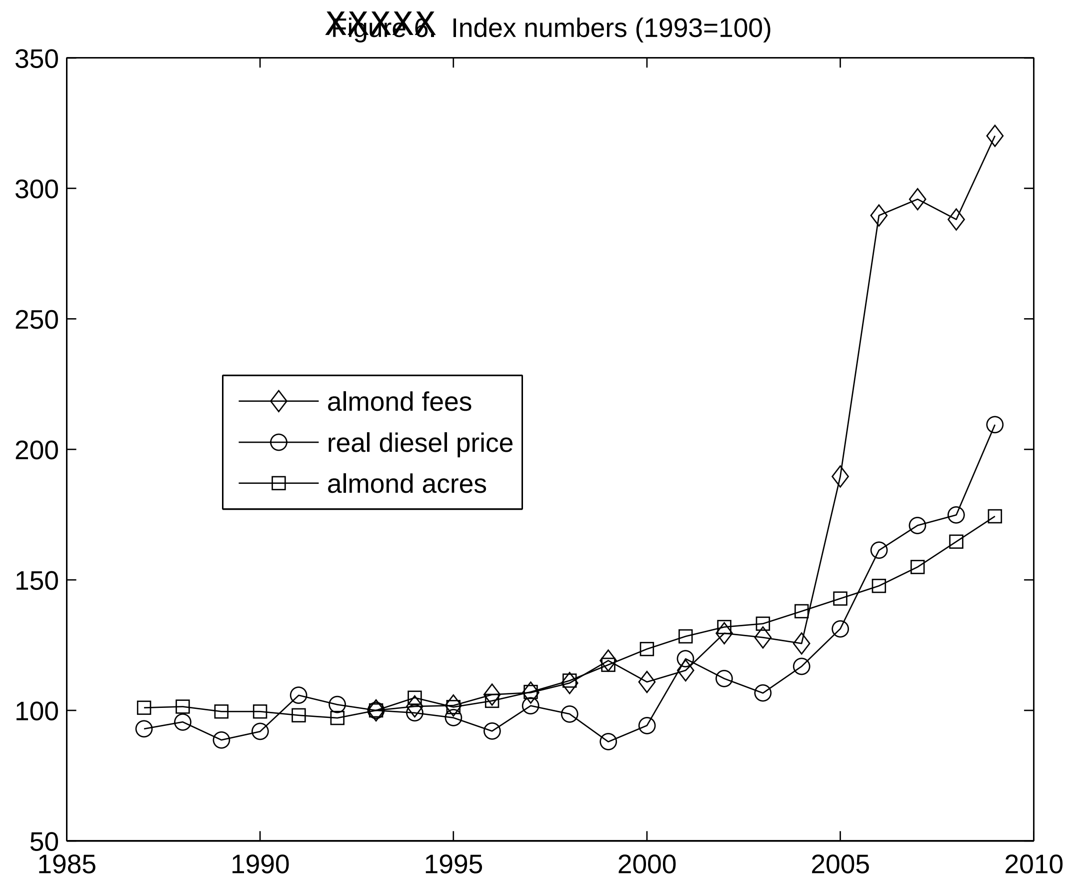

XXXXX Figure 6. Index numbers (1993=100)
350
300
250
200
150
100
50
1985
1990
1995
2000
2005
2010
almond fees
real diesel price
almond acres

Figure 8.

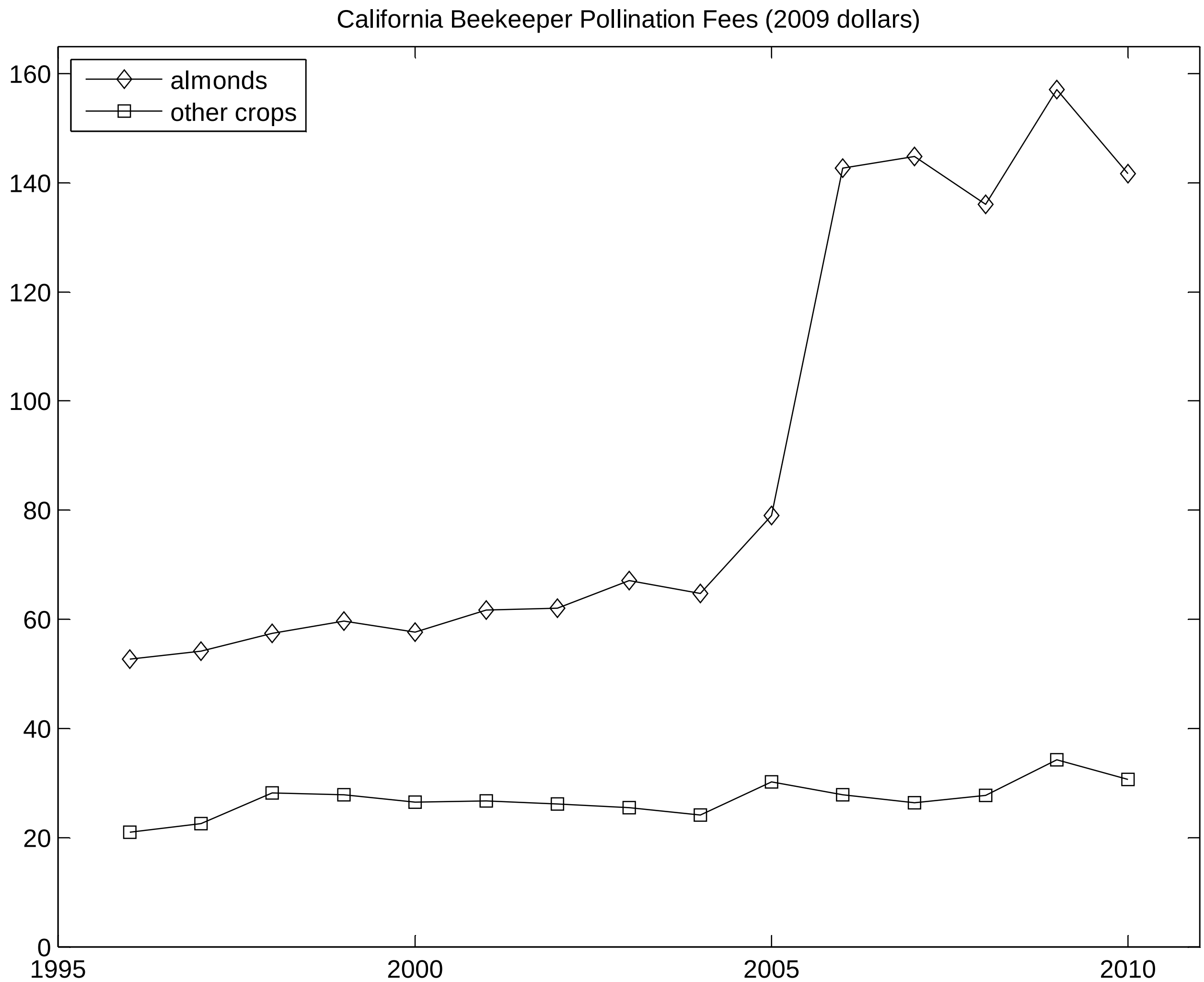

California Beekeeper Pollination Fees (2009 dollars)
almonds
other crops
160
140
120
100
80
60
40
20
0
1995
2000
2005
2010

Table 1

Regression Results
Dependent variable is U.S. Colony Numbers (in 1,000s): 1939-2009 [a]

	Model 1	Model 2	Model 3	Model 4	Model 5
Variable	Coefficient (Std. Error)	Coefficient (Std. Error)	Coefficient (Std. Error)	Coefficient (Std. Error)	Coefficient (Std. Error)
Intercept	5589 (115.8)***	5058 (438.2)***	4941 (442.5)***	4770 (404.4)***	4700 (287.7)***
Year	-30.15 (4.68)***	-20.60 (12.01)*	-11.19 (15.94)	22.75 (26.21)	73.46 (31.69)**
$Year^2$				-0.693 (0.378)*	-2.181 (0.743)**
Post-1985	-1072 (199.5)***	-1014 (400.1)**	501.9 (1695)	-852.3 (390.7)**	-7104 (2628)***
(Post-1985) × Year			-32.84 (36.05)		144.2 (60.95)**
CCD dummy (post-2006)	-34.59 (254.4)	55.54 (178.3)	94.04 (182.2)	141.5 (182.0)	155.7 (179.9)
AR1 coefficient		0.936 (0.042)***	-0.930 (0.045)***	-0.914 (0.052)***	-0.837 (0.080)***
R^2	0.8897				

[a] Number of observations = 67. *, **, and *** indicate significance at the 0.10, 0.05, and 0.01 levels.

Table 2: Estimated Impacts of CCD on Colony Numbers, by State

Model: Colony numbers = f(Year, Post-85, CCD) with AR1 error

State	CCD dummy	Standard Error	t-statistic	p-value (1 tailed test)
AL	2.04	12.69	0.16	0.44
AZ	-0.22	6.76	-0.03	0.49
AR	-4.03	6.54	-0.62	0.27
CA	-48.88	30.69	-1.59	0.06
CO	-4.12	3.84	-1.07	0.14
FL	-12.36	14.12	-0.87	0.19
GA	-2.53	9.70	-0.26	0.40
HI	0.42	0.93	0.45	0.33
ID	-3.49	16.07	-0.22	0.41
IL	7.97	12.37	0.64	0.26
IN	4.85	12.99	0.37	0.36
IA	2.67	12.09	0.22	0.41
KS	0.17	3.61	0.05	0.48
LA	-0.32	8.24	-0.04	0.48
ME	-2.97	1.66	-1.79	0.04
MI	2.45	10.48	0.23	0.41
MN	4.25	19.57	0.22	0.41
MS	1.15	4.62	0.25	0.40
MO	-0.45	9.18	-0.05	0.48
MT	3.03	6.98	0.43	0.33
NE	-3.11	7.27	-0.43	0.34
NV	0.57	1.79	0.32	0.38
NJ	-1.67	3.04	-0.55	0.29
NM	-2.02	2.38	-0.85	0.20
NY	-4.68	8.00	-0.59	0.28
NC	-1.09	7.75	-0.14	0.44
ND	69.94	23.15	3.02	0.00
OH	7.84	18.74	0.42	0.34
OR	0.18	3.99	0.05	0.48
PA	3.48	8.21	0.42	0.34
SD	-5.51	12.40	-0.44	0.33
TN	0.56	7.11	0.08	0.47
TX	20.03	15.99	1.25	0.11
UT	4.29	2.58	1.66	0.05
VT	-1.00	0.67	-1.49	0.07
VA	-1.00	5.40	-0.18	0.43
WA	-4.16	6.34	-0.66	0.26
WV	1.01	7.40	0.14	0.45
WI	-1.98	11.74	-0.17	0.43
WY	0.16	2.78	0.06	0.48
Sum	31.47			

Table 3: Estimated Impacts of CCD on Colony Numbers, by State

Model: Colony numbers = f(Year, Post-85, Y^2, Post-85×Year, CCD) with AR1 error, AR1), where AR1 is ML estimate

State	CCD	Standard Error	t-statistic	p-value (1 tailed test)
AL	6.09	12.94	0.47	0.32
AZ	3.84	6.71	0.57	0.28
AR	-5.67	6.12	-0.93	0.18
CA	-14.69	25.83	-0.57	0.29
CO	-3.35	4.11	-0.82	0.21
FL	-9.77	12.35	-0.79	0.22
GA	5.17	10.03	0.52	0.30
HI	-0.15	1.00	-0.15	0.44
ID	5.29	15.85	0.33	0.37
IL	4.79	12.01	0.40	0.35
IN	7.53	13.50	0.56	0.29
IA	1.90	12.55	0.15	0.44
KS	2.77	3.56	0.78	0.22
LA	3.42	8.05	0.42	0.34
ME	-1.64	1.86	-0.88	0.19
MI	1.11	11.06	0.10	0.46
MN	8.10	20.33	0.40	0.35
MS	3.48	4.53	0.77	0.22
MO	-0.35	9.67	-0.04	0.49
MT	0.98	7.63	0.13	0.45
NE	1.91	7.09	0.27	0.39
NV	0.27	2.04	0.13	0.45
NJ	1.34	3.05	0.44	0.33
NM	-0.44	2.25	-0.19	0.42
NY	-2.09	8.36	-0.25	0.40
NC	6.03	7.86	0.77	0.22
ND	61.47	21.94	2.80	0.00
OH	9.05	19.31	0.47	0.32
OR	2.46	4.24	0.58	0.28
PA	1.58	8.44	0.19	0.43
SD	2.87	11.45	0.25	0.40
TN	3.65	7.76	0.47	0.32
TX	25.32	15.88	1.59	0.06
UT	6.01	2.59	2.32	0.01
VT	-0.90	0.71	-1.26	0.11
VA	1.23	5.56	0.22	0.41
WA	7.19	5.69	1.26	0.11
WV	5.57	7.60	0.73	0.23
WI	-0.70	12.32	-0.06	0.48
WY	1.73	3.17	0.54	0.29
Sum	152.39			

Table 4. PNW colony replacement methods: winter 2007/2008

	2007/2008	2008/2009	2009/2010	3 Year Average
Replacement Method	**% of replacement colonies**	**% of replacement colonies**	**% of replacement colonies**	**% of replacement colonies**
Splits/Nucs (own colonies)	78.3	94.8	66.5	79.87
Nucs (purchased from other beekeepers)	15.9	0.5	12.0	9.47
Packages USA source	1.0	1.6	11.8	4.80
Packages Outside USA	1.8	0.5	7.7	3.33
Mature colonies from other beekeepers	3.1	0.5	2.0	1.97
Other	0.1	2.1	0.1	0.77

Table 5: Queen Price Regressions

Dependent Variable: ln(Real Price of Queens). Number of Observations = 785

Variable	Model A	Model B	Model C
	estimated coefficient (standard error)	estimated coefficient (standard error)	estimated coefficient (standard error)
Intercept	0.497 (2.80)	-0.107 (2.86)	0.035 (2.86)
ln(ALMOND ACRES)	0.207 (0.039)***	0.202 (0.039)***	0.205 (0.039)***
YEAR	0.0011 (0.001)	0.0014 (0.001)	0.0013 (0.0014)
QUEEN_DUM_1	0.170 (0.018)***	0.170 (0.018)***	0.170 (0.018)***
QUEEN_DUM_5	0.141 (0.018)***	0.141 (0.018)***	0.141 (0.018)***
QUEEN_DUM_25	0.060 (0.018)***	0.060 (0.018)***	0.060 (0.018)***
QUEEN_DUM_50	0.050 ((0.018)***	0.050 (0.018)***	0.050 (0.018)***
SELLER_DUM_2	-0.039 (0.028)	-0.043 (0.028)	-0.045 (0.028)
SELLER_DUM_3	-0.012 (0.029)	-0.016 (0.029)	-0.014 (0.029)
SELLER_DUM_4	-0.094 (0.032)***	-0.098 (0.032)***	-0.091 (0.032)***
SELLER_DUM_5	0.233 (0.056)***	0.243 (0.057)***	0.275 (0.058)***
SELLER_DUM_6	0.107 (0.028)***	0.104 (0.028)***	0.105 (0.028)***
SELLER_DUM_7	0.092 (0.028)***	0.087 (0.028)***	0.089 (0.028)***
CCD	---	-0.031 (0.031)	---
YEAR_2007_DUM			0.043 (0.043)
YEAR_2008_DUM			-0.094 (0.040)**

*** indicates significance at the 0.01 level.
**indicates significance at the 0.05 level.

Table 6: Package Price Regressions

Dependent Variable: ln(Real Price of Packages). Number of Observations = 768

Variable	Model A	Model B	Model C
	estimated coefficient (standard error)	estimated coefficient (standard error)	estimated coefficient (standard error)
Intercept	2.614 (2.45)	2.205 (2.51)	2.311 (2.50)
ln(ALMOND ACRES)	0.163 (0.034)***	0.160 (0.034)***	0.162 (0.034)***
YEAR	0.00039 (0.0012)	0.00059 (0.0012)	0.00054 (0.0012)
PACK_DUM_1	0.073 (0.016)***	0.073 (0.016)***	0.073 (0.016)***
PACK_DUM_5	0.063 (0.016)***	0.063 (0.016)***	0.063 (0.016)***
PACK_DUM_25	0.031 (0.016)	0.031 (0.016)	0.031 (0.016)
PACK_DUM_50	0.024 (0.016)	0.024 (0.016)	0.024 (0.016)
SELLER_DUM_2	-0.055 (0.024)**	-0.058 (0.024)**	-0.059 (0.024)**
SELLER_DUM_3	-0.063 (0.026)**	-0.065 (0.026)**	-0.064 (0.026)**
SELLER_DUM_4	-0.097 (0.028)***	-0.100 (0.028)***	-0.095 (0.028)***
SELLER_DUM_5	0.232 (0.049)***	0.239 (0.049)***	0.263 (0.051)***
SELLER_DUM_6	0.024 (0.024)	0.022 (0.024)	0.023 (0.024)
SELLER_DUM_7	0.014 (0.024)	0.011 (0.024)	0.012 (0.025)
CCD	---	-0.020 (0.027)	---
YEAR_2007_DUM			0.034 (0.038)
YEAR_2008_DUM			-0.067 (0.035)

*** indicates significance at the 0.01 level.
**indicates significance at the 0.05 level.

Table 7.

Table X. Pacific Northwest Beekeeper Survey of Pollination Fees

Panel of 12 crops over 23 years: 1987-2009, n=252
Cropwise-heteroskedastic GLS regressions

Dependent variable = Real (2009 dollars) pollination fee

Crop-specific intercepts fit in all specifications:
almonds, pears, sweet cherries, apples, red clover seed, crimson clover seed, vetch seed, cucumbers, blueberries, cranberries, radish seed, squash

Coefficients labeled "almonds" and "others" correspond to covariates interacted with almond and non-almond (11 crops) dummy variables.

		(1)		(2)		(3)	
Variable		coefficient	t-stat	coefficient	t-stat	coefficient	t-stat
CCD (post 2006 = 1)	**almonds**	14.47	1.76 *	21.85	2.62 ***	14.58	1.77 *
	others	0.59	0.30	-0.52	-0.30	0.70	0.36
Post 2004 = 1	**almonds**	36.51	4.04 ***	47.80	5.86 ***	36.71	4.04 ***
	others	4.63	2.19 **	2.92	1.74 *	4.75	2.28 **
Log honey price	**almonds**	7.03	0.66	-9.80	-0.66	4.24	0.28
	others	8.14	3.64 ***	4.43	1.51	2.03	0.61
Log diesel price	**almonds**	62.12	3.17 ***			56.78	2.04 **
	others	0.63	0.14			-8.55	-1.49
Log almond acres	**almonds**			56.02	2.17 **	8.82	0.27
	others			9.63	1.93 *	15.78	2.44 **
Varroa		6.19	5.14 ***	6.32	5.64 ***	7.09	5.76 ***
R^2		0.890		0.892		0.892	

Note: *, **, and * denote significance at the 10%, 5%, and 1% levels with two-sided tests.**

Table 8.

Table X. California Beekeeper Survey of Pollination Fees

Panel of 19 crops over 14 years: 1996-2009, n=236
Cropwise-heteroskedastic GLS regressions

Dependent variable = Real (2009 dollars) pollination fee

Crop-specific intercepts fit in all specifications:
apples, clover seed, cucumbers, almonds, avocados, kiwis, melons, onion seed, plums, prunes, pumpkins, squash, sunflowers, vegetable seed (hives), vegetable seed (nucs), alfalfa seed, watermelons, cherries (early), cherries (late)

Coefficients labeled "almonds" and "others" correspond to covariates interacted with almond and non-almond (18 crops) dummy variables.

		(1)		(2)		(3)	
Variable		**coefficient**	**t-stat**	**coefficient**	**t-stat**	**coefficient**	**t-stat**
CCD (post 2006 = 1)	**almonds**	15.04	1.33	26.72	2.24 **	15.06	1.33
	others	-2.51	-1.77 *	-1.95	-1.59	-2.53	-1.79 *
Post 2004 = 1	**almonds**	21.19	1.68 *	38.47	3.17 ***	21.23	1.68 *
	others	2.90	1.85 *	2.86	2.34 **	2.76	1.78 *
Log honey price	**almonds**	-16.96	-0.79	-15.55	-0.58	-16.60	-0.73
	others	-5.09	-1.92 *	-7.54	-2.83 ***	-7.20	-2.57 **
Log diesel price	**almonds**	86.34	3.04 ***			87.37	2.40 **
	others	9.92	2.73 **			3.69	0.79
Log almond acres	**almonds**			69.92	1.60	-2.17	-0.05
	others			16.56	3.69 ***	12.66	2.06 **
R^2		0.826		0.820		0.825	

Note: *, **, and * denote significance at the 10%, 5%, and 1% levels with two-sided tests.**