COLONY COLLAPSE DISORDER:
THE MARKET RESPONSE TO BEE DISEASE

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TO THE READER

We live in an imperfect world full of problems. That fact contributes to the ongoing media drumbeat over imminent catastrophe. Horror stories sell; news items about incremental improvements are not interesting except to people in the industries working to make life a little bit better.

One horror story is that of Colony Collapse Disorder, a mysterious phenomenon affecting honey bees. It is a real problem that not long ago produced headlines such as "Bee Colony Collapses Could Threaten U.S. Food Supply" (*Associated Press*, May 3, 2007).

Two prominent agricultural economists, Randy Rucker and Wally Thurman, look at the bee problem in a new light. The problem still exists but gets little news because, once again, the sky did not fall. People in the beekeeping industry reacted to the problem so swiftly that pollination continued and the food supply was saved.

Colony Collapse Disorder is one of the many episodes PERC has examined over the years, showing how people resolve real problems. Too often it is presumed when reading about environmental issues in the doom-and-gloom media that politicians are needed to save the day. In the case of colony collapse, luckily it never got to political intervention. As is often the case, the uncoordinated market quietly resolved what had been posited as a major crisis.

"Colony Collapse Disorder: The Market Response to Bee Disease" is part of the *PERC Policy Series* of papers on timely environmental topics. This issue was edited by Roger Meiners and Laura Huggins and designed by Mandy-Scott Bachelier.

COLONY COLLAPSE DISORDER:
THE MARKET RESPONSE TO BEE DISEASE

INTRODUCTION

Birds, bats, and insects all pollinate the flowering plants around us, but the most celebrated pollinator is the honey bee—and for good reason. Fifteen hundred U.S. commercial beekeepers take their 2.5 million hives of bees on the road each year to pollinate blueberries, almonds, cranberries, and a cornucopia of other fruits and vegetables. Without this cooperation of beekeeper, bee, and farmer, our diet would be less nutritious and less tasty.

Even casual observers know, however, that all is not perfect in the world of bees. Colony Collapse Disorder, or CCD, is the most recent scourge to hit honey bees. Between 2007 and 2011, approximately 30 percent of U.S. bees alive each fall failed to survive to pollinate blossoms in the spring. Widespread die-offs due to disease have long been recorded, but CCD has been worse than most.

Some authors have viewed this recent bee disease as canaries in the coal mine, signaling the environmental folly of relying on an industrialized farming system. Noted food and nature author Michael Pollan articulated this view in a 2007 edition of the *New York Times*:

> [W]hatever turns out to be the immediate cause of colony collapse, many entomologists believe some such disaster was waiting to happen: the lifestyle of the modern honey bee leaves the insects so stressed out and their immune systems so compromised that, much like livestock on factory farms, they've become vulnerable to whatever new infectious agent happens to come along.

Later, Canadian actress and *Juno* star Ellen Page narrated and promoted a 2009 documentary, "Vanishing of the Bees," which made a tour of college campuses across North America. Linking CCD to neonicotinoid pesticides, the salience of the bee problem was summarized by the often-repeated claim that "honey bees pollinate one-third of everything we eat."

Does public policy have a role to play in dealing with bee disease? Suggestions have run the gamut from increased funding for basic research to subsidizing the provision of native, non-honey-bee pollinator habitat or converting the scale of agriculture to strictly locally based provisioning. But if a policy to deal with the problem is to provide net benefits, an assessment of the economic consequences of CCD is in order. And to understand the ways in which bees and bee disease affect our well-being requires knowledge of the market institutions that coordinate beekeepers, farmers, and consumers, as well as an assessment of how those activities have been altered by recent changes in honey bee health.

COLONIES COLLAPSE

In October 2006, David Hackenberg, a Pennsylvania beekeeper, took 3,000 honey bee (*Apis mellifera*) colonies to Florida for the winter. In mid-November, when he checked on the hives he had left in Tampa, he discovered that 360 out of 400 were practically empty—there were no adult bees in the hives and no dead bees in or near the hives. On 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 reporting similar experiences. In February 2007, reports of this new bee affliction made national news and was christened Colony Collapse Disorder. 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 CCD—most focusing on the high winter mortality rates.

Possible causes of CCD are often discussed, and estimates of the value of pollination services are frequently 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]

Astute readers might 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.

Based on media reports, attentive readers who have tracked the issue might infer that managed U.S. honey bee populations are nearly gone. They might also believe that the nation 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.

HONEY BEES AND BEE DISEASES

Honey bees collect nectar and pollen from flowering plants.[3] In the process of moving from bloom to bloom, grains of pollen containing male gametes, or sperm, become attached to the bees' bodies and are transferred to the pistil, the female reproductive organ, of other flowers. This process enables reproduction of flowering plants. Worker bees are attracted to the blossoms by pollen and nectar, which is carried back to the hive. There, nectar is transformed into honey for later consumption (or extraction by beekeepers), and gathered pollen is stored for future use as a source of protein for the hive. A typical full-strength colony of honey bees consists of a single queen and 15,000 to 30,000 worker bees.

The queen lives for about two years and lays all the eggs in the hive. The worker bees are sterile half-sisters, with life spans of about six weeks. The colony also contains a few hundred males, or drones, whose sole function is to mate with fledgling queens from other colonies.

Honey bees have long suffered from a variety of diseases. One study documents about 20 episodes of major colony losses since the late 1860s (Underwood and vanEngelsdorp 2007). The most significant predecessors to CCD were two species of mite parasites that first appeared in North America in the mid-to-late 1980s. Varroa mites attach themselves to bees and feed on their blood.[4] Tracheal mites are endoparasites that attack bees' breathing tubes. Other diseases that currently affect honey bees include American foulbrood, a bacterial infection that attacks bee larvae and pupae and causes the death of immature bees; *nosema*, a fungus that invades the intestinal tracts of adult bees; and chalkbrood, a fungus that infests the guts of honey bee larvae causing them to starve. Over time, methods have been developed to combat each of these bee diseases and commercial beekeepers have managed to stay in business. That said, such methods are costly to commercial beekeepers, and bee diseases and parasites have devastated feral colonies.

BEES, BEEKEEPERS, AND 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). During most of beekeeping history, 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 Reverend Lorenzo Langstroth. Beekeeping, as practiced today, is based on the foundation of Langstroth's hive design, consisting of frames that can easily be removed without enraging the bees or destroying the hive. The Langstroth hive allows for expansion as healthy colony populations grow, and allows beekeepers to reuse wax combs.

> *In North America, crops that rely on the services of honey bees include almonds, pears, apples, cucumbers, blueberries, and vegetable seed crops.*

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

Supplemental pollination by European honey bees is an important input into the production of many crops. In North America, crops that rely on the services of honey bees include almonds, pears, apples, cucumbers, blueberries, and vegetable seed crops. Pollination services in 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 and travels at night with nets covering the hives (bees fly out of their hives only during the day).

Once a truck arrives at a field or orchard for pollination, forklifts 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 close to home. They will, however, fly up to three miles when pollen and nectar sources are more difficult to find (Seeley 1995, 46–50). In the case of tree fruits 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. The hybrid vigor that results from intervarietal pollen transfer promotes fruit quality and uniformity.

Bees are moved into an orchard or field for the flowering period, which lasts about three weeks for almonds and most tree crops but varies with the weather. A typical mobile beekeeper will pollinate several crops, collecting pollination fees from the growers of each. A majority of the commercial bees in the United States begin their pollination seasons in California almond orchards in February and March.[5] From there, beekeepers transport their bees back to their home bases to pollinate nearby blooming crops.

Migratory routes vary by region. 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 to pollinate local crops. Pacific Northwest (PNW) beekeepers, for example, whose home bases are west of the Cascade Mountains, pollinate tree fruits (apples, pears, and cherries), then soft fruits (strawberries, raspberries, and blueberries), followed by seed crops (onions and carrots), then cucumbers, pumpkins, squash, some legume seeds (e.g., clovers), and occasionally alfalfa seed.

After the blooming season in the north, the focus of beekeepers turns from pollinating to producing honey. Hives are placed in beeyards, often in the sunflower fields of North and South Dakota, for the rest of the spring and summer. There the bees pursue their nectar and pollen gathering, producing honey beyond what the bees themselves consume and providing beekeepers with a marketable surplus. When winter comes, the bees are moved one last time to winter quarters. For PNW bees, that could mean back to their home locations or, often, in yards next to the California almond groves to wait for the seasonal cycle to begin again.

Beekeepers follow analogous migratory routes along the Atlantic coast: from fruits and vegetables in Florida in early spring to blueberries in Maine in May and June. Routes vary by region, but their key features are the same: pollination in the early spring, honey production in the late spring and summer, concluding with winter rest.

BEE MORTALITY

The impact of CCD highlighted by the news media is high winter mortality. Over the four winters from 2006–2007 through 2009–2010, surveys estimate the annual average losses for the beekeepers who responded at 32 percent, 36 percent, 29 percent, and 34 percent.[6] Independent surveys of PNW 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 die every winter, whether CCD is present or not. Using a survey of PNW beekeepers, Burgett, Rucker, and Thurman (2009) estimate that normal annual winter mortality rates for commercial beekeepers were about 14 percent prior to the appearance of CCD.[7] Thus, colony replacement at some level is a standard part of beekeeping. Moreover, as we demonstrate below, beekeepers are adapting to increased mortality by increased replacement efforts.

Three methods are commonly employed by beekeepers to maintain and rebuild hive numbers. Understanding them is key to knowing how the beekeeping industry responds to disease. 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. The beekeeper moves 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." For a nuc to be viable, a fertilized queen is required. Newly mated queens for this purpose are typically purchased from specialized commercial queen breeders. Sometimes the nucs are not given newly mated queens, but instead are able to produce their own queens from the eggs and young larvae that

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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 on occasion beekeepers will purchase nucs from other beekeepers.

The original hive used for the split has a nearly uniform age distribution, from egg to mature foraging worker bee. Thus, the original hive can continually replace its cadre of pollinators and the hive will be strong enough to pollinate crops shortly after the split. The new hive, on the other hand, contains mostly adults and will not be strong enough to pollinate crops for about six weeks—the time it takes a newly produced brood to mature. In California, beekeepers typically do splits for the season in March, after almond pollination is complete. In Oregon and Washington, where winters last longer, beekeepers split hives in April. In addition, astute commercial beekeepers anticipate colony losses and regularly split hives later in the season to maintain colony numbers for next year's pollinating.[8]

The second method used to build or replenish hive numbers is to buy packaged bees. There are companies that 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 worker bees and a fertilized queen, is about $55. 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 in mid-April, it probably will not produce surplus honey until the following year.

The third method, used to maintain hive vigor (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 queen becomes less productive, a beekeeper will 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.[9] 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 and enhancement processes used by beekeepers? In a recent survey, PNW beekeepers reported that 80 percent of replacement colonies were obtained by splitting hives. 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. 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.

This discussion indicates that beekeepers are capable of quickly replenishing substantial numbers of hives lost to winter kill. Moreover, insofar as a beekeeper replaces colonies lost over the winter by splitting hives, he will have sufficient colonies available to replace winter losses up to 50 percent.

WHAT CAUSES CCD?

Colony Collapse Disorder is mysterious as it involves the disappearance of nearly all adult bees from a hive. While healthy bees do on occasion move from their homes en masse, most diseases leave sick, dying, and dead bees near the hive (Seeley 2010). The mass disappearance related to CCD has given rise to wide-ranging speculation about its causes, which has included cell phone signals (even space aliens!) as possible culprits.

Because answers to the CCD mystery are avidly being sought, any summary of the state of scientific knowledge will be quickly dated.

The state of the honey bee population—numbers, vitality, and economic output—are the products of not just the impact of disease but also the economic decisions made by beekeepers and farmers.

This being said, the 2011 consensus of the bee research community is that the CCD phenomenon is multifactorial and, as such, cannot be explained by a single causal agent. What has been discovered is the presence in the United States of several previously unrecognized pathogens, such as Israeli Acute Paralysis Virus 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 adopts the Asian honey bee *Apis cerana* as its natural host. *Nosema cerana* is now widespread throughout Europe and North America. The circumstances that brought about the spread of this parasite, which was previously believed to be confined to East and South Asia, are not known. More research is needed to understand how additional outbreaks of CCD can be prevented, what role is played by environmental factors like heat, cold, and drought, and what causes the bees to fly away from their colonies to die.[10]

ECONOMIC ASSESSMENT OF CCD

Given the concern about Colony Collapse Disorder and its real and significant impacts on honey bee health, how is the disorder affecting consumers, farmers, and beekeepers? What should be understood is that the state of the honey bee population—numbers, vitality, and economic output—are the products of not just the impact of disease but also the economic decisions made by beekeepers and farmers. In this section we review four indicators of such effects: honey bee numbers, honey production, the prices of inputs into beekeeping, and the price of pollination services paid by farmers.

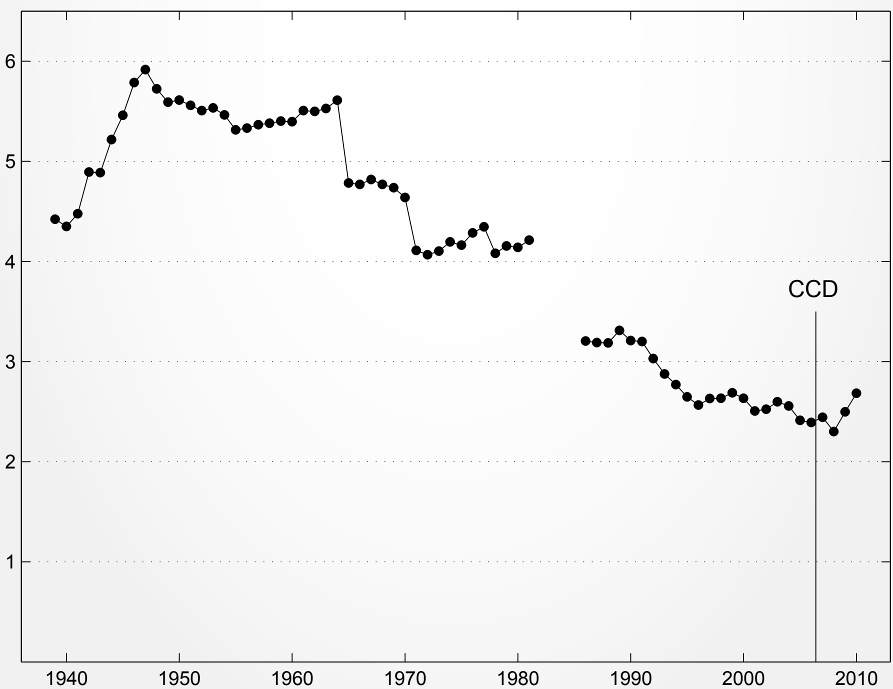
Honey bee colony numbers

The average annual rate of winter mortality over 2007–2011 was 33 percent.[11] A reasonable assessment derived from beekeeper surveys is that since the appearance of CCD, mortality rates have at least doubled.[12] 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 observed change in colony numbers.

Estimates of honey bee colony numbers can be obtained from annual surveys of beekeepers conducted by the USDA.[13] Data from these surveys are generally available back to 1939 and are plotted in Figure 1.[14] A prominent feature of the estimates of colony numbers in Figure 1 is their substantial decline since the mid-20th century. Particularly notable is the gap and abrupt drop in the early- to mid-1980s. The reason for the gap is that the USDA did not conduct its annual survey from 1982–1985. The abrupt drop is the result of a change in 1986 in the data collection procedures used by the USDA.[15] This fact suggests that any comparisons between the pre- and post-1985 periods should be made with caution.

What does the plot of colony numbers imply about the impacts of CCD? The vertical line in Figure 1 (and the following figures) that is drawn between 2006 and 2007 indicates when CCD might have had its first impacts. Colony numbers reveal no notable decrease in the years since the onset of CCD.[16] In fact, there were more colonies in 2009 than there were in 2006 (or any other year since 1999). 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? Perhaps it is because beekeepers have always lost hives during the winter. Sustainable and profitable commercial beekeeping requires them to replace dead and weak colonies using the methods described above. Since the onset of CCD, beekeepers have had to replace more hives to maintain their colony numbers, and the evidence suggests they have done exactly that.

Figure 1: U.S. Honey Bee Population: 1939–2010 in millions of colonies



Source: Rucker and Thurman (2011).

Honey production

Bee colonies are economic inputs into the production of honey and pollination services. Here, we examine data for one of the primary outputs of the beekeeping industry—honey—to look for evidence of the impact of CCD.

The above-mentioned USDA annual surveys of beekeepers report not only estimates of colony numbers, but also estimates of honey production. Each year, the survey asks beekeepers to report the total pounds of honey harvested from their colonies in all states. As with colony numbers, data from the surveys on honey production are available back to 1939 at both the national and individual state levels. The national data, plotted in Figure 2, indicate a sporadic upward trend in honey production until the mid-1960s, after which honey production has trended downward, albeit with substantial year-to-year variation.[17] As indicated above, the USDA did not conduct its survey from 1982–1985 (note the gap during this period in Figure 2), and then in 1986 changed its data collection procedures. Again, comparisons between the pre- and post-1985 periods should be made with caution. As was noted about colony numbers, visual inspection of the figure does not reveal a notable decrease in U.S. honey production in the years following 2006.[18] In fact, despite a clear preexisting downward trend in honey production in recent years, average production in 2007–2010 was 2.4 percent greater than honey production in 2006. Honey production in 2010 was 13.5 percent greater than in 2006.

Queen bee and package prices

Concluding that bee populations and honey production have not changed dramatically, if at all, due to CCD does not imply there have been no other adjustments to the phenomenon. In order for colony numbers and honey production to remain relatively stable in light of the increase in winter mortality of bees, beekeepers are making economic replacement decisions to rebuild colony strength, numbers, and economic output. One of the key ways in which beekeepers can

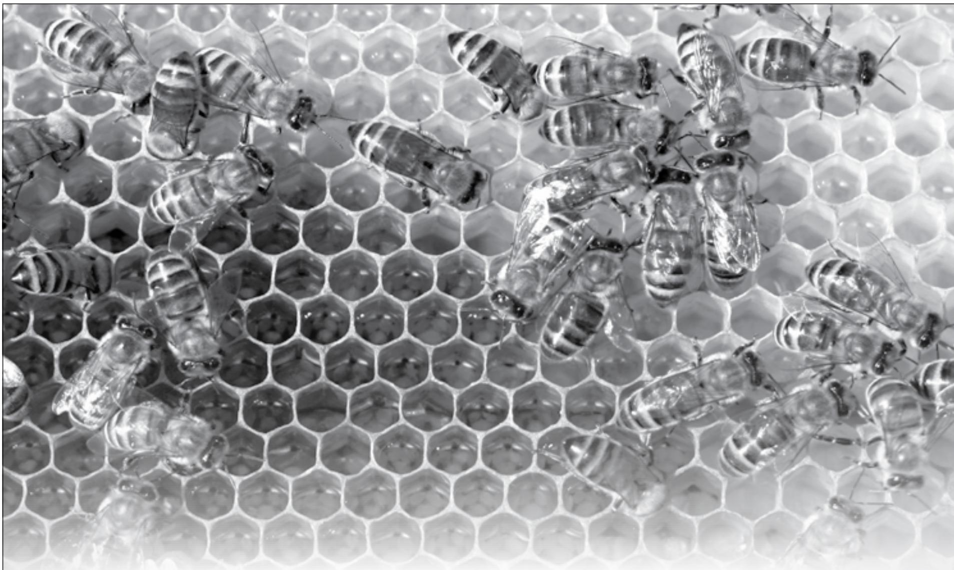
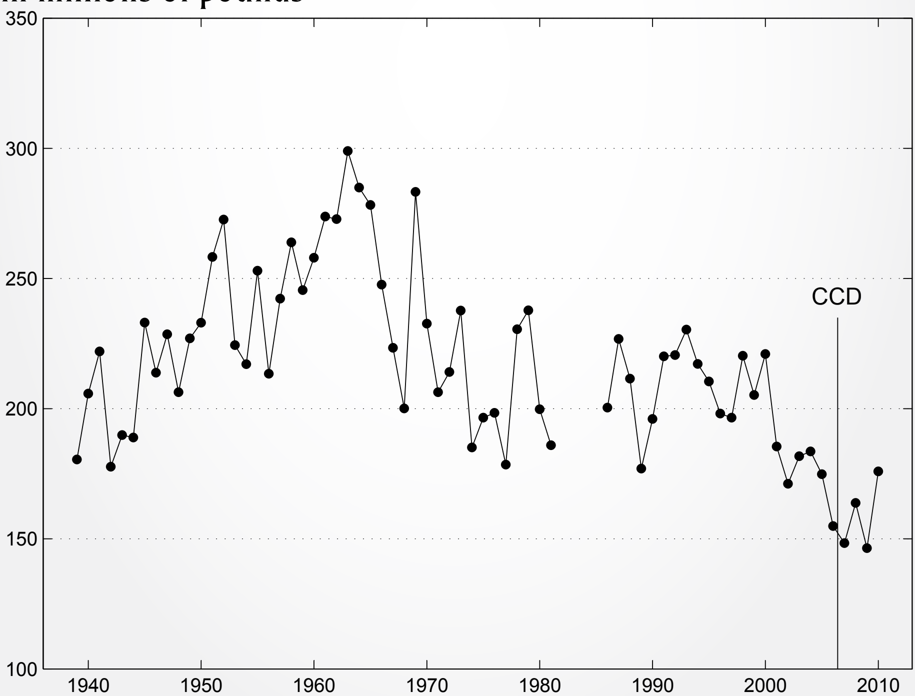


Figure 2: U.S. Honey Production: 1939–2010 in millions of pounds



Source: Rucker and Thurman (2011).

respond to colony death—either after the fact, or in anticipation of a higher incidence of such—is to build new hives based on purchased queens and packages of worker bees. A vital part of the beekeeping industry consists of beekeepers who specialize in the production of "breeding stock" (package worker bees and queen bees) to supply the beekeepers engaged in pollination and honey production.

In order for colony numbers and honey production to remain relatively stable in light of the increase in winter mortality of bees, beekeepers are making economic replacement decisions to rebuild colony strength, numbers, and economic output.

The economic logic of the likely impacts of CCD on package and queen prices is straightforward. Newly split colonies require new queens, which often are purchased from queen breeders. Alternatively, packages of worker bees (each containing a fertilized queen) can be used to start a colony from scratch. CCD has resulted in an increase in winter mortality of colonies. This also has resulted in an increase in the demand for queens and packages, which is expected to cause an increase in the prices of queens and packages insofar as the supply of queens and packages is less than perfectly elastic (i.e., unless increases in quantities supplied fail to increase price). Relevant to the supply elasticity question is the discussion in Laidlaw (1992), which suggests that queens can be reared in large numbers quickly: from egg to mated queen in less than a month. While the very shortest-run supply of queens is fixed, queen producers can expand production at what would seem to be near constant marginal costs with one month's lead time.

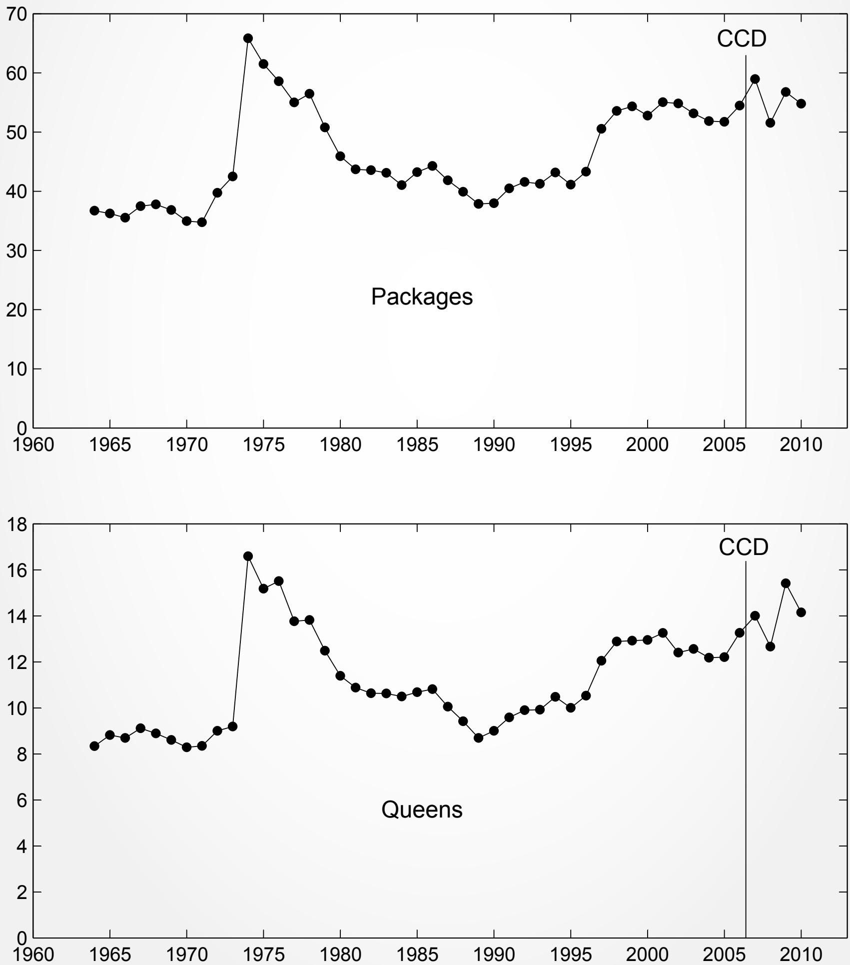
There appears to be no published analysis of the determinants of queen and packaged bee prices, and there are no available data series on either quantities or prices of queen and packaged bees. Therefore, we constructed a data series on prices for packaged and queen bees from advertisements in the monthly *American Bee Journal (ABJ)*, which has been published continuously since 1861. A detailed description of the procedure we use to collect these data is provided in Rucker, Thurman, and Burgett (2011). Briefly, we identified a number of sellers who advertised in the *ABJ* over an extended period of time and collected information on their advertised prices in each March issue since 1964. Because sellers offer quantity discounts for both queens and packages, we recorded prices for several quantities (1, 5, 25, 50, and 100) annually for each seller.

Figure 3 displays the annual average of the real (deflated) prices per queen charged by the nine sellers (for quantities of 50) for whom we collected information from the *ABJ* advertisements.[19] The first observation to make regarding these prices is that they were extremely high during the early 1970s, a period of high prices for many agricultural commodities. Second, real queen prices have roughly doubled since the mid-1960s, which suggests an average annual rate of increase of less than 2 percent. Third, the focus of our interest in the queen prices is whether they increased dramatically after the onset of CCD. As can be seen, the prices are quite variable in the years following 2006, but they have not dramatically increased.[20]

Figure 3 also displays the annual average (for the sellers in our *ABJ* sample) for real package prices between 1964 and 2010. Other than the level of the prices (package prices are roughly four times as high as queen prices), this series looks very much like the queen price data—high prices in the 1970s, package prices roughly doubling since 1964, and no dramatic increase in package prices following the onset of CCD.

What conclusions can be drawn from the preceding discussion? It seems clear that CCD has increased mortality rates and that beekeepers have had to replace more lost colonies to stay in business. As a result, the demand for package and queen bees has increased. The fact that the prices of these inputs have not increased dramatically is consistent with the supply of package and queen bees being quite

Figure 3: Package and Queen Bee Prices: 1964–2010 in real (2010) dollars



Source: Rucker and Thurman (2011).

elastic; sellers of these inputs have adapted by increasing quantities available without dramatic increases in marginal costs. The data suggest that this is true, even in the short run.

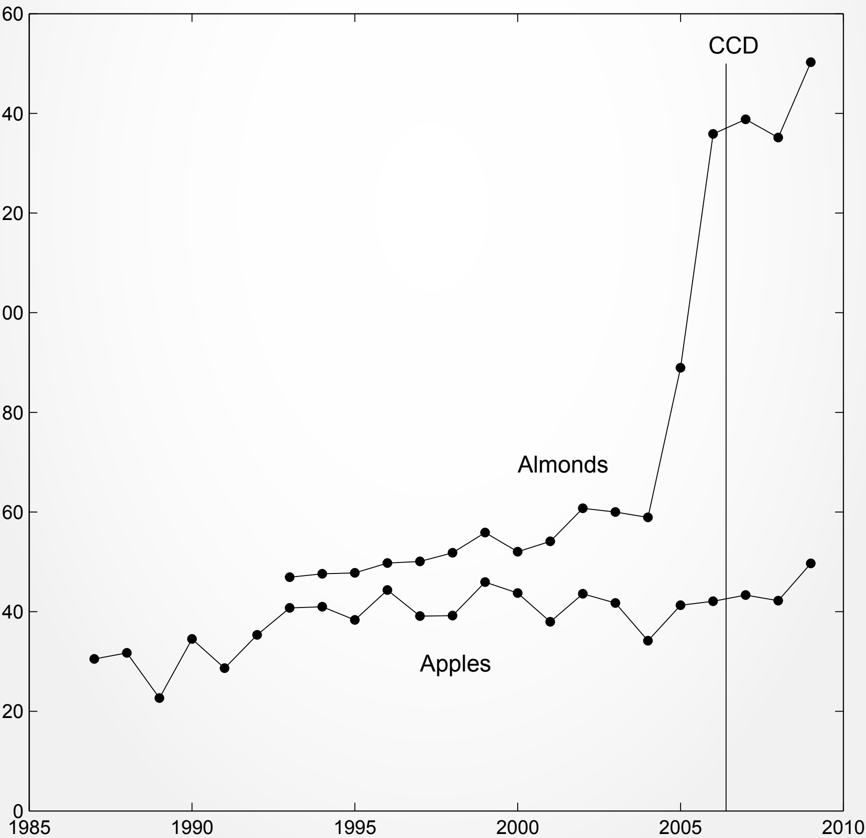
Pollination fees

Beekeepers supply the services of bees for two commercial purposes: to provide pollination for farmers and to produce honey. Bee disease that increases the costs of beekeeping should increase the price of the industry's outputs. Honey is traded internationally; and domestic honey price effects seem less likely than do price effects on pollination services. To look for evidence of increased pollination fees due to Colony Collapse Disorder, consider data from a survey administered by Michael Burgett of Oregon State University. Every year since 1987, he has surveyed Oregon and Washington (PNW) beekeepers, asking them what fees they received and for which crops. In recent years, his survey has yielded responses from beekeepers responsible for about two-thirds of bees used for commercial pollination from the region.

A broad sense of the PNW fees can be gained from Figure 4, which displays the annual average fee received for pollinating almonds and also for pollinating apples. 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 4 is that almond fees increased dramatically after 2004—behavior not seen for other surveyed crops, apples being representative of them. Almond fees rose from $59 to $89 between 2004 and 2005, and increased again to nearly $140 in inflation-adjusted terms for the years 2006, 2007, 2008, and 2009. It is tempting to attribute these fees to Colony Collapse Disorder—and CCD may be partly to blame—but 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 4 shows, almond

Figure 4: Selected Pollination Fees: 1987–2009
in real dollars per colony



Source: Rucker and Thurman (2011).

fees rose earlier: in 2005 and 2006. Similar conclusions can be drawn from surveys of California beekeepers conducted by the California State Beekeepers' Association since 1996 (see Rucker, Thurman, and Burgett 2011 for a statistical analysis of these data sources). They estimate there to be no CCD effect on non-almond pollination fees and $20 of the recent increase in almond fees.

Evaluating the Costs of CCD

Recent almond fees are near $140, so that the implied almond fee had CCD not arisen is $140 - $20 = $120. The implied percentage increase in almond fees due to CCD is then $(20/120) \times 100 = 16.7$ percent. Further, with a pollination fee for almonds of $120 per colony and a stocking density of two colonies per acre, the cost per acre of pollinating almonds is 2 × $120 = $240. Suppose, as recent industry data suggest, that 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.[21]

Next, suppose that Smokehouse® Almonds sell for $7 per pound at the retail level and that one pound requires 1.429 pounds of raw almonds (the rate of conversion from at-the-farm and in-the-shell almonds to retail shelled almonds). Then the cost share of farm almonds in the production of Smokehouse® Almonds is (1.429 × $2)/$7 = 0.41.[22] 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 a proportion of $0.167 \times 0.025 = 0.004$. Four-tenths of one percent of the $7/lb cost of Smokehouse® Almonds is 2.8¢, the implied increase in the shelf price of the can of almonds. Similar calculations could be made for other almond-containing products or products made from other pollinated crops. Given the relatively high cost share of pollination at the farm level, the calculation provides something of an upper bound on what one would find for other commodities and products. Against the backdrop of other sources of food price variation, it is no wonder that evidence of CCD at the grocery store has failed to materialize.

Costs to Beekeepers

Concluding that CCD has had little effect on consumers does not imply that its effects are of no concern to beekeepers. Consider first how CCD affects beekeeper costs. Responses to questions in the PNW survey about replacement methods indicate that beekeepers used the method of splitting hives 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.[23]

Burgett, Rucker, and Thurman (2009) estimate that PNW winter mortality rates increased from about 14 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 16 percentage point 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

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the survey are representative of the non-responding PNW beekeepers, the demise of about 14,400 (= 90,000 x 0.16) colonies in the PNW was due to CCD. 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 16 percent of their bees to CCD on average, the estimated CCD cost per beekeeper was 0.16 × 2,484 × $19 = $7,551.

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 section, we take the almond fee increase due to CCD to be $20, then the average PNW beekeeper with 2,484 colonies, who uses 72 percent 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 beekeepers benefit.

CONCLUSION

Colony Collapse Disorder has been portrayed as an environmental disaster that is decimating honey bee populations in the United States and elsewhere. While the difficulties faced by commercial beekeepers are considerable, our analysis of colony numbers, input (queen and packaged bee) prices, honey production, and pollination fees provides only slim evidence of a small economic impact.

The overblown response to CCD in the media stems from a failure to appreciate the resilience of markets in accommodating shocks of various sorts. Even capable and eminent economists can overlook the workings of markets and contracts. In their recent best seller, *Super Freakonomics*, Steven Levitt and Stephen Dubner (2009) discuss the concept of externalities, which is often described as a consequence of an economic activity that is experienced by unrelated third parties. As an example of inefficiencies due to positive externalities, the authors cite beekeepers and orchard owners:

> Fruit farmers and beekeepers create positive externalities for each other: the trees provide free pollen for the bees and the bees pollinate the fruit trees, also at no charge. That's why beekeepers and fruit farmers often set up shop next to each other. (p. 175)

The problem with this statement is that beekeepers and farmers do not set up shop next to one another and blithely produce unpaid benefits. They contract with one another. As in other markets, the two parties appear to take account of the effects that they have on each other and settle the difference through pollination fees and other contract terms.[24] The bees and orchard example used by Levitt and Dubner—and earlier authors such as Meade and Bator—may have been appropriate and accurate at some time in the distant past, but contracting for pollination services in North America likely began around 1910.[25] The positive externality does not describe the real world institutions that have developed to coordinate beekeepers and farmers.

The connection between an inapt characterization of markets for bee services and inaccurate claims about the effects of bee disease is that externalities reflect market failures. The use of apple orchards and beekeepers as an example of a (two-way) positive externality leads logically to the inference that markets for pollination services have failed. One would expect the impacts of CCD to be exacerbated in poorly functioning markets where prices do not reflect costs.

Our examination of the operation of pollination markets leads us to conclude that beekeepers are savvy entrepreneurs who use their wealth of knowledge of the particular circumstances of time and place (see Hayek 1945)—acquired over their lifetimes of work—

> *Beekeepers are savvy entrepreneurs who use their wealth of knowledge of the particular circumstances of time and place to adapt quickly to changing market conditions.*

to adapt quickly to changing market conditions. Not only was there not a failure of bee-related markets, but they adapted quickly and effectively to the changes induced by the appearance of Colony Collapse Disorder.

In contrast to the doomsday scenarios used to describe CCD at its outset, the workings of the forces of competition to accommodate bee disease make less compelling headlines. The receding of CCD from the national consciousness will be noted by few, but the resilience and adaptation to bee disease by the beekeeping industry is a story worth noting—and savoring—along with one's breakfast of honey on toast with pollinated fruit.

NOTES

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 a study by Morse and Calderone (2000), which represents an update of an earlier estimate of $9 billion from Robinson, Nowogrodzki, and Morse (1989). A recent study pegged the worldwide value of pollination at $217 billion (*Science Daily* 2008). These estimates are grossly overstated. 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 $15 to $75 billion is unclear.
3. Honey bees are but one of thousands of different animal species that pollinate about 90 percent of flowering plants. The remaining plant species reproduce through abiotic pollination, most of which is accomplished by wind, with the remainder pollinated by water.

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 Rucker, Thurman, and Burgett (2010) for a discussion of the importance of almond pollination in today's U.S. pollination markets.
6. See vanEngelsdorp et al. (2007, 2008, 2009, and 2011) for discussions of the surveys conducted by the Apiary Inspectors of America in cooperation with the U.S. Department of Agriculture.
7. Pernal (2008) and vanEnglesdorp et al. (2007) report comparable "normal" losses.
8. It is noteworthy that the three recent annual mortality surveys of PNW beekeepers reveal that commercial beekeepers have replaced more bees than they have lost. Commercial beekeepers who responded to the survey reported that 20.7 percent more colonies were started than were lost in 2008 (Burgett, Rucker, and Thurman 2009), 26.5 percent more colonies were started than lost in 2009 and 6 percent more colonies were started than were lost in 2010 (Caron et al. 2010).
9. For experienced beekeepers, the acceptance rate of new queens is between 80 and 95 percent.
10. See Johnson (2010). A news release written by A. Sparrow, 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. Three years after CCD was first discovered, 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.
11. This number represents the simple average of the four years of mortality rates estimated by vanEnglesdorp et al. (2007, 2008,

2009, and 2011).

12. Burgett, Rucker, and Thurman (2009), Pernal (2008), and vanEngelsdorp et al. (2007) all report pre-CCD or normal mortality rates as being about 15 percent.
13. Funding for conducting these surveys was recently eliminated.
14. See Rucker, Thurman, and Burgett (2011) for a discussion of possible biases in these data and their potential implications.
15. Estimates prior to 1982 included colony counts from all beekeepers; estimates after 1985 included colony counts only from beekeepers that maintained at least five colonies. Muth et al. (2003, 497–8) estimate the one-time reduction in colony numbers from this change in the USDA's survey methodology to be 863,000 colonies with a standard error of 195,000 colonies.
16. Rucker, Thurman, and Burgett (2011) provide a statistical analysis of the colony numbers displayed in Figure 1 and find no significant decrease following the onset of CCD.
17. One noteworthy change in U.S. honey markets is the growing importance of imported honey. In recent years, the quantity of honey imported has substantially exceeded the production of domestic honey. See Daberkow at al. (2009) for a discussion of past and recent conditions in U.S. honey markets.
18. Rucker, Thurman, and Burgett (2011) provide a statistical analysis of the honey production data displayed in Figure 2 and find no significant decrease following the onset of CCD.
19. 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.
20. Rucker, Thurman, and Burgett (2011) provide a statistical analysis of the prices displayed in Figure 3 and find no significant increase following the onset of CCD. The same is true for package prices (see below).
21. 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.

22. As with the previous calculation, this calculation is based on the assumption of zero profits in the production of Smokehouse® Almonds.
23. Another possible cost of splits might be forgone 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. A similar calculation suggests that replacing lost colonies by purchasing packaged bees would cost about $52 per colony. This higher cost estimate is consistent with the survey responses indicating that fewer than 3 percent of colony replacements were accomplished with packaged bees.
24. Such notable economists as J.E. Meade (1952) and Francis Bator (1958) also employed the bees and orchard example. In 1973, however, Steven Cheung published a study of Washington beekeepers that demonstrated that contracting between beekeepers and orchard owners was sufficiently common that ads could be found in the yellow pages of many rural Washington communities. More recently, a small number of other studies have documented and analyzed the intricacies of pollination markets and the activities of migrating commercial beekeepers who often transport their colonies thousands of miles annually. See Muth et al. (2003) and Rucker, Thurman, and Burgett (2010).
25. See Rucker and Thurman (2010) for a discussion of the origins and development of contracting and markets for pollination services.

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