Economics of the supply functions for pollination and honey: Marginal costs and supply elasticity

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Abstract:

We report new data and estimates of beekeeper costs and revenues, which include data on each activity undertaken by honey producers and pollinators, including labor, transport costs and materials for pest and disease management. We use these data, recent surveys and USDA NASS information to develop and characterize supply functions for (1) pollination services to crops that bloom in the late winter (dominated by almonds) and (2) pollination services to crops that bloom in the spring, and (3) U.S.-produced honey. The positions and shapes of these supply functions are crucial to understanding how the honeybee industry will respond to changes in demand for pollination services, and other market conditions, including shifts in honey import supply, and forage availability affected by climate change.

Introduction

Bee-conomics has advanced substantially over the past decade as modeling, empirical studies and simulations have uncovered important facts and relationships. We now understand how demand for early spring pollination (mainly for almonds) has rapidly increased pollination revenue and the share of pollination fees in per hive income relative to honey and other sources. An increasing number of beekeepers now focus more on pollination and maintaining hive strength for the coming season rather than on extracting honey. The impact of honey bee health changes is also better understood. For example, Ferrier et al. (2018) find that any increases in colony losses have been offset by increased (costly) efforts of beekeepers to replace colonies. As a result, the number of bee colonies in the United States is nearly the same today as it was two decades ago.[1]

The flare of concern for honeybee declines that rapidly spread through media and public in 2007 brought policy makers to support improvements in the collection of data on beekeeping and crop pollination in the US.[2] As a result, we are now better equipped than ever to understand the economic and biological forces that drive the beekeeping industry and its relationship to other crop industries through pollination.[3]

In this paper, we gather the findings of a decade of bee-economics and assemble a simple but compelling economic model of the U.S. beekeeping industry and pollination markets. We first report on a new full accounting of beekeeping costs, built on current data and analysis that details the costs and revenues of beekeepers that provide pollination services. Based on detailed interviews with a variety of beekeepers we document the major cost categories and the timing of costs. Aside from direct costs or labor, transportation, and materials including feed supplements and veterinary products, we identify access to forage as a key input to beekeeping.

Thus, we support that bee forage availability is a major determinant the shape of the supply curve for pollination and honey. We use new information from USDA sources to build a

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[1] According to NASS Colony Survey dataset, there were 2.67 million colonies in 2017 and 2.33 in 1997. Single year numbers are not as useful as averages over several years given flux in hive numbers. Also hive counts were probably less reliable in the past than they are now

[2]A similar crisis and response occurred the mid 1980's when federal statistics for beekeeping where re-established on a yearly basis after the catastrophic arrival of the Varroa mite on U.S. soil.

[3] However on December 6, 2018 USDA announced that it was suspending the Cost of Pollination report. Below we use the data from the 2015-2017 surveys.

spatial and seasonal outline of bee forage in the U.S., a key underlying limiting resource for the beekeeping industry. We conclude that the supply functions for pollination services and honey must be considered jointly, but that the available evidence indicates quite elastic long run supply responses.

Literature review

The last two decades have seen a tremendous increase in research on the entomology and epidemiology of honey bees, and pollinators in general. The economics of beekeeping and pollination has also made progress and a realistic picture of modern beekeeping is now available.

Pollination of crops is organized through contracts between growers and growers and pollination externalities are not a significant factor affecting the costs and returns to modern U.S. beekeeping. The empirical investigations of pollination contracts initiated by Cheung (1973) reveal the detailed mechanisms of these pollination contracts. On each crop, the value of the marginal product of bees (the bee wage) is derived from honey production and pollination services. Pollination fees specified in contracts redistribute a part of the pollination value (captured by growers in the crop harvest) to beekeepers when the value of honey (captured by beekeepers in the honey harvest) is below the bee wage or opportunity cost of the bee stock (born by the beekeeper).

Rucker, Thurman, and M. Burgett (2012) present this model in formal detail and carefully show that it is well supported by pollination fee data from 1987 to 2009 in the Pacific Northwest region. Their analysis outlines the dominance of almond demand in shaping the activity of an increasing proportion of beekeepers..

Goodrich (2017) furthers the study of pollination contracts and documents the development of clauses and third party controls designed to tackle asymmetry in information about hive quality as well as pesticide and other bee health risks. Ferrier et al. (2018) provide a current picture of the U.S. beekeeping industry and also exploit the recent improvements in data related to pollination and colonies. The focus of their investigation is the effect of changes in honey bee health on producers and consumers of pollinated crops. Their thorough analysis finds these effects to be very small but also provide a detailed account of current practices for crop pollination and beekeeping.

These contributions have greatly improved our understanding of pollination markets and transactions, however, they do not focus on the costs and returns of beekeeping itself and are thus not suited to build synthetic supply functions of pollination services or honey.

Studies of beekeeping as an industry, although few, date back almost a century and some develop complex econometric methods to estimate supply functions. For instance, Willets and French (1991) use three-stage least squares and data from 1952 to 1984 to estimate a dynamic and comprehensive model which includes the revenues of pollination, honey, and other bee products. Muth et al. (2003) estimate a response function for number of colonies to honey prices in order to quantify the welfare effects of the federal honey support program. These contributions provide a basis for building a supply model in the current context of a dominant almond pollination demand.

One important limitation of these models is the absence of bee forage as a key input of beekeeping. Champetier, Sumner and Wilen (2015) show that a limited forage resource can result in pollination and honey being substitutes in output rather than complements. Their analytical model better represents the dynamic relationship between the bee stock and the honey stored by bees in the hive.

Lee, Sumer and Champetier (2018) use elements of this dynamic and forage model to build an equilibrium displacement model connecting almond, pollination, and honey markets. This recent contribution highlights the extensive reciprocal relationship between the almonds industry and the beekeeping industry today. However, the simulation effort relies on elasticity parameter for supplies, demands and substitutions that do not take full advantage of available data on beekeeping costs and practices, pollination markets and bee forage.

In rest of this paper, we show how these advances in bee-economics can be applied to the new and recent data in order to both provide compelling and nuanced explanation of observed trends in the beekeeping industry and to anticipate future challenges related to changes in market conditions, climate and bee health. We contribute new detailed cost of production estimates for a synthetic multi-product beekeeping operation. We use these cost estimates and aggregate data from USDA and other sources to characterize and project supply conditions for the U.S. beekeeping industry.

Illustration of the main thesis and implications

We have identified supply functions for the three main outputs of the honeybee industry: the pollination of almonds and a few other early blooming crops, the pollination of other crops that bloom later in the year, and marketable honey. Lee, Champetier and Sumner (2018) simulated the impact of potential shocks to the industry after considering the three distinct outputs but assume a perfectly elastic supply of bee stock.

We focus here on hive numbers supplied and pollination fees in the late winter when almonds are in bloom because that is the binding time period when fees are about four times the fee in any other period. It is also a major revenue source of beekeepers nationally and has influenced supply of hive intensity to honey production.

Consider figure 1 which contains a characterization of the recent history of pollination supply and demand during the later winter period. Start with the 2004 intersection of the demand for pollination and the short run supply function at a pollination fee of about $60 per hive for about 1.1 million hives (inflation adjusted). Two years later, in 2006 the inelastic demand function had shifted out because of the expansion of almond acreage. The inelastic short run supply function (marginal cost of supplying hives) had shifted up due to an increase in winter losses and concerns about honeybee availability. The number of hives used rose by less than 10% to about 1.2 million hives, while the pollination fee rose by 140%. There is some evidence that the $60 pollination fee was below beekeeper full costs of production and the $145 per hive fee in 2006 was a reaction to spot market concerns about bee availability just before the almond bloom.

The subsequent history over the next dozen years is consistent with a continued steady shift out in demand by almost 100,000 hives per year (about 10 to 15% per year). The pollination fee has been relatively stable growing in by between 1% and 2% per year in real terms. Even this rate of increase may overstate the quality adjusted price increase as the number of active bees per hive has risen and the industry has instituted hive quality testing and certification. Figure 1 illustrates this later period by showing shifting demand along a relatively elastic long run supply curve. The period from 2006 to 2018 is consistent with a long supply elasticity of more about 5.0 (doubling of quantity with a 20% increase in price). If the quality-adjusted price increase has been less than 20% that would indicate an even larger long run supply elasticity of pollination services. Figure 1 suggests how we think about the current pollination market but provide no underlying basis for the position or slope of the long run supply function.

Typical beekeeper costs and revenues

Table 1 reports new information on costs of production of beekeeper operations (that supply all three markets) that is consistent with an elastic long run supply function. As we go down the list of cost items listed, all are supplied to the beekeeping industry elastically, given at least a few years to prepare for an expansion. Purchased feed, hired labor overhear and capital recover associated with capital good are all supplied at essentially constant costs to the beekeeper industry. It may take a couple of years to expand the supply of replacement queens. Hired labor can be trained over the course of a couple years. Beekeeper management is more specialized, but as number of hives per manager has grown over time the number of total commercial beekeeping operations has fallen, so even the number of experienced beekeepers have likely not been a limiting factor of production for the industry.

The use of the Langstroth hive, a modular wooden box with moveable frames on which bees build comb and store honey have been the standard of the beekeeping industry for more than a century. Aside from improvements in the transportation of hives with boom loaders and forklifts, or the mechanization of honey extraction, the main practices of beekeeping have not changed to the extent that, for example, dairy, hog or poultry operations have been radically transformed. The change in input mix used in beekeeping today has changed surprisingly little over the last few decades as illustrated by comparing the 1976 costs to the 2018 costs shown in in Table 1.

Purchased feed now comprises about 19% of total costs of beekeeping. Queens and replacements remain a major cost but the share has declined. Hired labor continues to be a major cost item. We emphasize this labor does not include the returns to expertise and management of the beekeeper, who is assumed to be the residual claimant for the operation. Materials and repair make a relatively small share of costs, but these would be significantly higher for the increasing share of operations that rely on interstate movement of bees into and out of California. Overhead and capital recovery costs are major cost share. Interest rates remain relatively low (5% for long-term credit), but a modern 1,000 hive beekeeping operation has several vehicles and forklifts as well as honey extraction equipment in addition to the hives themselves, which depreciate over a decade or so.

Pest management is central to modern honeybee management. The costs for material themselves are relatively small, but the time of the operator and hired labor is significant. As confirmed in Table 2, that bee feeding is standard practice for commercial operations nationwide and control of Varroa mites is practices by about half of all operations. Other pests although sometimes a great threat to the health and survival of bee colonies, only generate moderate expenses in materials when beekeepers implement best practices for early diagnostic and treatment.

The pollination revenues for our example are $171 per hive for 1000 hives used in almonds, $60 per hive for 300 hives used in cherries and $45 per hive for 500 hives used in sunflowers adding up to about $212 per hive (for the full 1000 hives). The hives average 36 pounds of honey at $1.80 per pound for a revenue of $65 per hive. In this example we use pollination fees from the 2017 pollination survey of the California State Beekeepers Association for 2017. Honey yield and price received are 2017 averages for California from the NASS Honey

Report of March 2018. In the typical California operation describe in Table 1, honey represents only about one-quarter of revenue, well below the national average of close to 50%. Almond pollination alone accounts for more than 60% of revenue for this typical operation and the national average includes the sizable minority of hives that do no almond pollination.

Table 1 provides an overview of operation costs and revenues for an entire year. Operations in beekeeping are highly seasonal. Costs and revenues occur at different periods of the year, following the seasons of forage availability and pollination demand. A practical reference point in this beekeeping cycle is the start of the active season with almond pollination. As in table 1, let us follow the time path for a typical 1,000 colony operation operating in Central California. The time path of beekeeper activities, costs and hive numbers is informative of the factors that affect the position and elasticity of marginal cost functions.

In January, the beekeeper will inspect and prepare hives to exit wintering. In early February, 1,000 hives are moved into almond orchards where colonies will begin the expansion of the number of bees that will continue for several months. This movement of hives, like all the others to follow, is a labor-intensive operation despite the use of forklift and pallets. The frequent monitoring and hive adjustments also are labor intensive and continue throughout the active season.

While in the almond orchards, colony populations will consume and store the abundant pollen protein. Almond bloom creates healthy nectar as feed for bees but is not suitable for producing marketable honey. When the almond bloom is over, this growing bee stock will be put to productive use in other pollination services revenue or production of honey from spring forage. Many possible migration routes could be available for at least some of the hives, and the beekeeper will allocate hives across locations based on (1) paid pollination opportunities, (2) other agreements with crop or land owners to allow bees to forage and make honey, (3) general forage conditions determined by the winter rainfall and (4) spring weather conditions. A typical case would be, for instance, to place 300 of the 1,000 hives for paid pollination in cherries in the early spring 500 of hives for paid pollination in sunflowers in the late spring. The rest of the hives and the rest of the season for all the hives would be devoted to finding forage for honey production or simply leaving hives in holding locations where there is at a minimal natural forage will be supplemented with protein and or carbohydrate feed.

Beside movement of hives to new sites, spring colony management requires extensive and qualified labor. The replacement of old queens with newly purchased ones, colony splitting and other specialized tasks require specialized beekeeping skills. From April to June, the beekeeper will separate hives with extra bees into new colonies with a new queen. This increases in the number of colonies is required to keep an annual steady state given anticipated hive losses to come in the second half of the year. A beekeeper with a stable operation size will add as many colonies as expected to lose. Expecting a gradual loss of 30%, to 40% over the second half of the year, a 1,000 colony operation would have to bring population to 1,300 or 1,400 hives by the end of the spring. Bee stock can be purchased later during the year, but a beekeeper with sufficient access to good forage will prefer to build his or her own stock of healthy hives. As the spring season progresses, and as abundant forage is available, operations will shift away from population management and towards extraction of honey from hives. This honey extraction and sale is a third of the income stream for the beekeeping operation.

Throughout the active season, diagnosis and treatment, both prophylactic and curative, require labor and veterinary products. There, the expertise of the operator is indispensable as veterinarians are not commonly involved. The end of the summer is when high feeding costs are most likely to occur in California as forage sources become scarce due to lack of rainfall. In other periods, feeding is used to compensate for temporary dips in the quantity or quality of forage. Reductions in the numbers of healthy hives and losses continue through the summer and fall. Overwintering practices depend on winter temperatures, with hives more active and requiring more management in areas with warmer weather in the late fall and early winter.

Table 1 shows a small net return of $17,000 for 1,000 hives. Clearly, this is insufficient to sustain a full-time manager, so a combination of four options are indicated: (1) Supplement the beekeeping operation with addition businesses or employment, (2) find substantial cost savings, especially in hired labor, (3) find additional revenue perhaps by commanding higher almond fees with higher quality hives or by doing additional pollination for a fee or finding forage to allow more honey production and finally, (4) in combination with options (2) and (3) expand the size of the operation. Many professional beekeeping operations are in the 2,000 to 5,000 hive category and some reach 10,000 hives or more. The costs we have outlined seem to scale up roughly in proportion to number of hives so long as managerial capacity is available.

Honey supply and markets

Table 3 describes the quantities and prices of honey over the past two decades that can help us characterize the honey supply function. During the 1990 the number of honey producing hives in the United States declined substantially from more than 3 million hive to an average of about 2.6 million hives during the five year period 1998 through 2002. In this period, those hives produced an average of 200 million pounds of hone for an average of more than 75 pounds per honey-producing hive. During this period honey revenue of about $200 million dominated pollination revenue. The number of hives has declined gradually over the next decade before recovering in the most recent 5-year period. However, as California almond acres have expanded and honey production declined there, honey per hive has fallen to 58 pounds per hive. (See Figure 3) At the same time however, the price of U.S.-produced honey doubled so honey revenue is up by more than 50%.

In addition to competition for hive procurement to almonds, the other factor affecting U.S. honey markets is competition from imports. The data show that more than twice as much honey imported with a price up by about 80 percent, which results is much more honey in the U.S. market at a markedly higher price. The ratio of price between imported and domestic honey has gradually fallen from just over 70% to just under 65%.

These patterns in price and quantity data are consistent with a shift up in the demand function that faces substitution with imports. Indeed, the price of domestic honey has risen slightly faster than the price of imports (See figure S1 in supplemental materials). Honey use has increased in aggregate, as the slight drop in domestic honey use has been more than offset by a significant increase in honey imports. The price differential indicates a relatively low substitution of imports for domestic honey and there are indications that most domestic honey is used in food processing and almost all U.S.-produced honey is sold in the retail market.

Forage availability

The key input not listed directly in Table 1 is the forage that bees collect from their temporary locations. In most cases, after bees leave the almond orchards there are few options for paid pollination services. University of California cost study participants pollinated an average of about one additional crop (for about one month) during the whole active period from the middle of March through the October. The main activity of bees during this period is thus simply staying safe from pesticide harm and perhaps making honey if nectar resources are sufficient. This honey production may occur in fields of commercial crops, for which no payment is made for any pollination services provided, or more likely in pastures or uncultivated areas without commercial crops.

Feed can be used as an imperfect substitute for forage collected from crops by bees themselves. However, maintaining colonies year around on feed exclusively is not practiced, while supplementing bee-forage with feed in order to balance nutritional intakes of colonies is practiced by a majority of surveyed beekeepers.

Figure 4 shows pollination costs and revenues nationwide and confirms the dominating position of California and almonds in the landscape. Almost two-thirds of acreage and more than 85% of revenue from California with almost no pollination revenue in regions such as the Dakotas which are home to many hives for much of the year. The great bulk of the central part of the United States has little or no paid pollination activity. Blueberry pollination in the North East also provides some revenues that are a fraction of almond revenues.

Current almond fees are high enough to compensate for transportation costs from most if not all locations in the country. Thus, the relevant forage resource for the supply of almond pollination is the entire country. While popular forage area of North Dakota and neighboring states may become overcrowded with bees, the South and Northeast remain rich in forage relative to colony inventories. As a result, the constraint of input limitations will not be exceeded quickly. The supply elasticity of almond pollination will be determined by the ease with which forage can be displaced away from honey production and into bee stock upkeep.

The spatial pattern of migration of bees triggered by almond pollination demand is visible from inventory counts recently implemented quarterly by NASS. Previous colony inventories are annual and fail to reflect the back and forth movement of colonies between California and states where forage or pollination contracts are available after early spring. Figure 4 shows the maximum inventory in per quarter and per state, averaged over the years 2015 to 2017. Colonies concentrate in California during the first quarter and move back to the Dakotas, Texas and Florida during the rest of the year. As overwintering conditions are often more favorable in California than in many states of origin, beekeepers when they can secure access to holding yards in California, bring their bees there before the winter. Summer is when the carrying capacity of California is the lowest, and the inventory the lowest of the year, with around 760 thousand colonies. Additional detail on the timing and location of the migration from and to California almonds orchards is provided by Goodrich (2017) who exploits a rich dataset of shipments inspected at the state border for phytosanitary purposes.

The supply of pollination services to crops blooming after almonds will be even more elastic than the supply of pollination services to almonds. Pollination fees in the rest of the year reflect the surfeit of honey bees in aggregate and the pollination fee will be close to zero, especially if the crop provides subsistence for the bees[4]. Only the specific cost of transactions, including transport, impacts on bee health or foregone honey income of pollinating crops that do not provide healthy forage or honey income. For crops that require pollination and provide any forage at all, pollination fees could decrease in fact. A crop blooming at a period and location where forage is very scarce will see the in-kind payment to beekeepers increase in value, reducing therefore the cash pollination fee.

One challenge to our elasticity hypothesis comes from the 2004-2006 jump in pollination fees. The importance of this jump is however curtailed on three accounts.

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[4] This situation is reminiscent of the Malthusian and Ricardian notion that worker wages would remain at subsistence determined only by the cost of survival and the Marxian notion of the "reserve army of the unemployed" keeping worker wages at subsistence levels.

First, the quality of hives rented has increased significantly over the last two decades. Lack of frame count data so far has prevented definitive quantification. However, all industry observers confirm an increase of counts from 4 or 5 internal hive frames full of bees to 8 frames or more. The abrupt jump in pollination fees from 2004 to 2006 is partly a reflection of a switch in frame contracts among the beekeepers providing almond fee data.

Second, the jump can be attributed to a sudden readjustment in a sticky price market, a plausible mechanism that has been suggested to us by several beekeepers and brokers. Transactions costs between beekeepers and growers are quite high. Almond acreage expansion has continued at a steady pace throughout the last 20 years or more. Yet, pollination fees before and after the single jump of 2004 to 2006 are stable or showing very moderate increases. Unexpected winter losses in 2004 and 2005 resulted in some almond growers revealing high willingness to pay for colony rentals. The price on often-informal contracts that run for years was suddenly readjusted.

Third, a sudden increase in colony losses, if that were to be a reason behind the jump in fees, is now less likely than it was twenty years ago given the great progress in research and monitoring of bee health accomplished since. This positive outlook is supported by the trend in Figure 3 which reports the percentage of colony losses since their first monitoring in 2007.

Concluding remarks

The attention garnered by increased winter losses about a decade ago still resonates among the general public and policy makers. Among other side effects, this attention to pollinators has raised concerns about other wild pollinators that may provide unpaid ecosystem service to agriculture and the potential for agricultural to provide ecosystem service in the form of forage for wild pollinators. For commercial honeybees, the dominant market-based pollinator for agriculture, the spread and morbid effects of varroa mites remains an important cost to the beekeeping industry, the crop industries it services with pollination and the supply of U.S.-produced honey. Changes in climate also have the potential to impact the beekeeping industry through changes in forage resources for bees both on and off farm.

Our assessment of the supply situation for the honeybee industry is one of stability and long run sustainability. Management is meeting challenges to bee health. Transportation is allowing bees to meet the growing demand for almond pollination in the late winter in California at stable real prices. These hives can then easily meet demand for commercial pollination of other crops as they occur mostly in the coastal fruit and vegetable industries.

Honey remains a vital source of revenue for most beekeepers and for the industry as a whole. The price of honey has risen demand has expand and supply of U.S.-produced honey has fallen slightly. Attention to almond pollination, which yields no marketable honey, has drawn hives away from intensive honey production so honey per hive has fallen substantially. The next step for economists is to develop quantitative estimates of the trade-off between almond pollination and honey production in an econometric context and such cross-section time-series data may now be available.

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TABLES AND FIGURES

Table 1. Cost of commercial beekeeping in dollars per hive (1,000 hive operation)

	2018		1976	
OPERATING INPUTS	*$/hive*	*share (%)*	*$/hive*	*share (%)*
Purchased Feed	50.21	19.4	1.72	1.0
Queens bees for replacement	30.38	11.7	30.16	17.9
Pest treatments (including Varroa)	6.17	2.4	0.86	0.5
Hired Labor (operator not included)	66.00	25.5	39.16	23.3
Other materials and repairs	6.22	2.4	27.83	16.5
Interest on operating capital @5.5%	4.23	1.6	5.00	3.0
TOTAL OPERATING COSTS	158.11	61.0	104.73	62.2
TOTAL CASH OVERHEAD COSTS (Rent, utilities, taxes etc …)	51.18	19.7	16.80	10.0
ANNUAL CAPITAL RECOVERY (interest and depreciation of capital)	50.00	19.3	46.78	27.8
TOTAL COSTS	259.29	100	168.31	100
Honey Revenue	64.80	23.5		
Other crop pollination	40.50	14.7		
Almond Pollination	171.00	61.9		
TOTAL REVENUE	276.30	100		

Source: University of California Agricultural Issues Center., "Cost and returns study for 1,000 colony beekeeping operation 2018". "Bee Industry Economic Analysis for California, Division of Agricultural Sciences, University of California, Leaflet 2345, April 1976. Figures reported in 2018 dollars.

Table 2. Feed and bee health practices among U.S. beekeepers.

Input	Adoption (% of operations)
Carbohydrate feed	88%
Protein Feed	47%
Varroa mite control	46%
Feeding: Supplements and Additives	31%
Nosema control	14%
Bacterial brood disease control	7%
Tracheal mite control	2%

Source: Bee Informed Partnership, National Management Survey 2015, available at https://bip2.beeinformed.org/survey/, Commercial Operations, percentage of beekeepers who used product out of respondents.

Table 3: Average Colonies, honey production, imports and prices in the U.S.

	Colonies	Domestic Production	Domestic Price	Import Quantity	Import Price
	(1,000)	*(1,000 lbs)*	*($/lbs)*	*(1,000 lbs)*	*($/lbs)*
1998 - 2002	2,607	200,330	1.00	172,099	0.72
2003 - 2007	2,479	168,616	1.28	224,434	0.85
2008 - 2012	2,512	155,464	1.70	258,436	1.21
2013 - 2017	2,697	158,766	2.05	380,776	1.30

Sources: Domestic data, *Honey Reports* USDA, Import data: United States International Trade Commission, GDP Deflator: Federal Reserve Economic Data.

Table 4: Geographic Distribution of pollinated acres and total payments value, average hive densities and average fees

Region	**Paid pollinated acres**		**Value of pollination**		**Average density**	**Average fee**
	1,000 acres	*(% share)*	*$1,000*	*(% share)*	*hives / acre*	*$ / hive*
1	240	(13.5)	17965	(5.2)	1.0	75
2	89	(5.0)	5,446	(1.6)	1.1	56
3	58	(3.3)	5,653	(1.7)	2.2	44
4	11	(0.6)	1,767	(0.5)	3.2	50
5	239	(13.4)	14,056	(4.4)	1.3	49
6 & 7	1,149	(64.3)	296,531	(86.6)	1.8	144
Total/average	1,786	(100.0)	342,418	(100.0)	1.8	120

Source: NASS, Cost of Pollination Survey, 2015, 2016, 2017.
Note: Major states in the numbered regions are as follows: Regions: 1: States of the Northeast and Midwest, including Kansas; 2: Appalachian and Southeast, 3: Florida, plus South and Southwest from Mississippi and Missouri through New Mexico; 4: Minnesota and Dakotas through Mountain states; 5: Northwest including Alaska; 6 &7: California, Arizona and Hawaii.

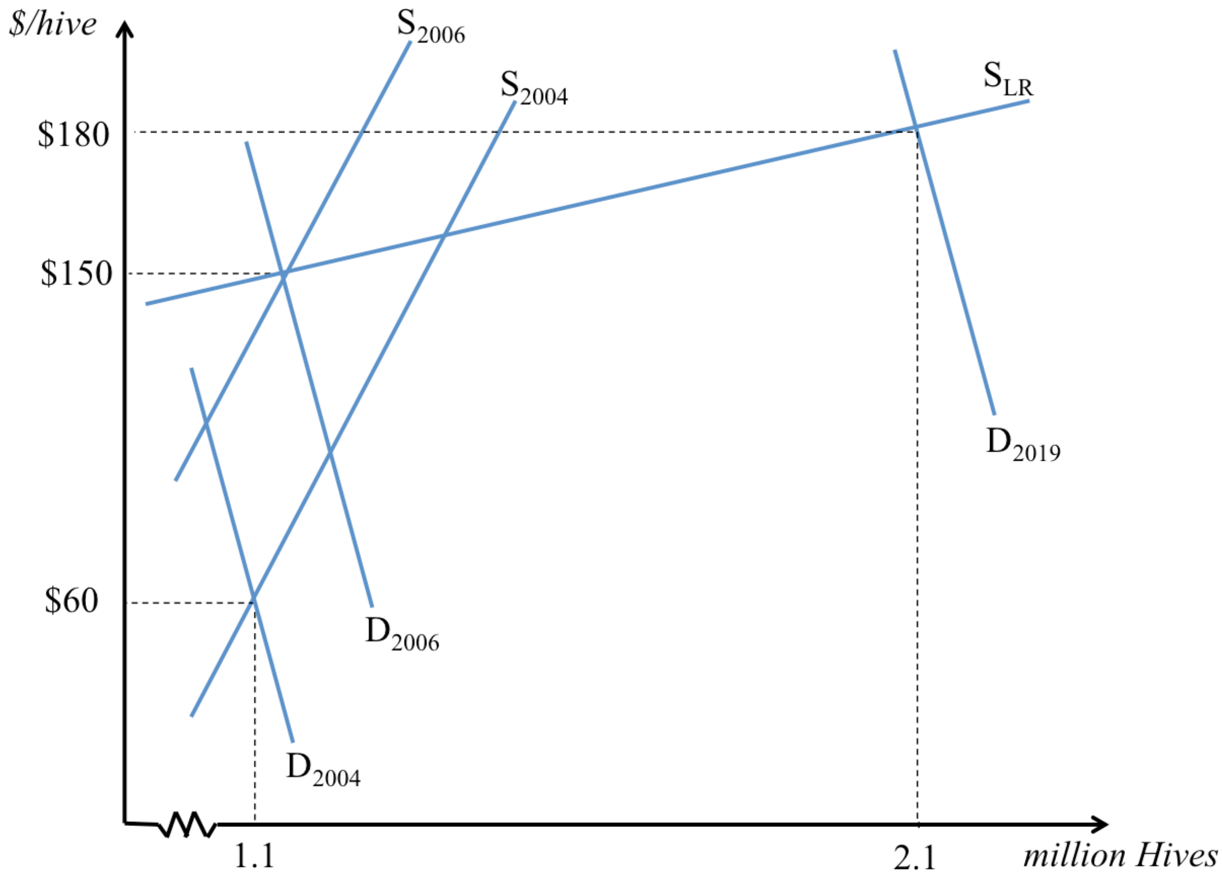

Figure 1: Supply and demand for late winter/early spring pollination services

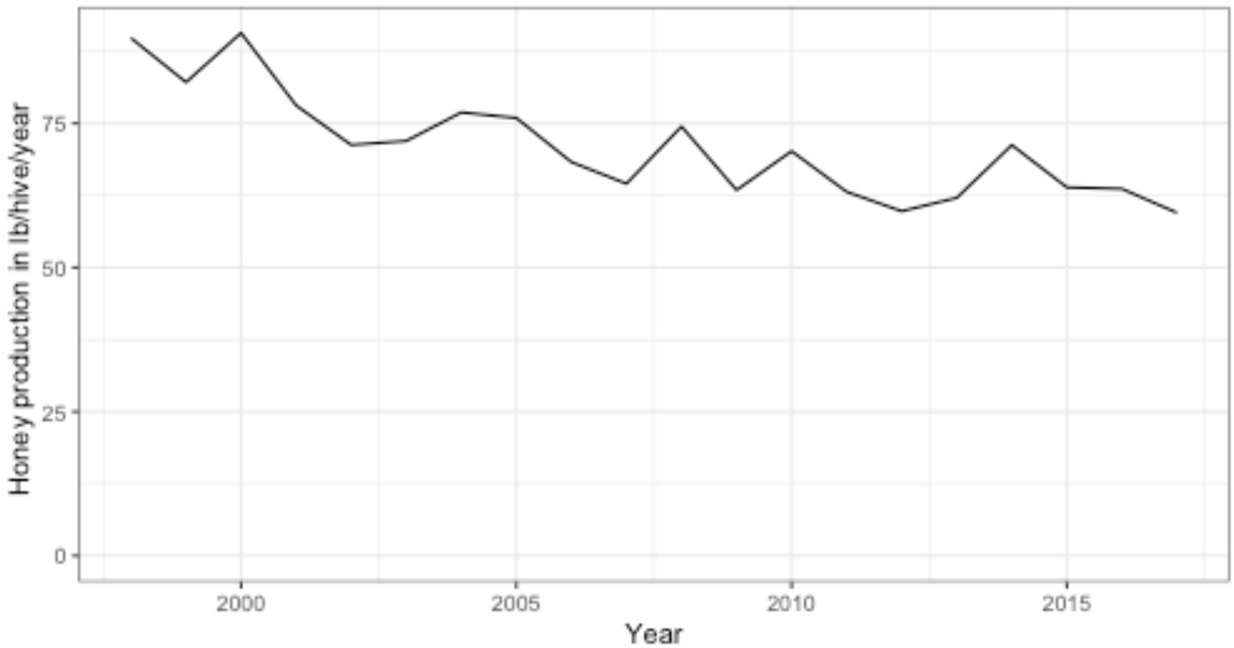

Figure 2: Average honey production in pounds per hive per year in the U.S.

Source: NASS, Honey Report.

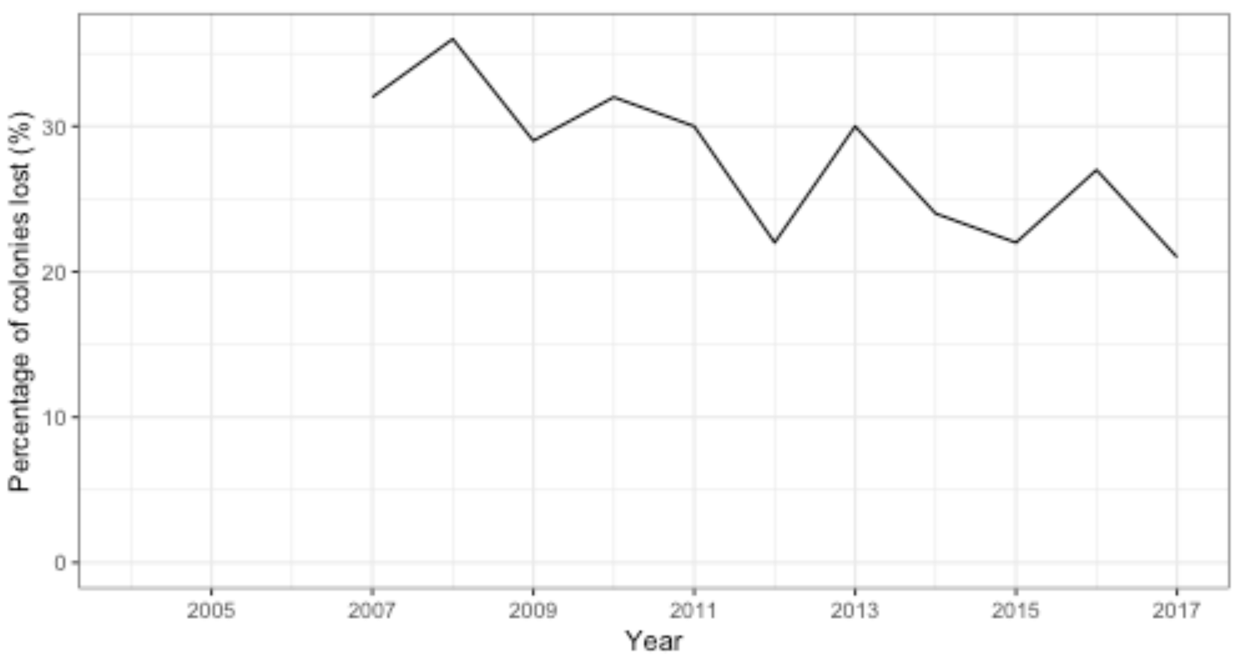

Figure 3: Percentage of colonies lost during winter in the U.S.

Source: Bee Informed Partnership. Colony losses surveys, 2007 to 2017.

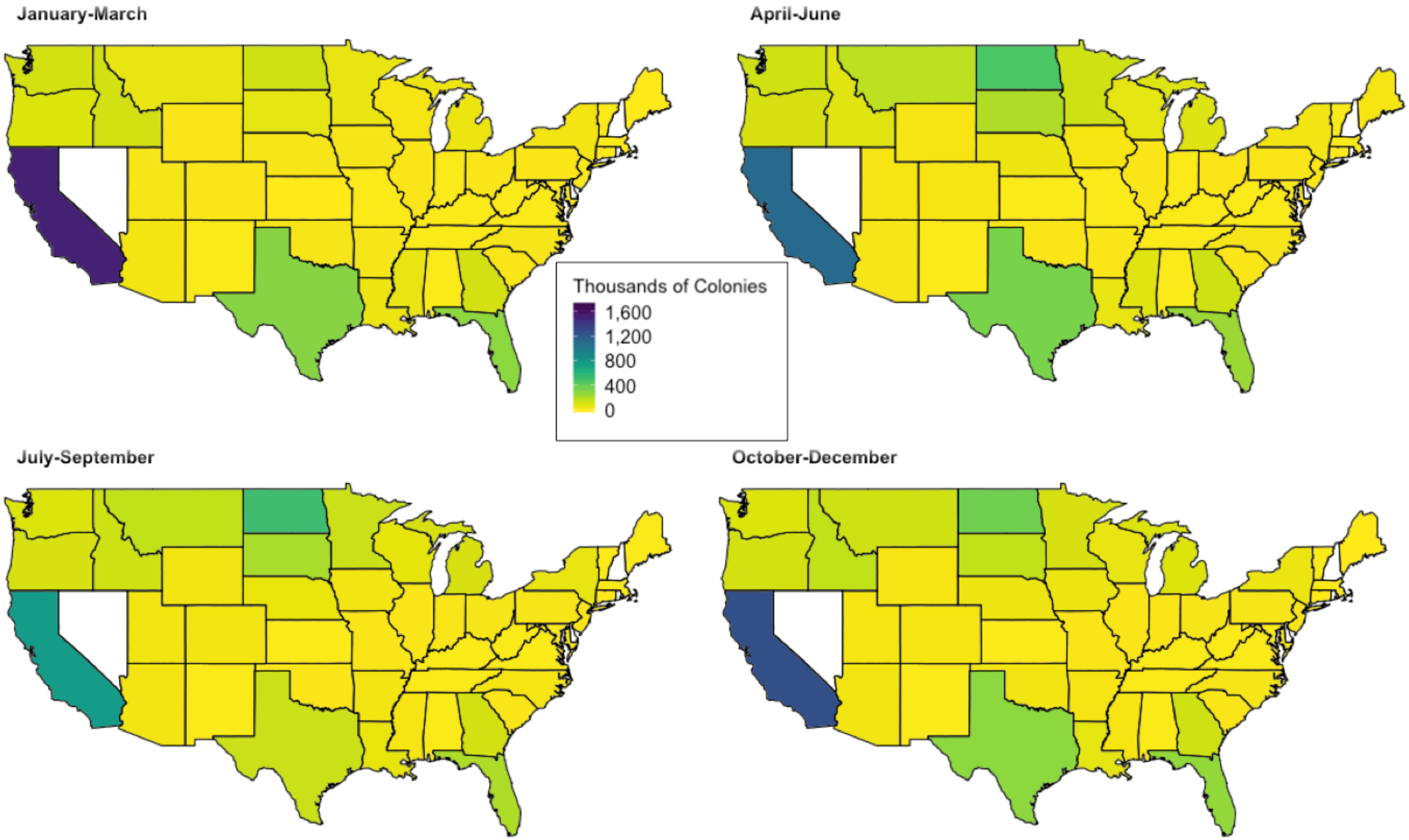

Figure 4: Maximum colony inventory by quarter, averages for 2015, 2016 and 2017.

Source: NASS, Colony Surveys.

SUPPLEMENTAL MATERIAL

Table 1. U.S. statistical surveys of beekeeping.

Years covered	Name	Variables	Participants, (% coverage)
1900s to present (5 years)	Agricultural Census	Colony Inventory on Dec. 30, Honey production for the year, number of operations.	Census, more than 5 colonies, both pollination and honey operations
1986-present Since 2016	Bee and Honey Inquiry Survey (originally Honey Report)	Max. colonies producing honey in year, honey price received, yield and production Costs and revenues	Honey producing operations
2015-present	Honey Bee Colonies		
2007-present	Colony Loss Survey	Winter losses and summer losses (since 2015??), imputed causes	Sample
2016	Cost of Pollination Survey	Colony use, and densities per acre, pollination fees	2017 sample size was 14,532 and the 2016 sample size was 19,931
1986-present, (yearly)	Pacific North West Beekeeper survey	Pollination fees, colonies used, densities per acre	
1995-present, (yearly)	California State Beekeeper Association Pollination Survey	Pollination fees	

Table S2: Example of colony inventory, losses and replacements for 1,000 colonies operation.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year max.
Almonds	0	1,000	1,000	0	0	0	0	0	0	0	0	0	1,000
Cherries	0	0	0	300	300	0	0	0	0	0	0	0	300
Sunflowers	0	0	0	0	0	500	500	500	0	0	0	0	500
Holding Yards	1,049	0	0	700	870	869	869	814	1,262	1,211	1,163	1,105	1,262
Total	**1,049**	**1,000**	**1,000**	**1,000**	**1,170**	**1,369**	**1,369**	**1,314**	**1,262**	**1,211**	**1,163**	**1,105**	**1,369**
													Year total
Splitting	0	0	0	170	199	0	0	0	0	0	0	0	369
Summer/Fall Losses	0	0	0	0	0	0	55	53	50	48	0	0	206
Winter Losses	52	0	0	0	0	0	0	0	0	0	58	55	166

Source: University of California Extension, Cost and returns study for 1,000 colony beekeeping operation 2017

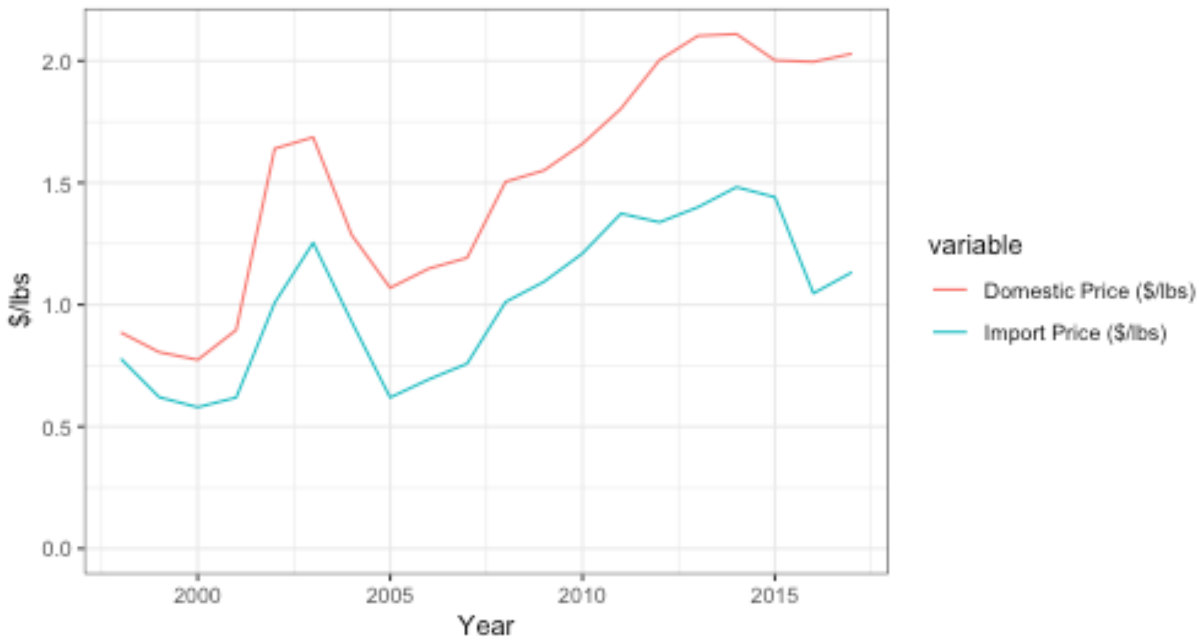

Figure S1: Price of domestic and imported honey between 1998 and 2017, in 2012 dollars per pound.

Source: NASS, Honey Report and US International Trade Commission

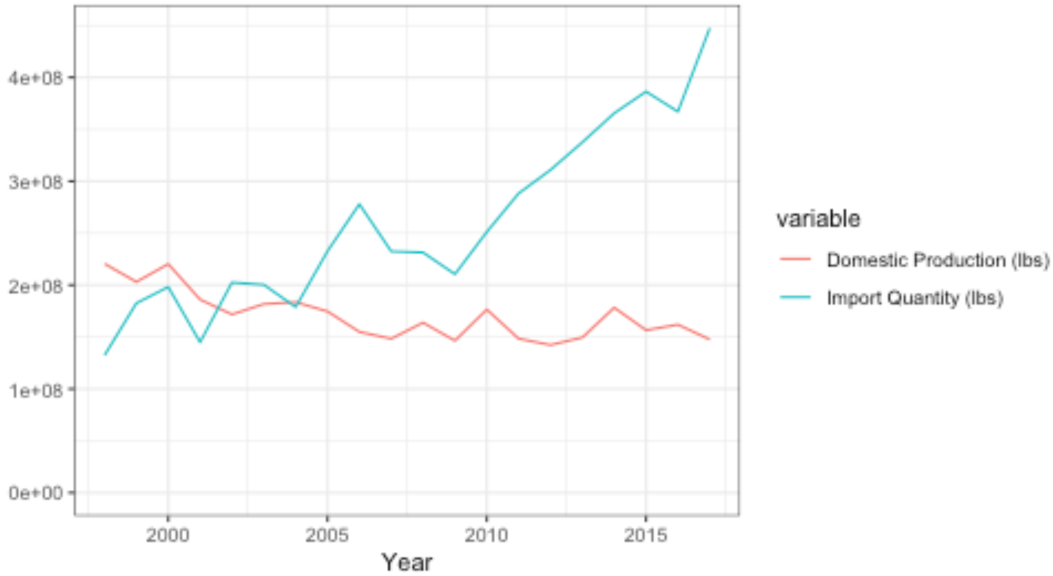

Figure S2: Domestic production and import quantity between 1998 and 2017, in pounds.

Source: NASS, Honey Report and US International Trade Commission

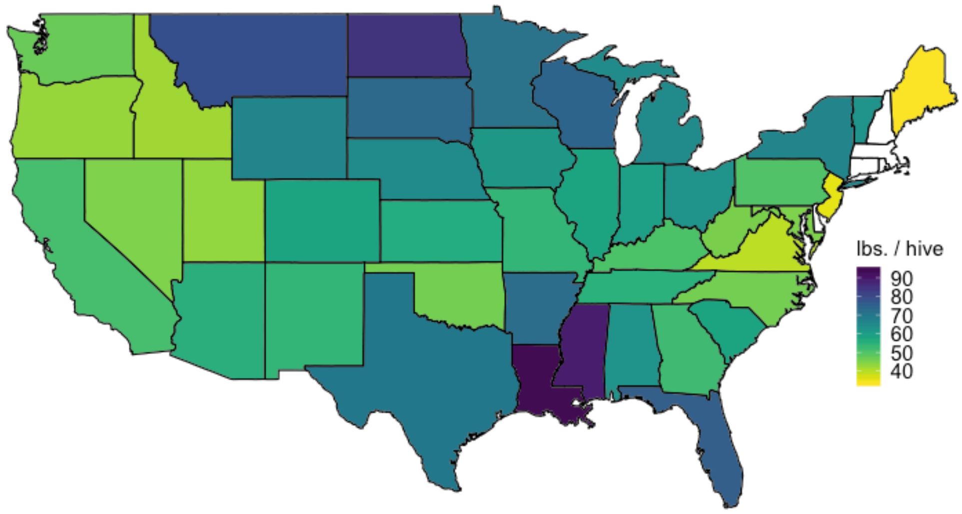

Figure S3: Average honey yield in pounds per hive between 1998 and 2017.

Source: NASS, Honey Report

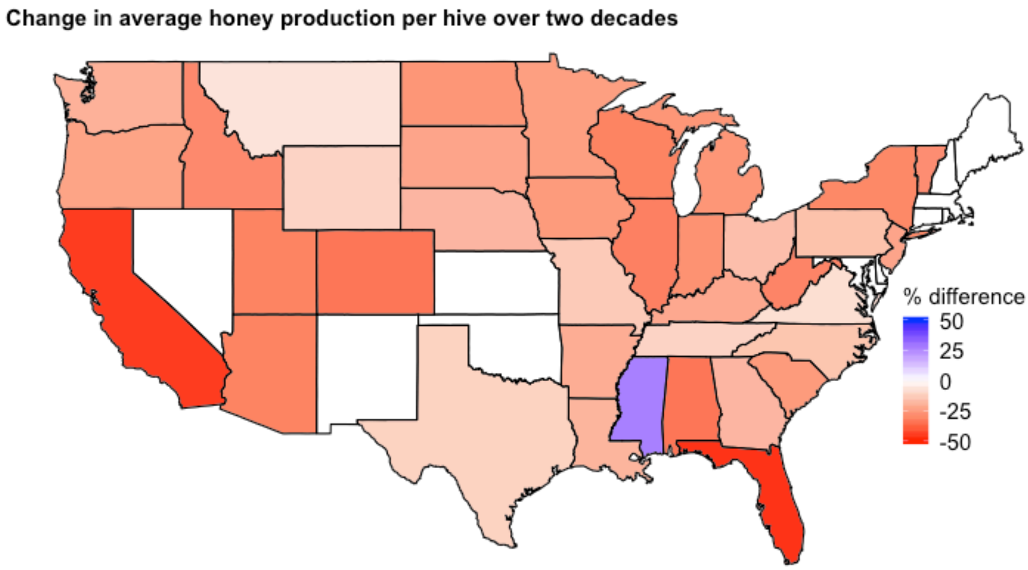

Figure S4: Percentage difference in honey production in pounds per hivc the U.S. between 1998-2002 and 2013-2017.

Source: NASS, Honey Report