Combing the Landscape:

An Economic History of Migratory Beekeeping in the United States

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I. Introduction

The European honey bee, *Apis mellifera*, does not seasonally migrate. But human beekeepers in many locations do. Migratory business models have developed such that commercial beekeepers and honey bees form a symbiotic pair–bees in hives, and humans in trucks, following the blooms of pollen- and nectar-producing plants across America.[1] Neither would follow the seasonal and geographic pattern of blooming plants without the other, but together they reliably do. The *Apis* species, in partnership with its human symbiotes, travels in the spring from flowering crop to flowering crop (almonds, vegetable seeds, and many fruits and vegetable), amplifying the pollination power applied to these crops. After the spring peak bloom season, humans and bees migrate to areas rich in blooming plants for nectar forage, and the economic production function shifts from pollination to honey production. The modern situation has been well described in the popular press (see Nordhaus, 2011) and economics literature (see Rucker, Thurman, and Burgett, 2012 and 2019).

In the modern day, well-developed markets for pollination services coordinate beekeepers and their bees with crop growers who demand their services in the spring. Prices in these markets embody the costs of beekeeping and the relative value across crops of the fruit and honey produced from pollination (see Rucker, Thurman, and Burgett, 2012), and broadcast these signals to suppliers and demanders. We argue in this paper that without the development of the migratory business of beekeeping there would be little or no contracting for pollination services and nothing that one would be inclined to call a market. Further, the late-19th and early-20th century history of beekeeping shows that the impetus for migratory beekeeping was the search for nectar and the economic return to producing honey. In this way, migratory beekeeping led to the introduction and subsequent widespread deployment of a non-native insect to the agricultural landscape, a transformation in North American beekeeping, and a transformation in the production of many economically important crops.[2]

Many of the economic forces that drove development of pollination markets are common to the broad economic history of North America in the 20th century – mechanization and the internal combustion engine importantly among them. But the effects of technological change on beekeeping were different from those on agriculture in general. They arose from a particular mix of industrial, biological, and economic innovation, and the development of basic knowledge in horticulture and entomology. The ultimate effects involved dramatic increases in the

[1] Less well documented, but similarly large-scale, beekeeper/bee migrations occur in China and India. See Yang (2016) and Dharni and Thurman (2018).

[2] The primary focus of this paper is the history of beekeeping as it relates to the agricultural economy: the production of crops and honey. There also have been ecological effects from the penetration of the European honey bee into niches previously occupied by native pollinators. See, for example, Thorp and others on competition between honey bees and native bumblebees.

employment of land, which mechanization did not induce in other areas of agriculture.

II. Migratory Beekeeping in the 21st Century and the Demand for Space

Migratory beekeeping in the United States is an evolved and complex system. The migration occurs largely by truck. A typical large-scale operation uses tractor-trailer combinations that each carries 400 or more hives of honey bees, each hive containing a single colony with a queen and between 15,000 and 30,000 workers. Once the truck arrives at a field or orchard for pollination, hives are moved to strategic points to spread bees throughout the flowering area. Bees typically stay close to home when placed in a pollen and nectar-rich flowering field. They will, however, fly considerable distances when pollen and nectar sources are more difficult to find.[3]

As bees forage across flowers, they pick up pollen (which contains the male gamete, or sperm) on their bodies and transfer it to the pistils (the female reproductive organs) of other flowers. In the case of nuts and tree fruit, 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.[4] 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: roughly three weeks for almonds and most tree crops, but variable with the weather—higher temperatures condense the bloom period and lower temperatures extend it. The placement period for some crops is longer—cranberries can require four to five weeks. After pollination of a particular orchard, field, or bog, the colonies are moved by forklift, then truck, to the next pollinating site, usually a later blooming crop or possibly the same crop farther north or at a higher altitude.

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[3] 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 ." Roughly consistent with these results, in the state of Montana, beekeepers "own" apiary circles with radii of three miles (4.82 km). The purpose of these circles is to define a beekeeper's property rights in an area where his bees can forage for the purpose of honey production with limited infringement from other beekeepers' bees.

[4] 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.

Spring pollination

Pollination markets today consist of contracts between farmers and migratory beekeepers.[5] There are several large-scale migration routes traveled by these beekeepers and their bees, including the route traveled by Washington and Oregon beekeepers who we study elsewhere (see Burgett, Daberkow, Rucker, and Thurman, 2010). Their pollination season begins each year in February in the almond groves of California.[6] It is estimated that fully 2/3 of the three million honey bee colonies in the United States are brought to pollinate almonds. Most are brought from out of state.

Following almond pollination, California-based bee colonies are often put into nearby citrus orchards. Although there are no pollination benefits to citrus and no fees received by beekeepers, the nectar is plentiful and valuable honey is produced. Information from a California State Beekeepers Association survey suggests that following almond pollination, on average between one-half and two-thirds of colonies are use to pollinate one more crop.[7]

Beekeepers based in the Pacific Northwest, on the other hand, next typically move their colonies north on flatbed trailers back to their home bases in Oregon and Washington. From there, they initially distribute their colonies among local apple, pear, and cherry orchards. Following that, the majority of the West-side beekeepers (those whose home bases are West of the Cascade Mountain range) rent their colonies out to pollinate additional crops—typically soft fruits (strawberries, raspberries, and blueberries) in May and June, followed by seed crops (especially such vegetables as onions and carrots), then cucumbers, pumpkins, squash and some legume seeds (e.g., clovers) and occasionally alfalfa seed.[8] The timing of colony placement varies across crops, as do the pollination fees collected by beekeepers.

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[5] Responses to the PNW surveys indicate that Oregon and Washington beekeepers often use written contracts when dealing with growers for the first time. Such contracts may include the pollination fee, delivery/removal time, number, strength, placement and management and operation of colonies, provisions to protect hives from pesticides, discussion of liability issues, a payment schedule, and so forth (McGregor, 1976, pp 59-63). With the recent dramatic increases in California almond pollination fees, industry observers report an increased focus on specifying (and checking) the number of healthy frames in colonies used for almond pollination. (See Goodrich, 2017.) For long-time clients, the contractual agreement is often a handshake.

[6] In recent years 100 percent of the PNW commercial beekeepers who responded to the Oregon State survey pollinated almonds in California. Even in the early to mid-1990s, at least 80 percent of responding PNW beekeepers took their bees to California to pollinate almonds. See table 5 (p. 39) in Burgett et al. (2010).

[7] See table 1 in Burgett et al. (2010).

[8] It is noteworthy that most alfalfa seed in the Pacific Northwest is pollinated by two species of "managed wild bees," the alfalfa leafcutting bee and the alkali bee. Further, survey data from the PNW survey suggest that PNW beekeepers engage in substantially more pollination activities than the California counterparts. On average, PNW respondents reported that each colony pollinates almost 1.5 additional crops after almonds. This number masks to some degree the extent of beekeeper activities. For example, on average, individual beekeepers reported pollinating 5.5 different crops in 6.8 counties each year. See table 1 in Burgett et al. (2010).

The fees paid by farmers to beekeepers vary across crops and over time. See figure 1, from Rucker, Thurman, and Burgett (2012), for a display of average fees received by Pacific Northwest beekeepers for pollination services from California to Washington. Variation in this price of pollination services is due to several factors that affect the costs and returns to pollinating. Early-spring-blooming crops (notably, almonds) require early rejuvenation of over-wintered bee colonies and require feeding of bees until later season forage crops bloom. Crops that yield the beekeeper a surplus of honey during the bloom pay part of their pollination fee in kind, in the form of honey, and competition among beekeepers reduces the pecuniary pollination fee to reflect this benefit. Costs of transportation (diesel fuel) and costs of bee pest management also influence pollination fees. (Rucker, Thurman, and Burgett, 2012.)

Later-season migration to forage sites

The East side of the Cascades is much richer in honey sources than the West side. As a result, beekeepers whose home bases are on the East-side of the Cascades typically pollinate California almonds and then tree fruits in eastern Washington and Oregon. After that, they spend the rest of the season using their bee colonies to produce honey.[9] Many of the colonies remain in eastern Oregon and Washington, with a minority of them making summer honey runs to Montana and other Northern Plains states. There, they join large numbers of other U.S. beekeepers, who also find summer range for their colonies in this region. For the rest of the summer, the hives remain at these sites, and the bees visit sunflowers, clover, basswood trees, and other nectar sources, producing honey for consumption by the hive and extraction for sale by the beekeeper.

Notably, the bees that are stocked so densely to pollinate almonds occupy a much broader range after the pollination season is over. An informed, but coarse, calculation gives an idea of the magnitude of the seasonal shift in stocking densities and the implication for summer demand for bee forage. Research by Smart *et al.* (2018) suggests that each colony of honey bees requires 79 acres of uncultivated forage in order for 80 percent of the colonies to survive into the next spring. (Survival of 80 percent would be considered an acceptable commercial standard.) Each of the two million hives occupying ½ an acre in February and March requires 79 acres of uncultivated forage later in the year – 158-fold decrease in stocking density, which facilitates the shift from pollination service provision to honey production and colony maintenance.

The implications for land use are dramatic: (2 million colonies in almonds) x (79 acres/colony) = 158 million acres of summer forage required.[10] The lower 48 states comprise about 2 billion acres, implying that the bees that pollinate almonds in the spring require forage area equal to 8

[9] West-side beekeepers produce honey, but the quantity is small relative to East-side production. The primary source of West-side production is blackberries.

[10] According to Smart (personal communication), 28 percent of the acreage needs to be uncultivated to achieve colonies with 80% survival, implying a "demand" for uncultivated land of 0.28 x 158 million acres = 44 million acres.

percent of the lower 48, or an area greater than the states of Montana and Minnesota combined. Figure 2 shows, as an example, the spatial distribution of apiaries in Montana in 2008.

Over wintering

In the fall, many U.S. beekeepers move their bees again, this time to winter in the South or in southern California. Some Washington and Oregon beekeepers move their bees to California in December and find locations to hold their bees until the next year's almond bloom.

Similar migratory routes move up the Atlantic coast, from fruit and vegetable crops in Florida to blueberry bushes in Maine.

III. Beekeeping Evolves in Response to Exogenous Shocks

Beekeeping in the western United States can be dated to the 1850s, before completion of the transcontinental railroad in 1869. The first bees in California were brought to San Francisco from New York via ship to Panama, across the isthmus by train and wagon, and then by ship again to San Francisco. (See Watkins on J.S. Harbison.) The later development of widespread migratory beekeeping is a story of technical innovation in beekeeping that occurred around the turn of the 20th century.[11] The story involves the rapidly improving transportation technologies – namely the internal combustion engine and the and truck[12] – and the less rapidly expanding transportation network infrastructure of the time. Practical management of bee colonies also progressed by leaps and bounds in the early 20th century.

An important feature of the evolutionary story here – one that sets it apart from other agricultural histories – is the unique dual product nature of beekeeping, based on the biology of the bee. Honey bees in the course of foraging for their colonies, visit flowers to collect both nectar and pollen. Nectar is carried back to the hive in the stomachs of worker bees, which is then disgorged inside the hive and turned into honey – a remarkably storable form of energy to sustain the hive. Pollen is also collected from flowers, on the hairs of the legs of worker bees. Pollen is carried back to the hive where it is fed to bee brood – bee larvae – and is a critical input into their healthy development.

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[11] Any story has its antecedents, and certainly the development of migratory beekeeping around 1900 in North America stood on the shoulders of previous accumulations of human knowledge of the honey bee, going back to the stone age. See Crane (1999). But the rate of market innovation was exceptionally rapid in commercial beekeeping in the first part of the 20th century. That period is referred to by many as the "golden age of beekeeping." Borst (2013) says the golden age of beekeeping occurred New York in the mid-to-late 19th century.

[12] Developments in beekeeping occurred at roughly the same time that the tractor began to revolutionize the cultivation of crops. See Olmstead and Rhode (2001). The management of outapiaries and development of migratory beekeeping did not much utilize tractors, but rather trucks.

As a specific instance of the evolutionary deal struck between pollinators and flowering plants, the reward to bees of nectar and pollen is repaid by seeming inadvertent transfer of pollen from stamen to pistil, within a flower, between flowers in a plant, and between flowers in different plants.

A different relationship has evolved between managed honey bees and humans. Human interest in the honey bee has long been based on the opportunity to extract honey from bee hives for human consumption. For this purpose, bee collection and transfer of pollen has been of little human commercial interest. But by the late 19th century the crop yield benefits from honey bee pollination were recognized for some crops, and the list of recognized crops grew through the middle of the 20th century. As apples, pears, vegetable seeds, alfalfa seed, and almonds became economically important demanders of pollination, the nature of beekeeping production became distinctly dual: pollination in the early spring blooming period, with honey produced spring and summer long. (Most recently, beekeeping has also exploited the bees' production of propolis – a waxy substance – and pollen, and even bee venom. These last developments make appropriate the labeling of the economic beekeeping production function as multi-product, not just dual product.)

Now, pollination demand is spatially concentrated in the regions that grow these crops and forage the rest of the year has taken on new importance to support the population of pollination service providers.

The development of migratory beekeeping has both exogenous and endogenous components. Exogenous included the development of the internal combustion engine and cars and trucks and roads. Notably, the transportation innovations that made possible migratory beekeeping and subsequent pollination markets stimulated not pollination markets at first, but rather the systematic combing of the American landscape for nectar sources. The production function of late-19th and early-20th century beekeeping was skewed almost entirely toward the production of honey. In fact, it was the technical understanding of the biology of the bee hive in regard to honey production that was so well developed by the early 20th century. Understanding the biology and commercial manipulability of pollination came later.[13]

Other exogenous forces include the waves of land use changes that have swept across U.S. agriculture, some market driven (e.g., crop choice and the extent of monocropping), others by government land and agricultural policies (e.g., the Conservation Reserve Program and its New Deal antecedent, the Soil Bank).

The technical innovations that spurred development of pollination markets happened crop by

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[13] See Olmstead and Wooten (1987) for a fascinating account of the application of honey bees to the pollination of the alfalfa seed crop in the 1940s. Since then, *Apis mellifera* has been superceded by alfalfa leafcutters – more specialization and exchange. See Appendix C.

crop and were based on horticultural scientific advance more than apiculture.

IV. The Roles of Transportation and Beekeeping Technology

The mechanization of agriculture is well appreciated by economic historians. For example, Olmstead and Rhode (2001) study the economic history of the tractor in American agriculture between 1910 and 1960. A coarse synopsis of their research is that the tractor, invented in the first decade of the 20th century, gradually and steadily replaced the horse over 50 years. At the end of the period, tractor use was nearly universal on American farms, farmed acreage was the same as it was at the beginning, and power per acre had increased 4.5-fold. The interesting economics of the transition had much to do with the asset replaced by the tractor – the horse (and mule), "a durable capital good with an inelastic short-run supply and a price that could adjust to keep the animal mode competitive." (Olmstead and Rhode, p. 682.)

While the development of migratory beekeeping and pollination has much to do with mechanization and the production transformation induced by invention of the internal combustion engine, the history we tell differs in important aspects.

IV.A. Beekeeping as technology

Specifically, the tractor replaced a different power source, the horse, for largely the same farm activities: preparing the soil, planting, cultivating, and harvesting. Further, as it turned out, the tractor did not expand the extensive margin of American farming as acreage was stable. The car and truck had a different effect on beekeeping. It allowed a sedentary, but fairly widespread, enterprise to become mobile and penetrate broadly the North American landscape. [see bee location maps for Montana and other states.] Bees themselves can forage within a two-to-three-mile radius of the hive. But a mobile beekeeping industry could forage hundreds and thousands of miles away from a beekeeper's home base to exploit nectar and pollen sources far away and available only temporarily.

The tractor led to more intensive production through greater application of power and related complementary inputs. Tractors displaced the horse and also, over time, substituted for human labor. Migratory pollination, on the other hand, uncovered profit opportunities on the extensive agricultural margin: locations with honey-producing potential and crop-producing potential that employed bees. There was no input like the horse that was replaced by migratory beekeeping. The important production relationship was the complementary relationship between bees and land. (See the theory section below for an elaboration.) Further, the diffusion of bees across the landscape was rapid as there was no inelastically supplied input–like the horse–whose price could adjust to delay and pace the adoption of the new migratory opportunity.

IV.B. Transportation and access in farming and beekeeping

Christopher Wells, in his 2012 environmental history of the automobile in the United States, poses the car as bringing about “a more uniform experience of space.” It could be argued that effective exploitation of bee forage requires uniform access to space, at least more uniform and different from the kind of access required by inter-city transportation; or even that required by farms.

Non-subsistence farming requires access to markets and the outside world. Thus, if there are farms, there is access, at least point-to-point routes to location to buy and sell. Beekeepers also need to buy and sell. But transportation is more deeply imbedded in the production function of modern migratory beekeeping that it is in farming. And so, while it might seem that migratory pollination and contracting should have followed the same historical path as farming, it didn’t.

Migratory beekeeping was driven by the search for forage, which was not (much) facilitated by the early network of roads that arose to connect farms to input and output markets.

IV.C. Contracting challenges

The migration of bees lead to new contracting challenges and to two new potential markets: markets for pollination services, rented from landowner farmers from beekeepers, and markets for forage land, rented from landowners by beekeepers. Notable contributions to economic theory (see Meade and Bator) assumed that such markets couldn’t, or at least didn’t, exist. Steven Cheung showed they were needlessly pessimistic about pollination service markets – at least in the Pacific Northwest of the United States. Rucker, Thurman, and Burgett (2012), writing 50 years after Cheung, study a more modern version of markets for pollination services in the western United States and find the efficiency properties that one would hope to find in markets, while acknowledging the transactions costs and contracting challenges that such markets face.

The extent and nature of the complementary markets for forage have not been studied systematically. In section VI below we discuss the theoretical foundation of forage markets and begin an empirical study of them.

IV.D. How trucks changed beekeeping

<u>Outapiaries (beekeeping with and without trucks)</u>

Useful descriptions of the business of beekeeping before the invention of the automobile and truck can be found in trade publications from the late 19^{th} century. A.I. Root, in an 1889 issue of the bi-weekly *Gleanings in Bee Culture*, describes the management techniques employed in his own apiary. The logistical complications of managing outapiaries in that time are revealed in the details of his techniques, which include contracting with owners of horse teams and paying them, at least in part, in kind.

> "As our readers know, every summer I manage one out-apiary myself [presumably in Medina, Ohio], and do nearly all the going and coming on a bicycle. ... [O]ne can hire a team [of horses] for one out-apiary or two, and possibly three or four. All hive stuff should be delivered early in the season, and then during the greater part of the rest of the year one can come and go on his bicycle... After the [honey] crop is secured, then of course he will be obliged to hire a team or teams to carry it to town. As a general thing a farmer will do the work for a little honey.

One probably should not infer from Root's enthusiasm how widespread the use of bicycles in beekeeping was in 1889. Root was in fact a bicycle enthusiast at a time when that enthusiasm abounded. His *Gleanings in Bee Culture* carried submitted stories from correspondents who reported their long-distance bicycle tours using single-geared bikes without brakes.

M.G. Dadant, editor of the *American Bee Journal* in 1919, wrote on the extension of beekeeping from a single apiary to multiple job sites where bees were kept and tended – outapiaries. In an article titled "Success with Outapiaries" he wrote in 1919:

> "No doubt the automobile and truck are responsible for most of the improvements in the methods of running outapiaries over what prevailed 20 years ago." (Dadant, 1919.)[14]

Dadant was writing little more than 10 years after the introduction of the Model T by Henry Ford in 1908. In the same article he identified the trend toward specialization that characterized commercial beekeeping at the time:

> "Where one beekeeper 20 years ago was an outapiarist, probably more than fifty are today. We are apt to lay this to improved methods of beekeeping and to the initiative of the modern beekeeper, who keeps bees for a living, rather than as a side issue."

Dadant goes on to recount how transportation costs before the turn of the century limited the movement of bees.

<u>On farmers as part-time beekeepers and specialized beekeeping</u>

Presumably, Dadant refers to the situation at the turn of the 20th century where beekeeping was a sideline by agriculturalists who ran a more diversified operation. The benefits of pollination at

[14] As Dadant alludes, the management of outapiaries did not begin with the automobile and truck. Borst (2013) points out that "W.L. Coggshall established his first out apiary in 1878 [in New York state], at a time when most of the beekeepers kept their hives at home. In each there would be a shed 12 x 16 feet which was large enough to hold the equipment needed for 80 to 100 colonies." (p. 1299). An undated photograph of a Coggshall beekeeping operation shows six workers preparing to travel to an out apiary on a wagon drawn by a pair of horses and four bicycles (photo also found in January 1989 *Gleanings in Bee Culture*.)

that time were known in general, and specifically for some crops (see below), and so bees presumably were purposefully kept in part to enhance yield, but by the growers of those crops. Cultivation and harvesting specific plots of land was a different business than that developed by commercial beekeepers who extended their range via the use of outapiaries to take advantage of floral diversity.

The ability to move hives at lower cost led even non-migratory apiaries to take advantage of economies of scale. With high transportation costs limiting a beekeeper to a single location, the scale of a beekeeping operation was limited to the numbers of hives kept at that location. An agriculturalist could occupy his time fully only by engaging in non-beekeeping enterprises. But outapiaries allowed the exploitation of several sites and economies of scale in the single-purpose beekeeping operation.

Migratory beekeeping was a way to further exploit economies of scale *and* to take advantage of asynchronous blooming periods; an exploitation of the range of flowering.

M.G. Dadant gives several examples of the utility of trucks in extending the range of outapiaries and through early instances of migration, but with limited range:

> "But with the elasticity in opportunity for out apiary expansion by means of the automobile and truck, he should do more than this; he should study carefully his territory for 100 miles in each direction. He may, by this same means, place his apiaries to best advantage, and he may, moreover change locations (migrate) with his bees to an extra crop."
> ...
> "Many beekeepers in California practice it, and ... take advantage of several crops in a single season." [follows with discussion of Edson's use of a "big 4-ton truck" on which he loaded 100 colonies.]

<u>Why the transportation revolution prior to the automobile didn't induce migratory beekeeping</u>

James McPherson in his *Battle Cry of Freedom* describes what he and others term the transportation revolution in the mid-19th century. (See also Taylor, 1951). Between 1815 and 1860, railroads and canals were constructed in America, revolutionizing rural ways of life. McPherson describes life in rural America (towns with fewer than 2500 residents) prior to the revolution as largely autarkic. Residents grew their own food, made their own clothes, and manufactured many of their implements, including guns. Prior to the revolution, says MacPherson, if one lived 30 miles away from the American coast, transportation costs to and from the nearest port equaled the costs of trans-Atlantic transport from England to America. Specialization and exchange, at least in rural America, extended only to one's near neighbors.

While part of the transportation revolution was the construction and improvement of a road system, traveled largely by horse and by foot, the major conduits of rail and barge had limited influence on beekeeping. There were instances of shipping of bees by rail and even attempts to migrate bee colonies among nectar sources by boat. But railroads and barges were suitable for shipping cargo, including bees from point to point along a relatively fixed network of destinations. The fine-scale scouring of the countryside for nectar by beekeepers and bees that developed post 1910 required the car and truck and the ability to move economically along small roads and off road.

Notable also is Dadant's 1919 discussion of California beekeepers use of trains to carry their bees to Nevada and Utah for alfalfa–California beekeepers shipping their colonies out of state in spring, to return in the fall. Compare this to the current situation where bees are shipped from across the continent *into* California for almond pollination and pollination of other crops. This is also notable because it indicates that, even with much wild land in California, beekeepers sought forage out of state. (Maybe things aren't so different now.)

Pellett (1938) describes the evolution of beekeeping from mostly small and stationary apiaries to large-scale mobile commercial operations. Early experiments with migratory beekeeping, as early as 1878, included moving hives on barges to forage locations along the Mississippi River. Roughly contemporary experiments were conducted on Florida waterways. According to Pellett, in California in 1876 beekeeper J.S. Harbison was shipping bees from location to location by rail car. Pellett made the following comment on the expense and difficulty of these early arrangements, and the drastic reduction in costs associated with the invention and adoption of the automobile:

> "The high cost of preparation, the long haul by freight and unloading and loading, and moving to apiary sites with horses and wagons resulted in too much expense to make migratory beekeeping by rail a practical method. The auto changed all this. ... Migratory beekeeping became common practice, especially in California, where large areas are devoted to the production of some special crops." [p. 113]

Pellett gives the following example of the movement of bees after World War I:

> "... one Californian was to become famous because of his frequent movement of bees in carlots [automobiles]. He became known as Migratory Graham, and boasted that he kept bees in 32 California counties and five valleys in Nevada. According to his own statement in 1918, he had shipped 161 cars of bees. A typical season with him was to start the bees in the almond belt of Butte or Colusa counties. From there he would move to orange in Tulare county and back to Sacramento or San Joachim Valley to the seed belt. From there he would go north to alfalfa and south again for jackass clover." [p. 113]

See figure 3 for the route Pellet reports for Migratory Graham.

Note that Graham's purpose in moving his bees was to exploit seasonally varying nectar and pollination sources in order to produce honey, and not augment his income with pollination fees.

V. How and When Contracting for Pollination Services Arose

Johnson (1973) claims that the first recorded renting of colonies for pollination in North America occurred in 1910. What factors were responsible for the evolution of market institutions for pollination and for the changes in the nature of the firms involved?

Several factors were critical, some technological. Many sources refer to the invention of the Langstroth movable-frame hive as defining the beginning of modern beekeeping. Reverend Langstroth was the first to recognize the importance of the internal architecture of bee hives and in 1853 invented what is now known as the Langstroth hive. It allows low cost extraction of honey and more intensive management of bees. Such management is essential to the standardization of the pollinating colony, now taken to be a Langstroth hive of approximately 30,000 active bees in the spring.

V.A. Discovery of the value of bees to crops

A gradual development, but one critical to the evolution of pollination markets, was the growth of knowledge about bee pollination. Crane dates the fundamental science as occurring between 1670 and 1880 (p. 473). Practical knowledge continued to grow after that time, however, as the details of pollination requirements of particular crops came to be better understood. For example, Olmstead and Wooten tell the story of how the benefits of pollination to alfalfa seed production were learned only in the late 1940s.

One early published recognition of the yield benefits from honey bee pollination appeared in a January 15th 1899 column by E.R. Root in *Gleanings in Bee Culture*:

> "We quote the following from Press Bulletin No. 8 of the Kansas Experiment Station, Manhattan, Kan.:
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>> If bees are kept from fruit-blossoms by netting or other artificial means, the amount of fruit set is little or none. It not infrequently happens that inclement weather prevents or hinders the flying of bees during the period when the flowers are receptive. A fruit tree, half of which was subjected to a continuous spray of water during the flowering period, produced no fruit upon the sprayed portion, but an abundance upon the other. ... An insufficient supply of bees will hinder the setting of fruit. While other insects may take part in the carrying of pollen, the fruit-raiser must rely chiefly on upon honey-bees. Experience shows that, though hungry bees may fly two to three miles, hives should be within half a mile of the orchard or small-fruit patch."

The title of the excerpted article is "Bees Near by Almost a Necessity to Successful Fruit Growing."

[add CC. Miller quote from Gleanings. Also consider the F.L. Morrill article in June 1 issue]

One impediment to the development of pollination markets was a lack of understanding of the potential gains to farmers from bees' pollination services as illustrated by the following events from the late 1800s (from Pellett, p. 85):

> "In the eighties and early nineties there was a serious conflict between California fruit growers and beekeepers. The fruit men accused the bees of injury to the fruit and numerous lawsuits were a natural result. In several instances the apiaries were burned by incendiaries. Harbison [a large-scale California beekeeper mentioned elsewhere] thus lost 350 hives in one year and himself broke up 700 more to avoid conflict. At one time, he owned 3,750 hives in 12 apiaries." [p. 85]

The development of crop varieties and production practices incorporating supplemental bee pollination required intensive work, on a crop-by-crop basis, by entomologists, crop scientists, and farmers. In the case of almonds–currently the most economically important application of honey bees–research funded by the industry in the 1960s led to planting and management techniques that better exploited honey bee cross-pollination of self-incompatible almond varieties. (See Horn, p. 205). Such progress continues today with active research on pollination by various species of solitary bees, which are costly to manage but for specific crops are more efficient pollinators per bee than are honey bees.

V.B. Landscape and environmental factors

Recently, development of pollination markets has been spurred by changes in the availability and quality of natural pollination. Examples here are changes due to *Varroa* and tracheal mites. Both are parasites that have had dramatic effects on wild and managed honey bee populations in recent years. These honey bee scourges have done two things: they have raised the costs of commercial beekeeping, and they have decimated feral colonies. Eliminating feral bee colonies causes a rightward shift in the demand for commercial pollination services, which results in an increase in the market value of the services, and acts as a spur to contracting and markets. Increasing the costs of commercial beekeeping also spurs development of markets inasmuch as it reduces the numbers of bee colonies that are used to produce honey and so reduces the supply of inadvertent pollination.

V.C. When did contracting for pollination services begin?

One well-known source is Pellet (1938), who provides a detailed account of the history of beekeeping in the United States. He covers periods up through the mid-to-late 1920s and includes much discussion of commercial beekeeping, including chapters on "Commercial Honey Production," Migratory Beekeeping," and "Bees in California." Notably, nowhere does he refer to bees being paid for pollinating crops or refer to crops as anything other than nectar and pollen sources for bees.

The importance of forage

The automobile made beekeepers mobile and expanded scale to some extent, but it was another exogenous change that led to large-scale bee operations: the establishment of clover crops in the northern great plains. In a chapter titled "Sweet Clover and Specialization," Pellett tells how in the northern plains there were nearly no acres planted in clover in 1910 and 1920. But in the following decade, the originally tilled soil had been depleted of nitrogen from continuous cropping of wheat. This led farmers in the Dakotas to begin rotating wheat with clover, a nitrogen-fixing legume that had been introduced to the area. Vast acreages of clover were planted, leading beekeepers to follow the bloom to the clover fields. In Pellett's view, this revolutionized the industry:

> "The man with a hundred hives wanted a thousand, and specialization became the order of the day. ... Instead of being a mere sideline ... honey production became an exclusive business . . . [S]weet clover was largely responsible for the final great change which commercialized the industry and closed the so-called golden age of beekeeping, at a time centering approximately on the year 1925." [chapter 22]

Thus, by Pellett's account, commercial beekeepers were mobile, migratory, and large by the 1920s. Exactly when commercial beekeepers began to augment their honey income with revenues from pollination fees is unclear.[15]

It is unclear from Pellett's historical account when the provision of pollination services for a fee developed into an important component of the migratory beekeeper's activities. Although Pellett's 1938 book contains no mention of bees generating income from pollination services, other sources suggest that pollination markets were starting to develop in the first two or three decades of the twentieth century. Johnson (1973) states that the "first recorded renting of colonies for pollination purposes occurred in 1910." Lindquist (2010) suggests that the first bees were rented for pollination in 1909 in New Jersey.

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[15] Borst (2013) discusses beekeeping in New York state in the mid-to-late 19th century. Among the entrepreneurs and innovators he chronicles are Moses Quinby and W.L. Coggshall.

Beekeeping in New York in what Borst refers to as the golden age of beekeeping was focused solely on honey production. Borst explains the importance of New York beekeeping by two factors: "the vast area planted to clover and buckwheat and the huge population centers in and around New York." The population of New York City provided a foundation for the demand for agricultural commodities and clover and buckwheat are excellent nectar sources.

"Coggshall gave the greatest importance to location. He was situated at the center of the vast white clover and buckwheat region which stretched from Massachusetts to Ohio. ... The clover was planted as forage for the huge dairy industry, and buckwheat was a food source favored by the immigrant populations who had become accustomed to it as a staple in the old countries." (Borst, p. 1299.)

Further anecdotal evidence regarding the early stages of development of pollination markets is provided by the following accounts, comments, and discussions from the American Bee Journal (ABJ):

- An article in a 1961 issue of the ABJ (Myers) indicates that farmer-owned bees suffered from disease in the early 1900s, which led to specialization in beekeeping. As a result of farmers' lack of success at maintaining bees, rental services developed. The author notes that he has been renting bees for more than 40 years.

- The author of a 1920 article (Pashek) mentions that he rents out 76 colonies, apparently in the Yakima Valley.

- A 1922 article from the Agricultural Experiment Station at the University of California indicates that prunes are being pollinated and that growers either own their own bees or rent hives at a density of one hive per acre.

- A 1963 article ("Renting Bees . . .") mentions an article in the April 1923 issue of the "Western Honey Bee" that reported that renting of colonies was a regular occurrence in California, where rental rates ranged from $1.50 to $2.50 per colony.

- A 1929 article (Hootman) indicates that beekeepers were being paid to use their hives to pollinate orchards in Michigan and that growers had agreed to discontinue spraying chemicals around the times that orchards were in bloom. The article also includes an anecdote about an orchard owner who rented hives to pollinate his cherry orchard and saw his yield increase substantially.

These tidbits from the *American Bee Journal* suggest that during the 1920s hives were being rented to pollinate crops, with many of the rentals taking place in California.

V.D. The history of almond pollination

By the time Cheung wrote his 1973 paper on bees, pollination markets in the Pacific Northwest were clearly well developed. In addition to the local pollination rental arrangements that Cheung reported, he also indicated that the practice of taking hives from the PNW to California in the spring to pollinate almonds was common, especially for beekeepers located in the southern part of Washington. Of the eight beekeepers from whom Cheung obtained information, however, only two reported that they pollinated almonds in California.

Prof. Michael Burgett began his Pacific Northwest Pollination survey in 1987 and the first year in which his survey asked explicitly about pollination of almonds was 1993. In that year, 83 percent of the commercial beekeepers who responded to the survey reported that they pollinated almonds in California. During the years 2005-2008, all of the commercial beekeepers who responded to the PNW survey indicated that they pollinated almonds. Today, almonds are by far the most important source of income in U.S. pollination markets.

Figure 4 (from Rucker, Thurman, and Burgett, 2012) provides insights into the importance of this income source and also provides insights into the expanding physical extent of the pollination market for almonds. The three lines show almond pollination demand as a proportion of all honeybee colonies in (1) California, (2) California plus the Pacific Northwest (Oregon and Washington), and (3) all U.S. bees. The demand for bees for almond pollination in a given year is estimated as the number of bearing acres of almonds in California multiplied by the number of hives per acre used for pollinating almonds–for the purposes of figure 4, we use the average density of 2.07 hives per acre reported by PNW beekeepers.

The first series, "Almond Demand as a Proportion of CA Bees," provides a crude indication of when the demand for almond pollination services might have outstripped the supply available from California beekeepers. If one estimates that 90 percent of the colonies in California are owned by beekeepers willing to provide commercial almond pollination services, then the point at which out-of-state pollination services would have been required was about 1973.[16] An obvious source of outside pollination services is from Washington and Oregon beekeepers. Thus, if one again assumes that about 90 percent of the colonies in California and the Pacific Northwest are available for commercial pollination services, the second series in figure 4 suggests that the demand for almond pollination services exceeded regional supply in 1977. The third series in the figure shows the substantial rise in the demand for almond pollination services relative to total U.S. honey bee colony numbers. Whereas almonds demanded less than 5 percent of U.S. colony numbers until the mid-1960s, they demanded about 15 percent by the late 1970s and currently demand about 60 percent of all U.S. bees.

Today, beekeepers are paid substantial premia to bring their colonies to California and place their bees in almond orchards during the bloom. In recent years, almond pollination fees reported by PNW beekeepers have increased dramatically—from an average of about $66 per colony in 2004 to almost $157 in 2006.[17] These fee increases have been attributed to recent increases in almond acres and expectations of further future increases in almond acreage.[18] Some sources also have

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[16]Data from the 2002 Agricultural Census indicate that about 88 percent of the colonies in the United States are on operations with 300 or more colonies and another 10 percent are on operations with 25 to 299 colonies. See table 1 in Daberkow et al. (2009). Assuming that virtually all of the beekeepers with 300 or more colonies pollinate some crops and that a fraction of the smaller operations are also involved in pollination, our use of the 90 percent estimate in the text seems reasonable.

[17] These fees are in 2009 dollars. For California beekeepers, reported almond pollination fees increased from about $73 in 2004 to $166 in 2006. See Burgett et al. (2010), tables 3 and 4. Also, see Rucker, Thurman, and Burgett (2012) for the empirical relationship between bee disease (Colony Collapse Disorder, or CCD) and this pre-CCD increase.

[18] See Sumner and Borriss (2006) and Ward et al. (2010).

suggested that the onset of CCD has resulted in increased pollination fees.[19] In other work, we estimate the determinants of pollination fees and find that only a relatively small fraction of the post-2004 increase in almond fees can be attributed to either increases in almond acres or CCD. It is clear, however, that one response to increased almond pollination fees has been the attraction of beekeepers from greater distances, some from as far away as the East Coast.

VI. Markets for Forage

Seasonal migration for forage (termed by Smart *et al.* as "spatiotemporally decoupled land use") is an economically driven activity. As such, economics predicts that market for forage would develop to coordinate suppliers of forage (land owners) with demanders of forage (beekeepers).[20] Important preconditions to the development of markets are the existence of property rights and transaction costs not so large as to preclude exchange. Without these market-enabling conditions, bee forage should be considered to be an open access commons.

In this section we examine the aptness of referring to the combing of the forage landscape as a market. The motivation for this treatment is the observation that contracts and prices for pollination services are commonplace today and documented in the historical record. Evidence on contracting for access to bee forage land is more elusive. Beekeepers, today, routinely give landowners non-trivial quantities of honey – often five gallons – for the privilege of exclusive placement of bees on land. (Five gallons of honey at 12 pounds per gallon and $5 per pound makes a five-gallon payment worth $300.) Is this a price of forage, termed by Cheung an apiary rent? Or should it be thought of as the complement to a handshake and a smile? If it is a price, it should reflect the scarcity rent value, if any, that a site provides. We are aware of no systematic reports of apiary rents, contemporary or historical, but there is anecdotal evidence of variation across sites by forage quality and costs of access.

We begin by developing a theory of how a market for forage should operate. This sets the stage for more search for evidence of forage contracting and an assessment of its consistency with the theory.

VI.A. A Model of Equilibrium in the Market for Apiary Services

The theory developed here describes how migratory beekeepers and land owners cooperate in a competitive equilibrium in the production of honey and, implicitly, bee-pollinated crops. The explicit focus on honey emphasizes the activities of beekeepers and land owners during the late spring and summer months, after pollination-for-fee opportunities are over. But the value generated in the production of honey conditions the supply price of pollination services in the

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[19] See Ward et al. (2010).

[20] See related arguments about the development of grain futures markets in Cronon (1992) and Thurman (2011)

spring and so the two problems are closely connected.[21]

The two asset owners in the theory are migratory beekeeper firms and land owners. A beekeeping firm (or beekeeper) owns hives and bees, trucks, and the human capital required to commercially manage bees. A beekeeper rents from a landowner a unit of land termed an apiary, which is the size that bees forage over.[22] Individual bees forage across a wide area. (See Seeley.) For concreteness, and as an approximation, think of an apiary as being the land in a one-mile radius circle: 3.14 square miles or, approximately, 2,000 acres. The property rights to the apiary are assumed to be held by the landowner and, once rented to a beekeeper, access to the apiary is assumed to be exclusive to the contracting beekeeper.[23]

Figure 5a displays the economic problem faced by a beekeeper in deciding the optimal stocking of bees in an apiary. The number of bee colonies is denoted as B and the number of apiaries is denoted as A. The horizontal axis measures b = B/A, the number of colonies put on an apiary. The curve labeled MP is the marginal product of bees in the production of honey, assumed to be declining over its domain. The curve labeled VMP is the (vertical) product of MP and P_H, the price of honey. The cost of colonies to the beekeeper is depicted as constant at the level c, which includes the user cost of a hive, per-hive maintenance of the approximately 30,000 bees that live in it, and the cost of transporting the colonies to the apiary.

As in the conventional theory of a competitive firm, the optimal employment of bees on the apiary is b^*, where the VMP of bees equals the marginal factor cost of c.[24] This optimum is independent of the per-apiary rental rate that the beekeeper must pay and also independent of the entry costs of the beekeeper into the industry. The shaded triangle in figure 5a represents the surplus value generated by the beekeeper, net of the costs of bees, but gross of the costs of entry into the industry and also gross of any apiary rent. The shaded triangle in figure 1 will be termed Gross Apiary Value and denoted as g.

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[21] Note, importantly, that the theory abstracts entirely from the contracting problems discussed in Barzel, Rucker and Leffler, and many other studies in the contracting and property rights literature. Contracting problems due to measurement costs and incomplete definition of rights abound in beekeeping, as they do elsewhere. The purpose of the theory is to characterize the potential values that could be generated by exchange in competitive markets and that incentivizes market participants to address contracting problems and solve them subject to the constraints imposed by transaction costs.

[22] In Montana, apiaries are registered by the state as 3-mile-radius circles. Once one registers a site, another beekeeper cannot locate within the circle..

[23] This assumption ignores the contracting problems that arise from the inability to fence bees, contracting problems that presumably led to the registration system observed in several states, including Montana and North (but not South) Dakota.

[24] For concreteness, a typical apiary might have 48 colonies. For a 2,000 acre apiary, the stocking of 48 colonies translates to 40 acres per colony. Contrast this typical summer foraging density with the much greater springtime stocking density of bees on, for example, almonds at a typical rate of two colonies per acre.

For illustration, figure 5b shows the comparative static effects of an increase in the price of honey. The shift from VMP_o to VMP_1 induces an increase in the stocking density from b_o to b_1 and results in an increase in the Gross Apiary Value from the smaller triangle of size g_o to the larger triangle of size g_1.

Next consider how Gross Apiary Value and the supply of beekeeping induces a market-level demand for apiaries. Bees are a variable input in the production of honey (see figures 5a and 5b) but beekeepers and apiaries are assumed to be combined in fixed proportions. Given a price of honey that results in a Gross Apiary Value of g, combining one beekeeper with one apiary produces the value g. Figures 6a and 6b show the market-level derived demand for apiaries given beekeepers of identical skill but heterogeneous opportunity costs, and given a fixed g (implied by a fixed price of honey and homogeneous apiaries). If variations in the quantity of apiaries employed and honey produced resulted in movements along a downward sloping demand for honey, then the g curve would itself be downward sloping.

The curve D_A, the demand for apiaries, is derived as the vertical difference between g and the curve c_{bk}, which is the cost of the marginal beekeeper. The latter is assumed to be upward sloping to reflect the scarcity of beekeeping skills and human capital, which implies that in equilibrium inframarginal beekeepers will earn rents.[25] As explained in Friedman (chapter 7) and Marshall (ch. x), the demand price of apiaries, i.e. the maximum marginal willingness to pay for an apiary, is the difference between the value generated by the marginal apiary (which is g) and the minimum cost of the beekeeper input required to produce g. That minimum cost is the cost of the marginal beekeeper, which rises with industry employment of apiaries and beekeepers.

Equilibrium in the market for apiary services is found by the intersection of D_A and S_A, the supply of apiaries. In figure 6a, the supply of apiaries is drawn as perfectly inelastic at a quantity that exceeds the quantity at which the demand price has fallen to zero. Thus, the equilibrium employment of apiaries is A^o, less than S_A, where the cost of the marginal beekeeper equals g and the marginal beekeeper is willing to pay exactly zero for an apiary. Thus, the equilibrium rental rate of apiaries is zero.

Figure 6b portrays the same circumstances as in 6a with one exception. The supply of apiaries is now assumed to be less than the quantity at which the apiary demand price falls to zero. The equilibrium employment of apiaries is the perfectly inelastically supplied quantity of A^o and the equilibrium rental rate of apiaries is r^o. By the construction of D_A, the cost of the marginal beekeeper is equal to Gross Apiary Value (g) minus the apiary rental rate and the marginal beekeeper earns no rents.

Figures 7a and 7b introduce two types of apiaries, which differ in forage value. The triangle of Gross Apiary Value in figure 5a is g_H for a high quality apiary, while the triangle is a smaller g_L

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[25] Strictly speaking, in the model, all beekeeper entrepreneurs have access to identical honey production functions but vary in their opportunity costs of employment in beekeeping.

for a lower quality apiary. Several dimensions of heterogeneity might result in this situation. Most straightforwardly, the MP curve for the H-type apiary could lie to the right of the MP curve for the L-type apiary because of a greater density of nectar-producing flowers, resulting in higher stocking densities and greater output of honey on H-type apiaries. But a higher g would also result from an apiary that had lower costs, c, perhaps due to lower travel costs to a less distant site, or from an apiary containing nectar that produced higher-valued honey.

Figure 7a shows how the two types of apiaries are employed and compensated in equilibrium. The demand for H-type apiaries is given as D_H, the vertical difference between g_H and c_{BK}. That demand curve is relevant up to the quantity A_H^0 at which point demand price falls by g_H - g_L, the difference in value between the two types of apiaries. If apiaries beyond A_H^0 are employed they must be L-type, and the marginal value–hence demand price–is determined by D_L. In the situation shown in figure 7a, low-quality apiaries are abundant – supplied in a quantity beyond where marginal apiary value is driven to zero. Hence, all A_H^0 high-quality apiaries are employed but only A_L^0 low-quality apiaries are employed. Low-quality apiaries are redundant at the margin and their equilibrium rental rate is zero. The rental rate of high-quality apiaries is r_H^0, positive but lower than it would be were there no low-quality apiaries. The rental rate of high-quality apiaries has been bid down by the employment of low-quality apiaries because the cost of the marginal beekeeper has been driven up.

Several types of equilibria are possible with multiple apiary qualities. Figure 7b shows an equilibrium in which both types of apiary are scarce. Each commands a positive price in equilibrium: r_H^0 and r_L^0. Rental rates for the two types of apiary differ by the difference between their Gross Apiary Values, g_H - g_L, which implies that beekeepers are indifferent between the two types of land given their rental rates.

Next up: what are the contracting costs that complicate the relationship between landowners and beekeepers, among beekeepers, and among landowners? How are they dealt with?

VI.B. Evidence on contracting for forage

[TBD. Primary sources in the UC-Davis archives contain the collected papers and business records of J.S. Harbison, "California's leading late- 19th century beekeeper" and among the first to bring bees to California–in 1856. They are a promising source of information on possible contracting for forage sites, among other topics in early migratory beekeeping.]

VII. Concluding Comments

An economic history of migratory beekeeping and the economic provision of forage is especially relevant because of the increasing contemporary importance of forage for honey bee health. See Smart *et al.* (2018) and Champetier, Sumner, and Wilen (2015).

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Figure 1. Real pollination fees (2009 dollars)

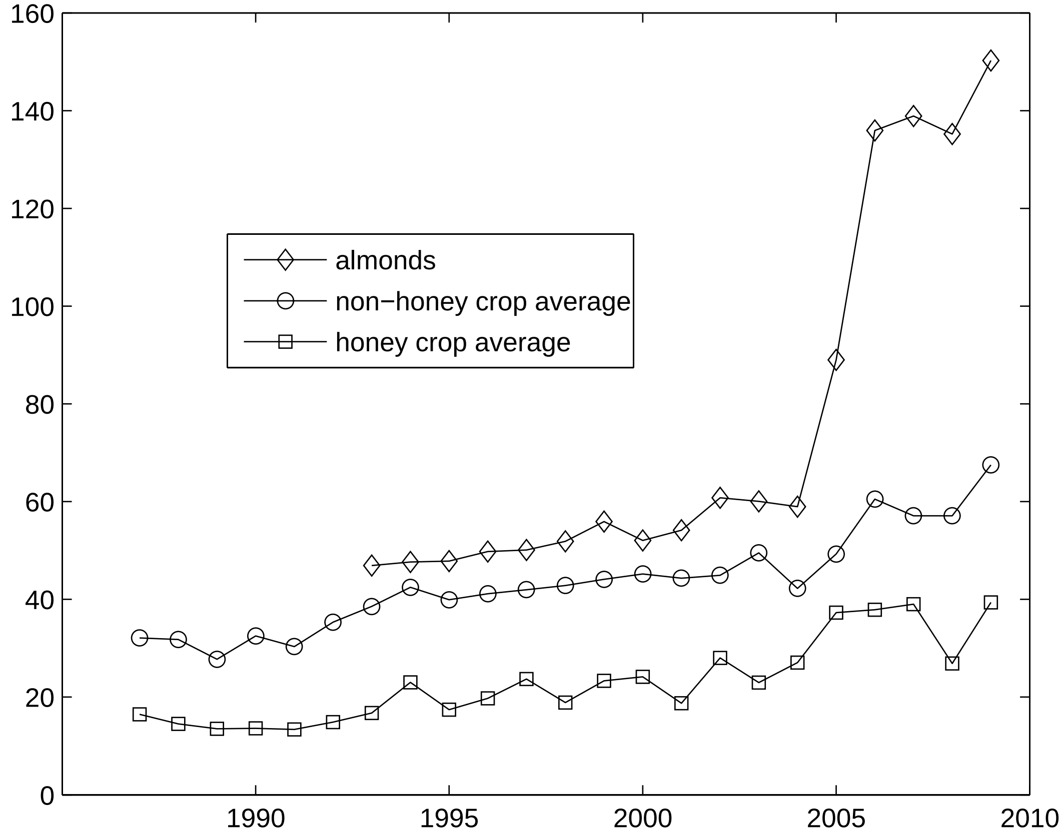

Figure 2. Apiary Locations in Montana in 2008

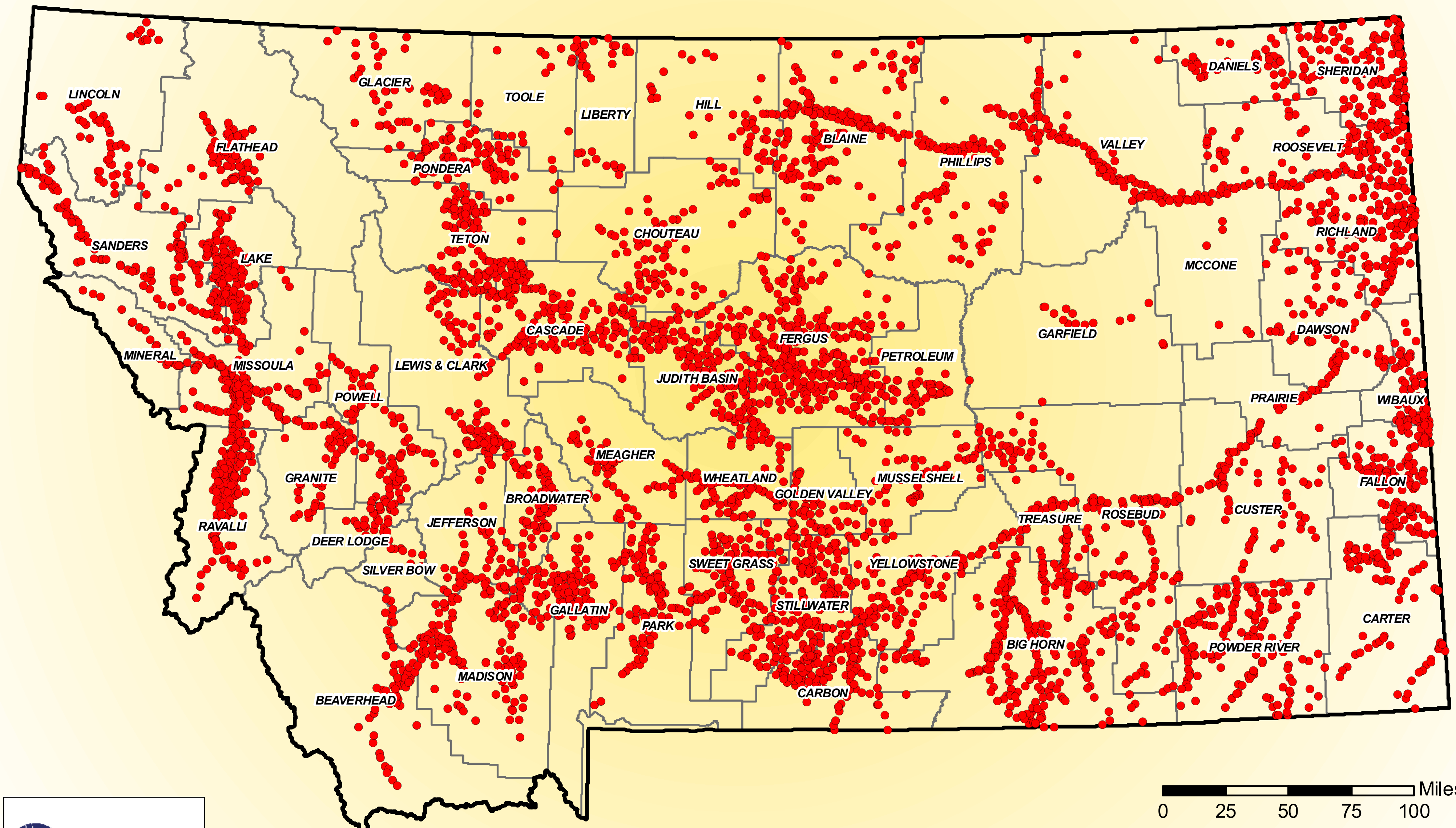

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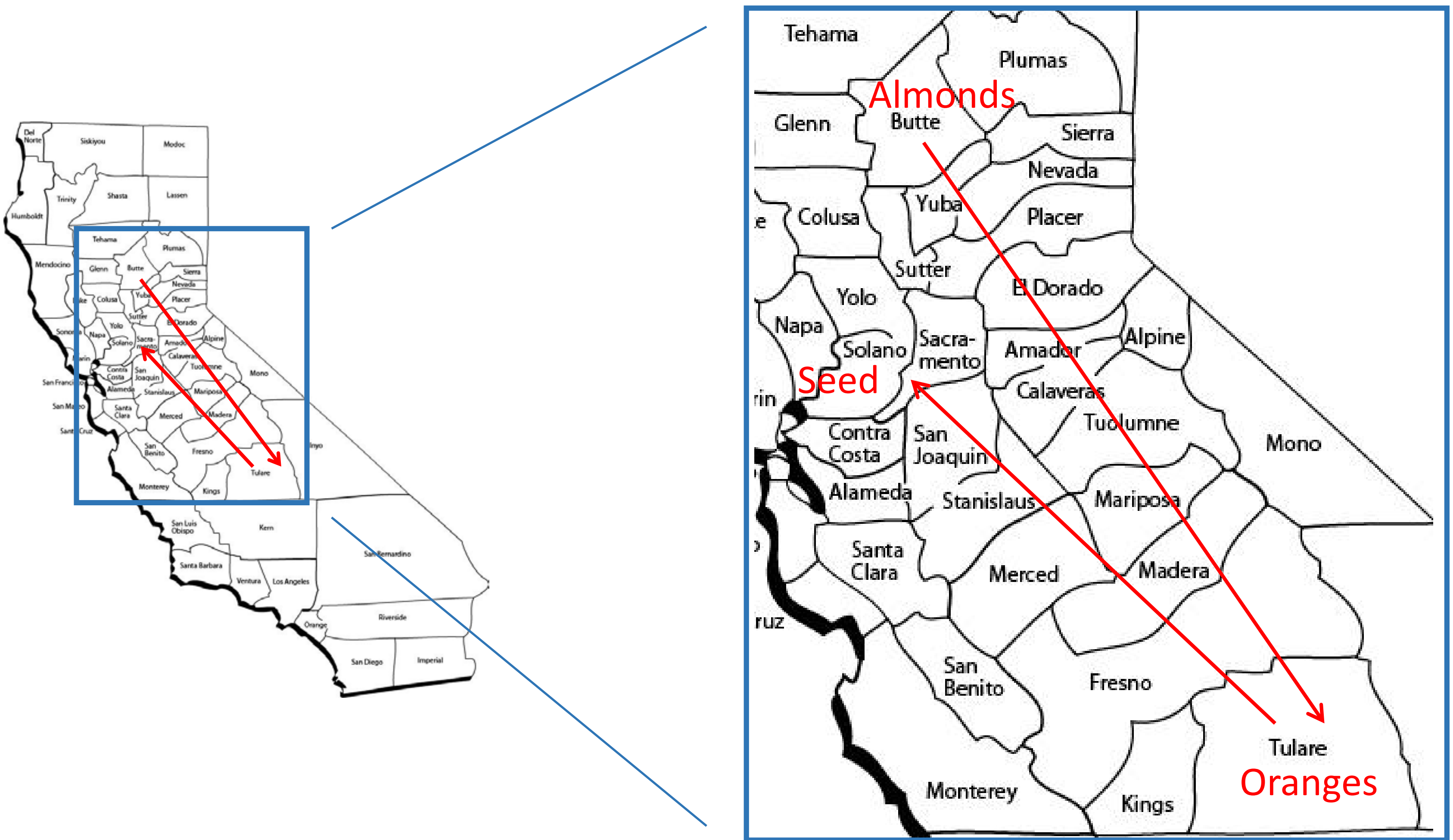
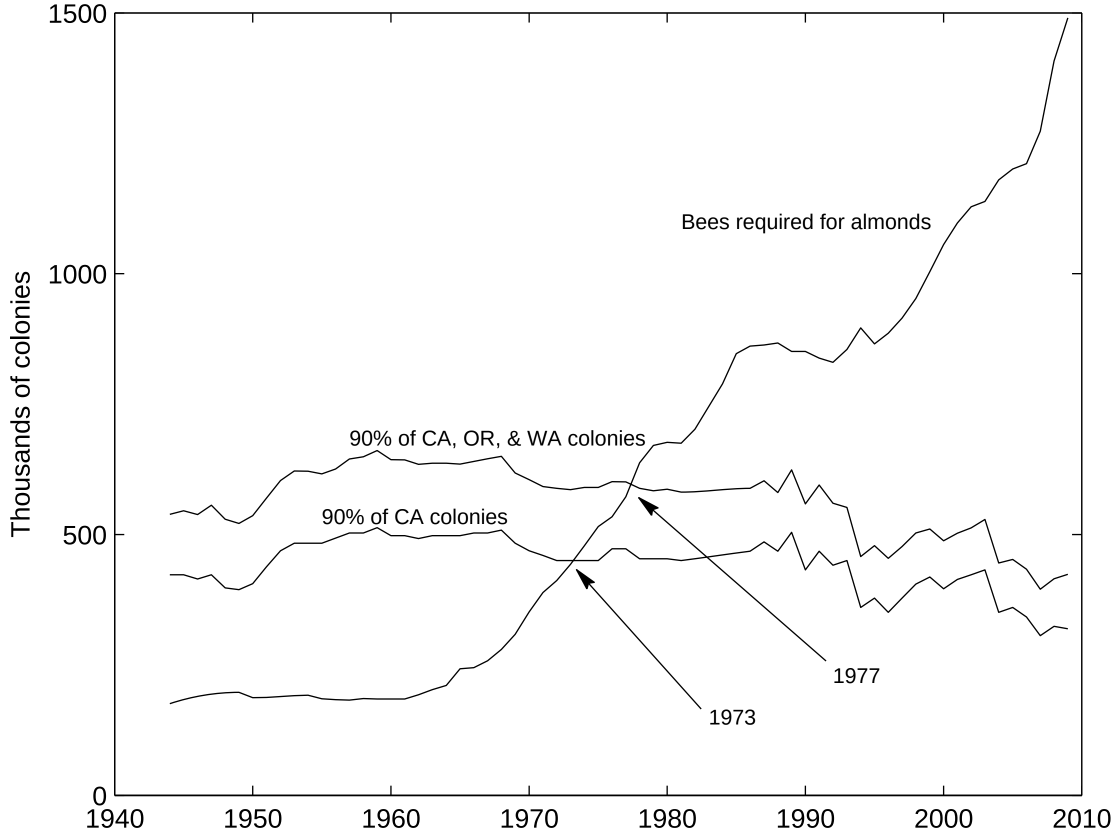
Figure 3. Migratory Graham's Route - 1918

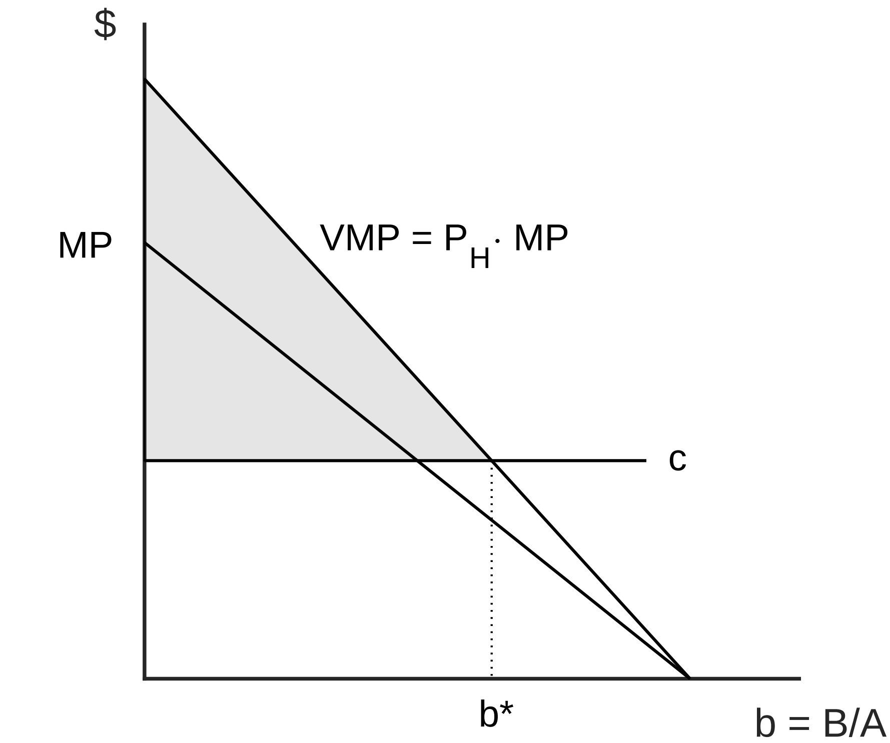


Source: Pellett (1938).

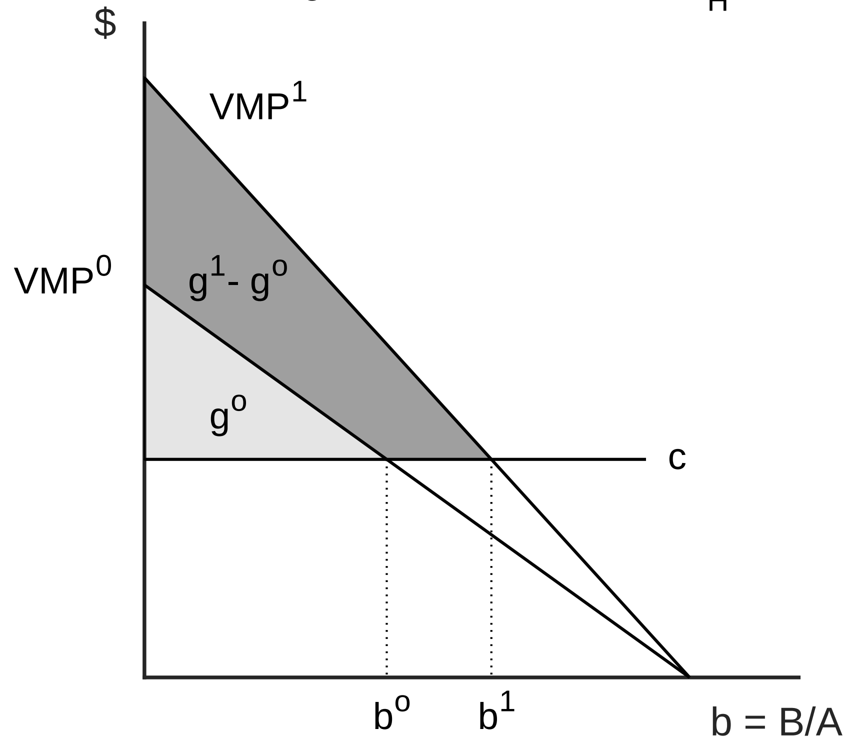
Figure 4. Almond Bee Requirements Rise Beyond Regional Colony Numbers



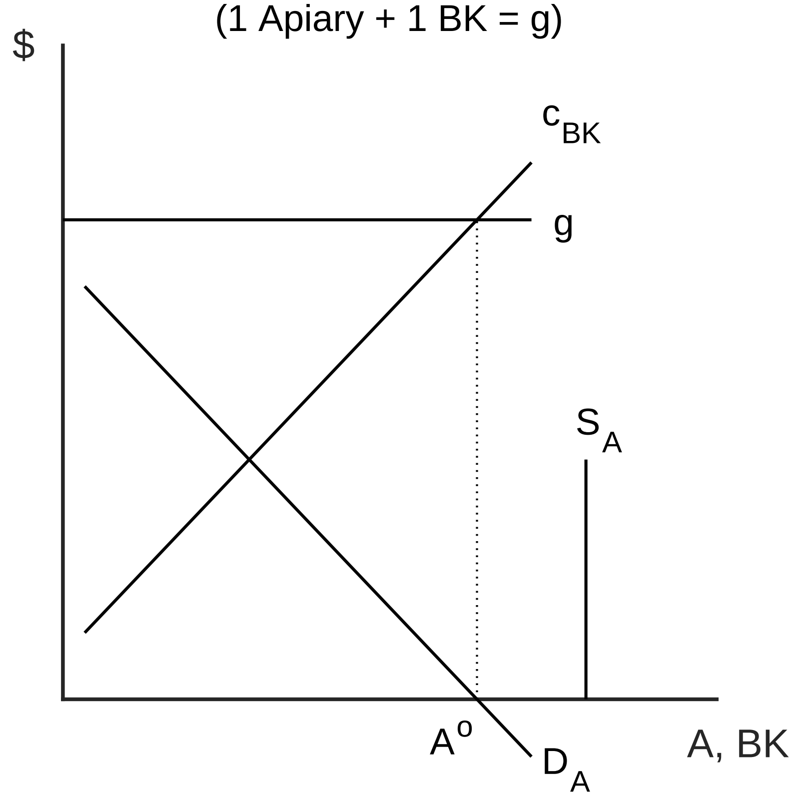
5.a Optimal Bee Stocking of an Apiary



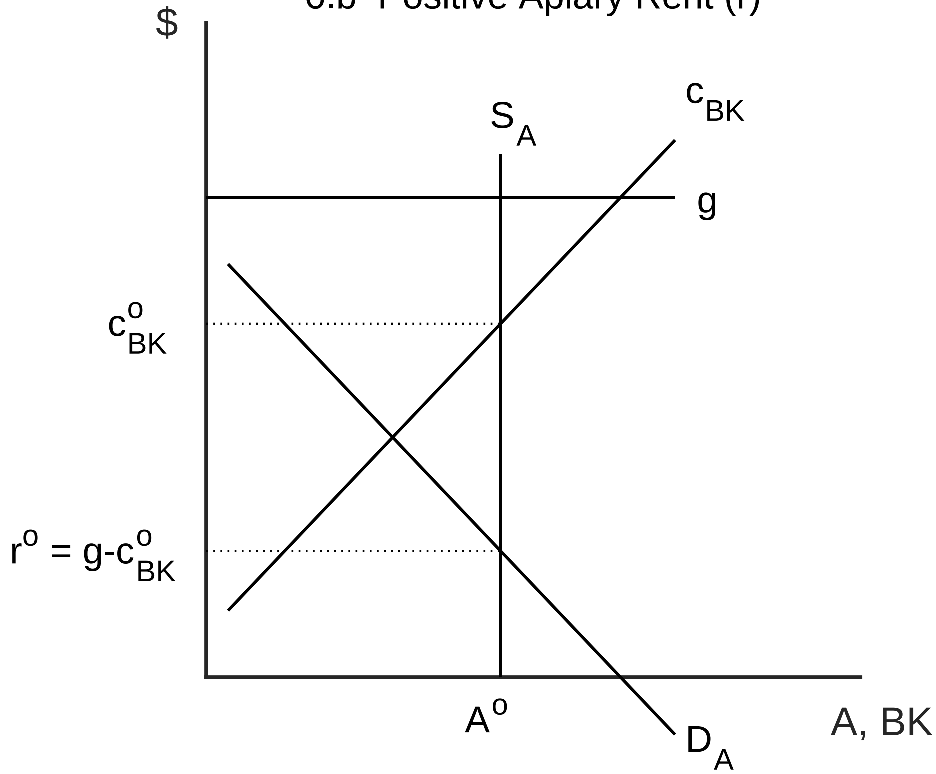
5.b Gross Apiary Value (g):
Change from an increase in P_H



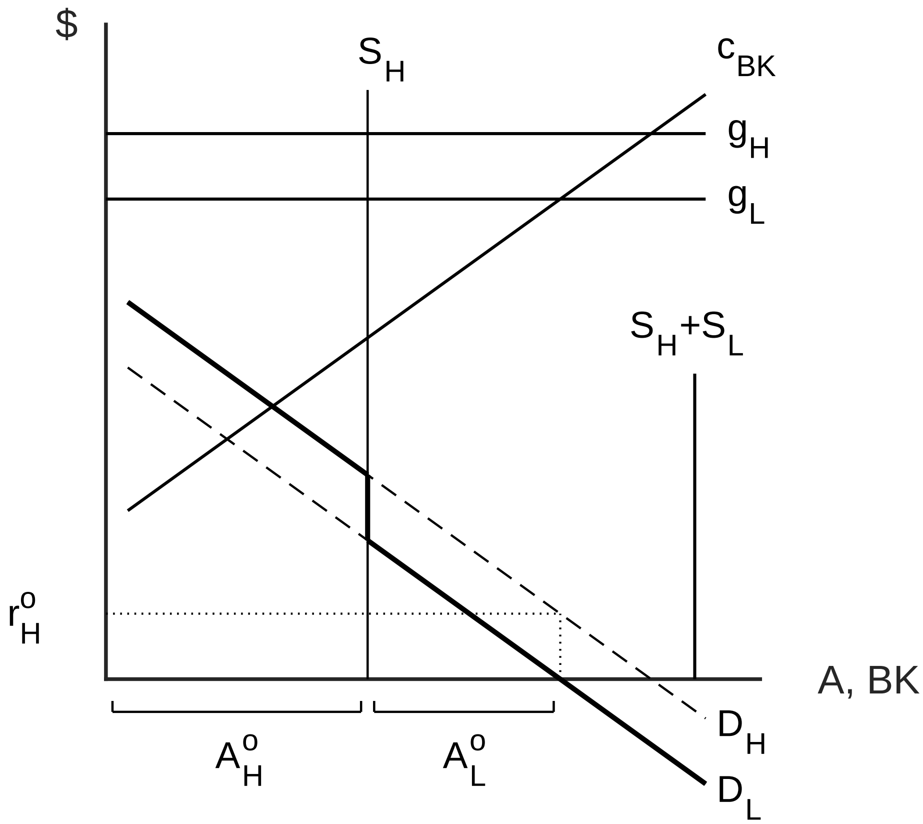
6.a Derived Demand for Apiaries
(1 Apiary + 1 BK = g)



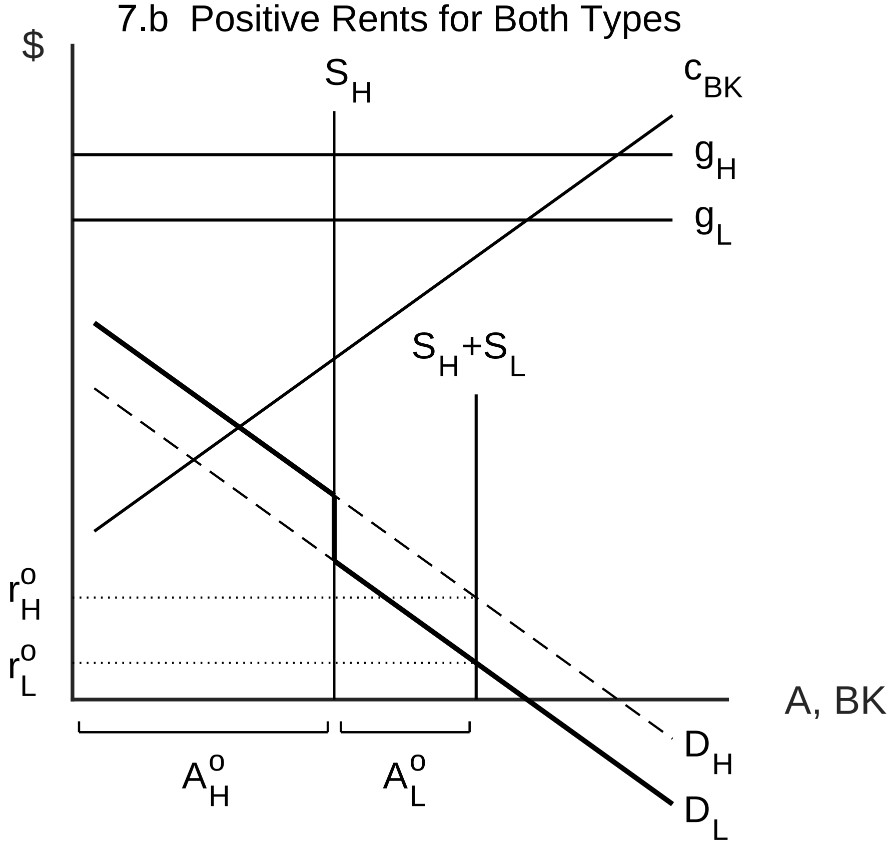
6.b Positive Apiary Rent (r)



7.a Two Qualities of Forage



7.b Positive Rents for Both Types



Appendix A: Timeline of Dates Relevant to Migratory Beekeeping

1670-1880	Crane (1999) dates the development of the fundamental biology of pollination to this period.
1815-1860	The transportation revolution – railroads and canals. (Taylor, MacPherson)
1852	Patent date of the Langstroth moveable-frame hive (Rev. Lorenzo Langstroth, 1810-1895)
1853	First successful importation of bees to California – from Eastern U.S.
1869	Transcontinental railroad completed
1876	J.S. Harbison was shipping hives by rail (Pellett, 1938)
1878	Experimental transport of colonies by barge on the Mississippi River to forage sites.
1889	A.I. Root described managing outapiaries, using hired horse teams
1890	Pellet reports conflicts between beekeepers and fruit growers in late 1880s/early 1890s: fruit growers sue beekeepers for "damage" to crop. "[A]piaries were burned by incendiaries."
1900s	Early 1900s bee disease led to specialization in beekeeping
1899	Kansas Experiment Station report on benefits to fruit from honey bee pollination
1908	Model T Ford introduced
1909	Bees rented for pollination in New Jersey (Lindquist)
1910	First recorded renting of colonies for pollination (according to Johnson) Tractors began to replace horses (Olmstead and Rhode)
1918	Migratory Graham was actively moving bees among forage sites in California (Pellett)
1919	M.G. Dadant "automobile and truck responsible for most of the improvements in running outapiaries" and "[w]here one beekeeper 20 years ago was an outapiarist, probably more than 50 are today."
1922	California Ag. Exp. Station report: prunes are pollinate, growers rent or own bees.

1923	*American Bee Journal* article "Renting Bees": California rentals at $1.50-$2.54 per colony
1920-1930	Widespread planting of clover in the northern plains states, mainly the Dakotas, induced regular long-distance migration for forage
1922	Prunes pollinated in California; growers own bees or rent at 1 colony/acre
1920-1930	Widespread planting of clover in Dakotas (Pellett)
1929	Beekeepers paid to pollinate Michigan orchards
1933	Publication date of *Economic Aspects of the Bee Industry* (Voorhies, Todd, and Galbraith.) Less than three pages of 117-page devoted to "Renting Bees for Pollination"
1938	Publication date of Pellett's *History of American Beekeeping*. No mention of contracting for pollination.
1940s	Honey bees first used in alfalfa seed pollination
1959	Alfalfa leafcutter bee (*Megachile rotundata*) discovered and applied to alfalfa seed production
1960s	Active research adapts almond planting to bee forage activity (Thorp)
1973	Growth in almond acreage induces importation of bees from outside of California

Appendix B: Evolutionary Perspectives

Several evolutionary tales are relevant here, at different scales.

1. Pollinators like bees co-evolved with flowering plants. I think some evolutionary biologists have made a big deal of this. It is worth a mention.

2. Humans and honey bees have co-evolved as described above.

3. Almond cultivators and bees/beekeepers have co-evolved to provide pollination services. Part of the co-evolution has to do with the self-infertile almond varieties that are grown and that especially benefit from the availability of bee pollination.

4. Bees, humans, and *Varroa* have co-evolved – a perspective adopted by Randy Oliver. The practical importance of the lessons learned from the economic history of the early 20th century and attention to the co-evolution of bees, humans, and bee parasites and pathogens.

   Ewald (1994) analyzed the evolutionary origins of pathogen virulence. On the one hand, pathogens and parasites (multi-cellular pathogens) will gain reproductive advantage by not harming their hosts too badly. From this perspective, the ideal parasite is one that skims a narrow stream of the biological rents that its host produces, thus allowing reproduction of the host and reproduction of the parasite. However, this argument does not disprove the existence of highly virulent parasites that kill their hosts. For instance, it doesn't disprove the existence of highly virulent parasites that kill its host only after the host has produced offspring. Another example is one Ewald terms attendant-borne transmission. Ewald's example is the high virulence of hospital strains of diarrhea-causing bacteria that kill infants in newborn wards with high probability. The reproductive disadvantage to the bacteria from killing their hosts is negated in large part by the transmission from baby to baby of the bacteria by attendants – nurses – who themselves are largely immune to the disease. Babies die at high rates, but before they do, nurses pick up the bacteria and pass them on to the next baby. Highly virulent bacteria are strongly selected for, in preference to their more benign relatives, by attendant-borne transmission, intensified by the fact that more severely ill infants are handled more frequently by their attendants.

   Attendant-borne transmission is relevant to the case of the evolution of *Varroa destructor*, the current non-native scourge of the honey bee and beekeeper. Randy Oliver details the logistics of transmission by beekeeper/attendants unaware of the evolutionary consequences of their management methods. In particular, he criticizes a management approach that emphasizes the evolutionary potential of honey bees, but excludes consideration of the evolutionary potential of *Varroa.* That philosophy argues that the fighting of *Varroa* through chemical means allows complacency to develop in honey bee (*Apis)* genetic stock, and that by exposing colonies to *Varroa* one selects for colonies that combat *Varroa*, possibly by selecting for bees that engage in meticulous grooming that keeps mite counts low. However, as Oliver points out, this strategy encourages the transmission of *Varroa* from collapsed colonies to less-infected colonies unless the beekeeper intervenes to kill of the *Varroa*-infested colonies before they collapse and turn into *"Varroa* bombs."

Another evolutionary problem faced by the beekeeping industry in *Varroa* management is the fact that colonies can be replaced at low cost and that the natural economic response to dead colonies is to split healthy colonies and create more. While the relatively low-cost ability of beekeepers to generate new hives is a good thing in that pollination services and honey can be produced at lower cost in the face of bee disease, without the adoption of best management practices such as the ones Oliver promotes, the replication of *Apis* colonies produces nearby and available hosts for *Varroa*. In their natural economic response to *Varroa*, beekeepers inadvertently become the attendants in Ewald's theory of attendant-borne transmission.

Ewald (1994, p. 90): "If attendant-borne transmission increases virulence, the severity of infections should increase as the extent of institutional transmission increases." Applying this prediction to beekeeping: the *severity* of infections due to parasitism and disease should increase as the geographic extent of migratory beekeeping increases. From this perspective it would be interesting to examine the history of virulence of *V. destructor* in its southeast Asia origins. Presuming there is no attendant-borne transmission in those areas, the varieties of *V. destructor* should be less virulent.

Co-evolution of species can be described in contractual terms. The human/bee pair can be described as contracting entities. What does the implicit evolutionary contract look like? Humans agree to house, care for, and transport bees – care includes treating for bee parasites. Bees agree to provide pollination services and to provide surplus honey when external conditions warrant. The ultimate reward for bees is increasing their progeny – the ultimate reward in all biological evolution. The reward for commercial beekeeping is similar – sustainable beekeeping and perpetuating the business model. A good indicator of that reward is the profit of beekeepers.

Appendix C: Non-*Apis Managed Pollinators*

Alfalfa seed crop pollination by alkali bees (*Nomia melanderi)* and alfalfa leafcutting bees (*Megachile rotundata*)

Alfalfa hay is grown for livestock feed throughout North America, the largest producing states being in the West. It is a perennial crop that typically is re-seeded after several years. The crop is harvested several times a year, typically before the alfalfa flower blooms. Thus pollination by bees or others plays no role in production of the hay crop. Alfalfa seed producers, however, grow the crop out until seeds set, which requires pollination of the blooms and so requires a pollinating agent.

According to Olmstead and Wooten (1987) alfalfa seed production prior to 1949 was decentralized, with farmers allowing a portion of their crop to flower and produce the seed necessary for subsequent replanting. There was little specialized seed production and the decentralized producers depended upon wild insects and the wind for pollination. The focus of their study is how honey bees were introduced into California alfalfa fields in the late 1940s, and shown to increase dramatically seed production. They report that the technological advance led to rapid and widespread adoption of bee pollinators and the coincident specialization of alfalfa seed production and geographic concentration in California, Idaho, Washington, and Oregon. They conclude that markets developed and contracts for pollination were standardized quickly once the benefits of alfalfa pollination (for seed) were realized.

Olmstead and Wooten's story is about honey bees and California. They note that the honey bee is ill-suited for pollinating alfalfa seed crops outside the Southwest and that in the Great Basin and Pacific Northwest states–beginning in 1948–alfalfa seed producers became aware of the benefits of pollination by the native alkali bee (*Nomia melanderi)* and the non-native alfalfa leafcutting bee (*Megachile rotundata*). The shift to specialized seed production witnessed in California also took place in other states and at about the same time, although with different pollinating bees triggering the change.

Mayer and Johansen (2003) give evidence on what happened outside of California, and specifically with reference to the alkali and alfalfa leafcutting bee and the dramatic transition from one to the other.

The alkali bee is native to dry areas of the Great Basin desert and Pacific Northwest. It is ground dwelling and solitary. Mayer and Johansen report that "[d]uring the 1950s and 1960s, [the alkali bee] was the major pollinator of alfalfa ... in many areas of the U.S. Pacific Northwest. ... In 1961, most alfalfa seed growers in California, Idaho, Nevada, Oregon, Utah, Washington, and Wyoming maintained alkali bee beds for pollination." (p. 139) The alkali bee might be said to be a poster child of ecosystem pollination services: a native bee whose value was recognized and whose habitat was preserved and enhanced by alfalfa seed producers.

But the alkali bee became displaced by the alfalfa leafcutting bee, which now is the dominant pollinator of alfalfa seed crops. While the alfalfa leafcutting bee is quite different from the honey bee (it is solitary and univoltine, in particular) its application in agricultural is similar in that the bee is reared and placed directly into the fields requiring pollination. In contrast, alkali bee pollination is accomplished by maintaining bee habitat surrounding the pollinated fields. Thus, the displacement of alkali bees by alfalfa leafcutting bees represents a shift away from what might be thought of as enhanced ecosystem services and toward more reliance on specialization and exchange.

There appear to be three main reasons why the nonnative managed bee replaced the native alkali bee. The first is that because alfalfa leafcutting bees are put directly into fields, the farmer can be more assured of effective pollination than if he relied upon a resident population of alkali bees. Management is more routine. Shelters are put out in the spring, with holes drilled for the individual bees. Bees are incubated and introduced to the shelters, where they make their homes and from which they fly to pollinate the alfalfa plant. The bees die at the end the year and new bees need either to be reared or purchased from specialized bee producers, many in Canada where cold winters reduce bee disease problems (notably chalkbrood). Despite their advocacy of alkali bees, Mayer and Johansen concede that "growers are more comfortable with the increased management practices [associated with the leafcutting bee] even though pollination costs much more than with alkali bees." (p. 146).

The second reason is that the spread of honey bees and alfalfa leafcutting bees resulted in the native alkali bees being out competed for nectar and pollen. This is the subject of experiments also reported in Mayer and Johansen. Other bee scientists have cautioned against the introduction of non-native pollinators because of the deleterious effects they might have on native populations. The decline in alkali bee populations appears to be a case in point.

The third reason for the alkali bee receding from the scene has to do with the difficulty in coordination among alfalfa seed producers who cannot prevent their alkali bees from pollinating neighbor's fields. The examples in Cheung suggest that such potential free- can be addressed, but tantalizing stories in the literature suggest that they often were not. Stephen (2003) recounts:

> "Heated exchanges have occurred among growers about bee ownership and bee services, which in turn have led to unfulfilled threats of the physical destruction of several large managed bee beds. It was, however, the discovery and development of the alfalfa leafcutting bee (*Megachile rotundata*), as an alfalfa pollinator in 1959 (Stephen 1961) that moved *N. melanderi* into a secondary role as an alfalfa pollinator." (p. 46)

More evidence on collective action problems come from (Mayer and Johansen):

> "We know of one case in which a grower plowed a good bee bed because he did not want the bees to forage in a neighbor's field. In another case, a grower plowed a good bee bed when he ceased raising alfalfa seed because he did not want the bees to forage in a neighbor's field. In another case, a grower plowed a good bee bed when he ceased raising alfalfa seed even though

neighbors offered to pay rent and maintain the bed." (p. 147).

The difficulty in managing such externality problems is magnified by the wide-ranging foraging behavior of the alkali bee. Stephen (2003) reports that "by the end of a season, uninterrupted by rain or pesticides, the population of a large bed might be found on hosts more than three miles from 'home'" (p. 46). In contrast, Olmstead and Wooten state that "[t]he leafcutter bee ... has a much shorter flight range than alkali bees, making it easier to internalize pollination benefits." (p. 61). For comparison, honey bees typical stay within a one-mile radius of their hive.

Appendix D: Contracting Costs and the Organization of Beekeeping Firms and the Industry

What role do the particular transaction costs associated with beekeeping, the production of pollination-dependent crops, the provision of pollination services, and honey production play in determining the organization of the beekeeping industry and the structure of pollination contracts?

Specialization and Coase's theory of the firm

Development of transportation infrastructure also expanded the geographic extent of produce markets, giving rise to increased specialization in production. Apple farmers, who once kept bees themselves, came to out source the provision of pollination services, contracting with specialist beekeepers. As suggested by Coase (1937), the boundaries of the firm shifted in favor of market exchange as the costs of market exchange declined and the returns to specialization increased.

The boundary between the firm and the market adjusted in response to a number of changes discussed above.[26] First, the development of roads, automobiles, and trucks capable of pulling large flat bed trailers reduced the costs of transporting bees and also made large migratory/mobile beekeeping operations more viable. Second, as farm operations increased in size and become more mono-cultural, the ability of wild pollinators to provide the services required for viable commercial production was exceeded. As a result, the demand for the services of managed pollinators from beekeepers capable of providing substantial numbers of hives increased. Third, the appearance of various pests made being a part time beekeeper much more costly by increasing the time and effort required to keep hives healthy. Recent cost-increasing pests and diseases include *Varroa* and tracheal mites, as well as Colony Collapse Disorder.[27] Fourth, honey bees are generalists, which means they will gather pollen and nectar from a broad range of flowering plants. Because they are capable of pollinating a wide variety of crops the overall demand for their services is much greater than it is for specialist pollinators. The market for honey bees as pollinators is therefore capable of supporting a substantial number of large beekeeping operations. Fifth, over time the demand for honey bee pollination services increased as producers of particular crops came to understand the potential benefits from pollination.

Transaction costs and the structure of contracts

Consider next the role of transaction costs in determining the structure of contracts between beekeepers and landowners. Beekeepers and farmers provide inputs that together produce honey and fruit. In a zero-transaction costs world, both might be paid a monetary wage by a hiring firm. (See

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[26] For ease of exposition, we assume that land owners are also growers. Klein, Crawford, and Alchian offer explanations for why, say apple orchards are more likely to be vertically integrated than an annual crop like cucumbers. That said, it is interesting to note that industry observers indicate that almond orchard owning and growing are often not vertically integrated.

[27] See Underwood and vanEnglesdorp (2007) for an accounting of more than 20 instances of large scale colony losses since the late 1860s. See Rucker, Thurman, and Burgett (2019) for an analysis of the economic costs of CCD.

Rucker, Thurman, and Burgett, 2012.) In fact, beekeepers receive their payment in kind in those instances where surplus marketable honey results from a hive placement. In pollination transactions, farmers keep the resulting crop output and pay pollinators a pre-determined monetary fee (as distinct from a payment or share in the form of apples or clover seed).[28]

The observation that payments are not made to beekeepers in the form of apples or clover seed reflects the facts that (1) it would be difficult for beekeepers to annually confirm the contribution of their bees to apple and clover seed yields and (2) beekeepers almost certainly place a below-market value on the quantities of apples or clover seed that would correspond to the appropriate monetary pollination fees.[29]

Barzel (1997, Chapter 1) predicts that production and price risk will tend to be borne by the transacting party who has the most influence over those sources of income variability. Thus, the allocation of honey yield and price risk to beekeepers, and fruit yield and price risk to orchard owners described above, is in accord with their relative abilities to maximize economic value in response to those sources of income variability.[30]

Other relevant transaction costs involve the measurement and monitoring of hive strength and other attributes of the pollination services provided by beekeepers. These issues are of great concern to farmers. The strength of hives is assessed partly by inspection of hives by farmers, partly by third

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[28]It is interesting to note that when leafcutter bees are used to pollinate alfalfa seed, the beekeepers are paid (at least some of the time) on a crop-share basis.

[29] One might also consider the symmetric situation where a beekeeper places his colonies sequentially on two different farms, and in which each placement results in the production of surplus marketable honey. Suppose that the net benefits from both of the colony placements are such that an equilibrium payment is required from the beekeeper to the farmers/landowners. We know of no instances in which such situations result in payment to the farmer in the form of honey based on either the number of colonies or the resulting honey yield. It easy to imagine that the measurement and monitoring costs of such contracts would be high. A contract specifying payment as, say a share of honey production would require the extraction, or at least the accurate estimation, of honey reserves after each crop was pollinated. Given that extraction equipment is typically located at a beekeeper's home base, extraction after each pollination set would be costly. Moreover, it is difficult to imagine how a farmer might validate estimates of honey reserves accumulated while colonies were located on her land.

[30]After providing pollination services for early season crops like California almonds and possibly apples and cherries in the PNW, many beekeepers take their colonies to apiary sites in the northern plains for honey production for the remainder of the summer. A typical arrangement here is for beekeepers to give landowners five gallons of honey. To our knowledge, these payments do not vary with the number of hives placed or the amount of honey produced. We believe that Cheung misinterpreted the nature and purpose of these payments (which he viewed simply as negative pollination fees and referred to as apiary rents). Instead, we interpret these payments (which are small relative to the value of the honey produced) as "good-will" gifts made to farmers for the possible inconvenience of having bees on their land. Good honey locations away from crops are so ubiquitous (especially in the High Plains states) that the equilibrium supply price of nectar is effectively zero. In light of this, it is a bit of a puzzle that the state of Montana has a program in which beekeepers "own" apiary circles that require annual registration payments to the state. Reportedly, similar programs in Wyoming, South Dakota, and Florida have either been discontinued or are not enforced.

party inspectors and, in some cases, by the assurances of bee brokers who guarantee colony strength in rented colonies.[31] Reputation effects provide an incentive for beekeepers to provide full strength hives, especially in instances (which are common) where hives are placed with a particular farmer year after year (see Klein and Leffler, 1981). Some almond growers reportedly specify a sliding pollination fee based on hive strength, which is assessed by third party inspectors.

[31] We are currently investigating the role of bee brokers in the beekeeping industry.