

**The Great Bee Migration: Supply Analysis of Honey Bee Colony Shipments into California
for Almond Pollination Services**

Brittney Goodrich
Auburn University
Department of Agricultural Economics and Rural Sociology
213 Comer Hall
Auburn, AL 36849
Phone: (334) 844-5614
E-mail: bkg0007@auburn.edu

Jeffrey Williams
University of California, Davis
Department of Agricultural and Resource Economics
2144 SS&H
Davis, CA 95616
Phone: (530) 754-7625
E-mail: williams@primal.ucdavis.edu

Rachael Goodhue
University of California, Davis
Department of Agricultural and Resource Economics
2146 SS&H
Davis, CA 95616
Phone: (530)-754-7812
E-mail: goodhue@primal.ucdavis.edu

*Invited paper by the President of the Agricultural & Applied Economics Association for
presentation at the 2019 annual meeting of the Allied Social Sciences Association, Atlanta,
GA, January 4-7, 2019.*

Copyright 2019 by Goodrich, Williams and Goodhue. All rights reserved. Readers may make verbatim
copies of this document for non-commercial purposes by any means, provided that this copyright notice
appears in all such copies.

Abstract

Over the last two decades, the number of honey bee colonies performing pollination services for the California almond industry has grown steadily and now equals a substantial share of all colonies in the U.S. Most U.S. beekeeping operations have not expanded their colony numbers at the current levels of almond pollination fees. Thus, as almond acreage has increased, the marginal supplier of colonies has moved further away from California, increasing interstate shipments. We provide a conceptual representation of the supply and demand of U.S. colonies for almond pollination, and utilize the relatively inelastic demand for colonies to explore spatial elasticities of supply. We analyze temporal and spatial characteristics of the supply of colonies for almond pollination using colony shipment data from 2007 through 2018 provided by the California Department of Food and Agriculture. We use a geographically weighted regression to calculate supply elasticities for each state during this time period by combining the shipment data with prices from the California State Beekeeper’s Association pollination fee survey. Florida and Texas, where beekeepers have hesitated to participate in almond pollination due to relatively high transportation costs and the potential for local honey production at the time of almond bloom, have some of the highest price elasticities of supply. This suggests that beekeepers in areas with low transportation and/or opportunity costs have supplied all available colonies, and increases in almond pollination fees have had little effect. We estimate that Florida, Georgia and Texas had the largest number of colonies which did not participate in almond pollination in 2017, so further increases in supply are likely to come from these states.

1 Introduction

Spatial relationships are an important component of the supply of many agricultural commodities. Commodities are typically produced over a wide area, and transportation to a destination market constitutes a large portion of costs (Fackler and Goodwin, 2001). Many studies have examined spatial price relationships, not to mention market integration, in various types of agricultural markets, e.g., corn and soybeans (Goodwin and Piggott, 2001; Barrett and Li, 2002), ethanol (Khachatryan, Yan, and Casavant, 2011; McNew and Griffith, 2005), and livestock (Faminow and Benson, 1990; Goodwin, 2006). Almond pollination services is another example of a market in which spatial relationships are important, because colonies are housed all over the United States (U.S.) and transported to their destination market in California each February. The complexities of the spatial relationships are greater in this market than for many other commodities because the destination market is temporary. The effect of the spatial nature of the beekeeping industry on the supply of pollination services in the U.S. is pronounced and has yet to be thoroughly explored, even though some of the complexities of migratory beekeeping have been highlighted by past literature, e.g., Bond, Plattner, and Hunt (2014); Ferrier et al. (2018).

Forage is a limiting factor for honey bee populations, so the location and availability of forage creates geographical variation in the U.S. beekeeping industry (Nickeson and Wolfe, 2017; Nye, 1980). For example, roughly a third of honey production in 2017 took place in North Dakota and South Dakota, yet no bee, let alone beekeeper, wants to spend the whole year in North and South Dakota due to the harsh winters. Winter weather can have a substantial impact on winter mortality rates, i.e., the percentage of colonies that do not survive the winter. Because of such variation in climate and forage availability, commercial beekeepers are often migratory, avoiding harsh weather and/or “following the bloom” in order to avoid

paying for supplemental food to feed their colonies (Bond, Plattner, and Hunt, 2014).

California almond production required approximately 81% of honey bee colonies in the U.S. in 2018 for its pollination needs (USDA, 2018). This dominance of almonds for a few weeks in February would not matter if bees were utilized for pollination or honey production in California the rest of the year. Over 1.8 million colonies were shipped into California in 2018, compared with the approximately 600,000 colonies native to California (USDA, 2018; California Department of Food and Agriculture, 2018). Almond pollination now makes up a third of U.S. beekeeping income, and many commercial beekeeping operations depend on the almond pollination market (Lee, Sumner, and Champetier, 2019). Commercial beekeepers usually start out their migratory year in California for almond pollination, taking advantage of the relatively high pollination fees, and then move colonies elsewhere for the remainder of the year.

In addition to influencing the geographic nature of the beekeeping industry, forage limits the ability of a beekeeping operation to expand, as expanding makes it more costly to feed colonies. The commercial beekeeping industry is dominated by large operations with more than 1,000 colonies (Daberkow, Korb, and Hoff, 2009). According to Jones Ritten et al. (2018), beekeeping operations with more than 1,000 colonies experience decreasing returns to scale. Expansion of a beekeeping operation's capacity involves large fixed investments (Randy Oliver, personal communication). Thus, most beekeeping operations throughout the U.S. would not be willing to expand the number of their colonies without significant increases in almond pollination fees.¹ Because beekeepers in California and nearby states hesitate to expand operations, the supplier of colonies for the additional almond pollination demand has moved further away from California, increasing interstate shipments of honey bee colonies.

To make almond pollination profitable for any one beekeeping operation, almond pollination fees must cover the costs of transportation to the almond orchards, as well as any opportunity costs. Because colonies are coming from far distances, beekeepers want to take advantage of economies of scale in shipping, so colonies usually come into California via tractor-trailer loads. In 2018, the average number of colonies per shipment into California was 398 and there is little variation about this number (California Department of Food and Agriculture, 2018). One might think that smaller beekeepers could combine their shipments into one truckload, but that seems rarely to happen. Beekeepers ship by the truckload and this discreteness matters given their typical scale. For example, if a beekeeping operation wants to expand, it has to do so by a truckload of colonies to make it economical. In regards to opportunity costs, beekeepers in some southern states historically have observed opportunity costs of participating in almond pollination due to the potential for honey production at the time of almond bloom (ETBA, 2000; Ellis and Zettel Nalen, 2010).

¹There also could be an expansion of the number of beekeeping operations in nearby states, but that has not seemed to have happened.

Thus, almond pollination fees must cover lost honey production revenue as well.

Given the transportation costs and the alternative of honey production, it is important to answer the following questions regarding the supply of pollination services in almonds: From which states are colonies transported? How has the supply source changed as almond acreage has increased in recent years? What effect do winter mortality rates have on the supply of colonies for almond pollination? Learning more about the supply of colonies for almond pollination can serve as a basis for future studies of markets for pollination services, in addition to helping almond growers and beekeepers make informed decisions regarding the market for almond pollination services.

Using data provided by the Pest Exclusion Branch of the California Department of Food and Agriculture (CDFA), we analyze shipments of honey bee colonies into California through its Border Protection Stations (BPS) for almond pollination seasons 2008 through 2018. The largest increases in shipments into California since 2008 have come from the states of Florida and Georgia, where beekeepers have relatively high transportation and opportunity costs. We find that a one dollar increase in the net per-colony pollination fee (fee less transportation costs), increases colony shipments into California by 1,414 colonies. Due to the geographic nature of the beekeeping industry, we use a geographically weighted regression (GWR) to determine spatial price elasticities of the supply of colonies for almond pollination. When geographic variation is accounted for, we find that states in the Southeast have an elastic supply and are more responsive to fee increases than other states. Some states, e.g., North and South Dakota, have negative supply elasticities, which contradict economic theory. We attribute this to transshipment through other states, e.g., Idaho, Oregon, and Washington, prior to almond pollination so that colonies may overwinter in warmer areas.

Increasing almond acreage, and therefore the increasing demand for colonies, has been of interest within the almond pollination industry. Using the aggregated estimates, we find that almond pollination fees would have to increase by 1.6% by 2020 to account for increasing demand; however when using more appropriate spatial estimates, we estimate that fees would have to increase by 7.9%. This contrast in estimates indicates that the spatial characteristics of the supply of pollination services are important. We estimate the number of colonies that did not participate in 2017 almond pollination using 2017 colony shipments into California compared with USDA estimates of honey bee colony populations by state. We estimate that Florida, Georgia, and Texas have the largest number of colonies which did not participate in almond pollination in 2017. Thus, we predict that as almond acreage continues to increase, further increases in colonies shipped will likely occur from these states, so long as pollination fees increase accordingly.

The prior literature on the economics of pollination services primarily has concentrated on determinants of pollination fees with a special focus on the reciprocal benefits of honey production and pollination, showing that pollinated crops with higher honey production receive lower pollination fees (Sumner and Boriss, 2006;

Ward, Whyte, and James, 2010; Champetier, Sumner, and Wilen, 2015; Carman, 2011; Rucker, Thurman, and Burgett, 2012). We provide the first comprehensive exploration of the supply of colonies for almond pollination. The substantial spatial differences in per-colony transportation costs have not been highlighted by previous literature on the economics of pollination services, despite likely being one of the primary factors influencing beekeepers' decisions regarding almond pollination. Our findings add to the expanding literature regarding pollination services, which will continue to grow in importance as the demand for honey bee pollination services increases worldwide (Aizen and Harder, 2009). For example, Lee, Sumner, and Champetier (2019) use an equilibrium displacement model, which provides an implied supply elasticity of colonies to almond pollination of 0.77. We estimate that 148,000 additional colonies will be needed by 2020, using the Lee, Sumner, and Champetier elasticity results in an approximate 10% increase over the 2017 almond pollination fee compared with our GWR estimates which require a 7.9% increase in fees. Thus, we provide parameters that can be used to calibrate future models of the pollination services industry.

Though it is not the primary focus of this paper, we find that winter mortality rates have a significant negative relationship with honey bee colony shipments for almond pollination. Colony health issues over the winter can effect both the per-colony fee received by a beekeeper, as well as the quantity of colonies a beekeeper can rent for almond pollination (Goodrich, 2017). Knowing that a large portion of commercial beekeeping operations in the U.S. depend on almond pollination income, this relationship can have important consequences for the economic sustainability of beekeeping operations, as well as almond production.

The supply of pollination services in the U.S. has spatial characteristics that set it apart from the spatial nature of other commodities. In early February, there is only one destination market (California almonds), reducing decisions regarding which market to ship to. However, the fact that bee colonies must be kept alive to maintain their value, means that strategic movements may occur prior to placing colonies in the almond orchards. Beekeepers want to minimize pesticide and disease exposure for their colonies, so they may transship colonies through other destinations before arriving in the almond orchards. Related to this, colonies must leave California after almond pollination due to the lack of available forage, so their destination market is not final, merely temporary. A discreteness occurs in this market, which can be compared to other commodities, i.e., it is most profitable to maximize the pounds of cattle that are shipped. However, unlike cattle, corn, and soybeans which can be combined by an intermediary and shipped to market, beekeepers often do not combine colony shipments for almond pollination. Such arrangements lead to disputes when it comes time for payment or when the returning health of the colonies has been compromised.²

We begin by providing some background regarding the reasons behind regional variation in the U.S.

²Many contracts for almond pollination involve fees that are based on colony strength requirements (Goodrich and Goodhue, 2016; Goodrich, 2017). We have heard from industry participants that disputes arise when one beekeeper gets paid less per-colony than another due to these requirements.

beekeeping industry, and we conceptually illustrate the market equilibrium in almond pollination. In Section 3, we describe the apiary shipment data utilized in this analysis. In Section 4, we outline the geographically weighted regression (GWR) methodology used to analyze the data, and we present results of the GWR analysis. After discussing the results, we provide a look at the future demand and shipments for almond pollination services, then in Section 5 we conclude.

2 Background

Due to climate variability and the locations of forage sources, there are regional differences in honey production and honey bee colony populations within the U.S. Climate variability influences colony health, while forage sources influence the quantity and quality of honey produced, and consequently, the cost of feeding colonies. These spatial characteristics ultimately impact the market equilibrium of almond pollination services industry.

2.1 Regional Variation in the U.S. Beekeeping Industry

In nature, colonies are not placed to produce particular types of honey. Beekeepers, in contrast, strategically place colonies to produce any number of the hundreds of different honey varieties. These varieties range in quality. Some varieties are found only in specific regions, some almost everywhere. Clover honeys, a desirable type, are one of the most common honeys produced in the U.S., and these can be produced in almost every state (USDA Agricultural Marketing Service, 1985; National Honey Board, 2007). Also in this group of desirable honeys are honeys such as fireweed (produced in northern U.S. states), and orange blossom (produced in California, Texas, Arizona and Florida). USDA has two other designations for honey varieties, “Honeys that have a distinctive flavor” and “Honeys least desirable or even unpalatable.” Many crops requiring pollination services fall into the last category, i.e., avocado, cantaloupe, carrot, cucumber, onion, and almond. To emphasize, honey produced during almond pollination has little to no value.

Nye (1980) outlines regional variation in the beekeeping industry, highlighting the major honey crops of each region and the differences in the types of beekeeping operations. Nye’s beekeeping regions are displayed in Figure 1. For example, Nye discusses that the severe winters of the Northeast translate to few commercial beekeeping operations, while the Plains region is known for its large number of commercial operations because of the high amount of honey-producing forage during the summer months. The Southeast and Southwest are good areas to overwinter colonies due to mild winters. Consistent with the regional variation highlighted by Nye, both major beekeeping magazines, *American Bee Journal* and *Bee Culture*, provide honey market

reports by regions that are similar (*Bee Culture Magazine*, 2018; *American Bee Journal*, 2017).

Without adequate forage, beekeepers must supply colonies with sucrose syrup and artificial pollen (Alger et al., 2018). To reduce the amount of food supplements that must be purchased, many commercial beekeeping operations move colonies from one blooming crop to another (Bond, Plattner, and Hunt, 2014). This movement can be local, or can occur on a much larger scale, such as the movement from almonds in California to Maine for high bush blueberry pollination. Almonds bloom in early to mid-February, a time when very little else is blooming elsewhere in the U.S. After the almond bloom, beekeeper’s paths diverge, their bees pollinating other blooming crops in the Pacific Northwest or the Southeast. Bond, Plattner, and Hunt (2014) estimate that 65-85% of the commercial honey bee colonies in the U.S. spend summer months producing honey in North Dakota, South Dakota, Montana and Minnesota.

Table 1 provides a comparison of the 1978 colony populations in each region with comparable populations for 2015, more specifically, the maximum number of honey bee colonies in each region from October through December 2015.³ Table 1 indicates that overall U.S. colony populations have increased slightly since 1978, though this increase could be primarily due to differences in the statistics being compared.⁴ Regional colony populations as a percentage of the U.S. total have remained similar across time. The largest fluctuation in the total share of U.S. colonies was in the North Central region, a decrease of fewer than eight percentage points. California saw a large increase in its share of U.S. colonies from 1978 to 2015, which is likely due to early transport of colonies from other regions for almond pollination.

2.2 Market Equilibrium in Almond Pollination

Figure 2 shows a conceptual representation of the supply and demand for colonies for almond pollination. The supply of colonies is segmented into beekeeping regions following Nye (1980). Should each region have a distinct minimum marginal cost, the supply of colonies can be represented as a step function. The regional differences in marginal costs represent transportation cost and opportunity cost differences across regions.⁵

³Because of the migratory nature of commercial beekeeping operations, the maximum number of colonies in each region October-December 2015 is the closest in comparison to the December 31, 1978 population numbers. USDA collects colony populations as of January 1, though these are not useful in comparison to the 1978 population numbers because during the October-December time period many colonies are now transported to California for almond pollination.

⁴The maximum number of colonies from October through December 2015 may not account for any colony mortality taking place during this time, while October through December colony mortality would be accounted for in the December 31, 1978 colony count.

⁵In reality, the regional marginal cost curves may be nonlinear, differ in slope, and likely overlap. For example, a beekeeper in the Southeast region with high transportation costs may choose to transport colonies for almond pollination at a lower price than a beekeeper in the Southwest region if the Southwest beekeeper has relatively high opportunity costs of participating in almond pollination due to honey production. As will be discussed later in Section 4.2, there are beekeepers in regions other than the Southeast and Northeast who are not yet participating in almond pollination. This could be due to other transaction costs of entering the almond pollination market, or arrangements to transship colonies through other states. Additionally, beekeepers may choose not to transport some (or all) of their colonies to California for almond pollination due to the potential risks to colony health.

The relative marginal costs depicted are estimates based on information from industry participants. The dominant fact is that marginal costs increase as the distance travelled to California increases. Table 2 shows estimated per-colony shipment costs from each region using a cost of \$3 per-mile for a truck shipment of 400 colonies.⁶ Shipment costs range from \$9 per colony in nearby states, (less than 1% of the 2018 pollination fee) to \$50 per colony for states in the Northeast (26% of the 2018 pollination fee). These substantial spatial differences in per-colony transportation costs have not been highlighted by previous literature on the economics of pollination services, despite likely being one of the primary factors influencing beekeepers' decisions regarding almond pollination.

The demand for colonies for almond pollination is represented as effectively perfectly inelastic on a per-acre basis using the industry rule of thumb of two colonies per acre of almonds.⁷ We depict two demand curves, one which represents recent pollination demand in 2016 and one based on the almond pollination demand of 1977. This year was chosen to illustrate a conclusion of Rucker, Thurman, and Burgett (2012) that the demand for colonies for almond pollination exceeded most of the supply of colonies from Pacific Northwest and California beekeepers after 1977. According to the 1978 USDA Agricultural Census, there were 347,159 acres of almonds which would have required roughly 600,000 honey bee colonies for pollination.⁸ Table 1 shows the USDA Agricultural Census colony populations in each beekeeping region at the end of 1978. California and the Pacific Northwest beekeeping region had just over 600,000 honey bee colonies, consistent with the conclusion of Rucker, Thurman, and Burgett (2012). In 1977, therefore, the marginal supplier of colonies for almond pollination was in the Pacific Northwest. After 1977, the marginal supplier has been located in other parts of the country with higher transportation costs.

Because the current distribution of colonies throughout the U.S. is fairly similar to the distribution nearly 40 years ago as seen in Table 1, it seems that any supply shocks that have altered beekeeping costs have done so similarly across all regions, leading to vertical shifts in the total supply of colonies. The vertical supply shifts would change the equilibrium almond pollination fee, but would not significantly change the location of the marginal supplier of colonies. Thus, for simplicity, Figure 2 shows one supply curve. The similar distributions in Table 1 also provide evidence that the levels of almond pollination fees thus far have not been high enough to incentivize beekeeping operations to substantially expand their capacity in any region, even those in close proximity to California.

As the demand for colonies for almond pollination has increased due to increased acreage, the equilibrium pollination fee has increased to bring colonies from regions further away to meet pollination needs. Figure 2

⁶From conversations with commercial beekeepers, in 2017 per-mile shipment costs ranged from \$2.75-3.15 for each semi-load of colonies.

⁷See Goodrich (2017) for further discussion on the use of the rule of thumb in the almond industry

⁸Some of these almond acres were at non-bearing age.

depicts this relationship. In 2018, colonies were shipped into California from as far as the northeastern U.S. Almond pollination fees have risen accordingly to cover transportation and opportunity costs.⁹

To take advantage of the size of a truck, beekeepers would want to put as many hives as possible onto one semi-truck.¹⁰ Beekeepers are limited by weight and size restrictions in shipment, so typically a semi will carry 400-450 colonies (Wyns, 2018). For example, looking at Table 2, if only 200 colonies were transported per shipment, that doubles the per-colony cost of shipment. For far away regions, such as the Northeast and Southeast, that would increase shipment costs to around \$80 per colony, roughly 40% of the 2018 almond pollination fee. According to Daberkow, Korb, and Hoff (2009), nearly 90% of U.S. honey bee colonies in 2002 were owned by beekeeping operations with 300 or more colonies. Thus, these larger operations are going to be the ones supplying colonies for almond pollination, and they contemplate sending one or more trucks.¹¹

3 Data on Origin of Apiary Shipments

The California Border Protection Station (BPS) records every truck shipment of honey bee colonies entering the state. As seen in Figure 3, there are sixteen border stations in California.¹² The inspection of apiary shipments seeks to prevent the spread of invasive species that may be hitchhiking on hives or beekeeping equipment (California Department of Food and Agriculture, 2015). Information is gathered on each apiary shipment regarding the origin location, destination in California, and the number of colonies it contains. The origin is important because shipments coming from states with known populations of invasive species are scrutinized more closely.¹³ At the border station, the outsides of the apiary shipment are inspected, and then the destination county’s Agricultural Commissioner’s Office is notified so that a more intensive inspection can be conducted upon arrival at the destination. If an apiary shipment is rejected at the border, it must be cleaned before attempting to re-enter.¹⁴

⁹Some of this rise in almond pollination fees could be due to vertical supply shifts resulting from colony health issues which have likely increased costs of production for beekeepers.

¹⁰Beekeepers may own and operate their own semi, however they often contract through shipping companies. Because bee colonies are put on pallets and shipped, trailers do not have to be specialized for shipment. Not every shipping company ships bees, but most that ship bees will ship other freight, as well. For example, the following freight companies ship bees and other freight: Herren Enterprises, Inc. (<http://www.herreninc.com/>) and U.S. Freight Finders, Inc. (<https://www.usfreightfinders.com/>).

¹¹From industry interviews, we determined that many commercial beekeepers travel to California with their bees. However, some do have arrangements with pollination brokers or other beekeepers to care for their colonies while in California. We do not take into account costs of the beekeeper’s travel arrangements (hotel, airfare, etc.) into our analysis.

¹²Most of the apiary shipments go through eight of these sixteen (Blythe, Dorris, Hornbrook, Needles, Vidal, Winterhaven, Yermo and Truckee).

¹³For example, apiary shipments from many Southern states, e.g., Texas and Arizona, are searched specifically for the Red Imported Fire Ant.

¹⁴Nearly all rejected shipments are cleaned and ultimately enter.

The dataset contains records of each apiary shipment into California from January 1, 2007 through November 30, 2018.¹⁵ Because this paper focuses on the almond pollination market which occurs in February each year, we only utilize data on shipments from April 1, 2007 (beginning of shipments for the 2008 almond pollination season) through March 31, 2018 (end of the 2018 almond pollination season).¹⁶ Table 3 shows the total number of shipments, the total number of colonies shipped, and the average number of colonies per shipment for each almond pollination season.

Honey bee colony shipments into California have increased from roughly 1.1 million colonies in 2008 to 1.8 million colonies in 2018. Figure 4 shows a histogram of truck shipments into California, while figure 5 displays densities of the colonies shipped into California for each almond pollination season. Because the number of colonies per truck shipment varies, figures 4 and 5 could, in theory, look very different. In practice, however, the two figures are similar, indicating that the number of colonies per shipment does not vary significantly throughout the year. In fact, most of the shipments in the dataset fell between 350 and 500 colonies. According to figures 4 and 5, colonies are primarily transported into California starting in October and continue through the almond bloom period in the following year in February and March. From these seasonal shipment patterns, it would seem that most, if not all, of the honey bee colony shipments into California are participating in the almond pollination market.¹⁷

Shipments during January and February have increased from approximately 383,000 colonies in 2008 (35% of total shipments in 2008) to 1 million in 2018 (55% of total shipments in 2018), implying that most of this increase in colony shipments can be attributed to an increase in demand for colonies for almond pollination. Colony shipments into California begin to pick up in October at a time when honey production is wrapping up in major honey producing states in the Plains region. Many colonies are transported from these states to California to overwinter in a warmer area before almond bloom. A lull in shipments occurs each year right around the New Year, likely due to limited operating hours and staff at the California BPS (Figures 4 and 5).¹⁸ Only around 3-6% of colonies are transported into California during the months from April to September.

Figure 6 shows the estimated demand for colonies based on almond acreage in comparison to the number

¹⁵Any records prior to 2007 are not digitized.

¹⁶For the purposes of this analysis, we define each almond pollination season as April 1 of the previous year through March 31 of the almond pollination season year.

¹⁷Historical data are needed to say definitively how many colony shipments into California occur specifically because of almond pollination. Some beekeepers may take part in honey production in the upper Plains states and would transport colonies into California to overwinter in warmer areas regardless of participation in the almond pollination market. Data prior to 1977 (before California almond pollination demand exceeded the in-state supply of colonies) would be necessary to determine a baseline level of shipments.

¹⁸Proper staffing at the Border Stations during peak shipment times is of concern for beekeepers because delays can be detrimental to the colonies being shipped. CDFA discusses how to improve conditions at the Border Inspection Stations with the California State Beekeepers Association (CSBA) on an annual basis; see for example the CSBA Board Minutes Summary November 20, 2015 (<http://www.californiastatebeekeepers.com/news/Minutes2015/SummaryMinutes-11-20-15.pdf>).

of colonies shipped into California for each almond pollination season. Each year, there is a gap between the estimated demand and the number of colonies shipped into California of around 300,000-350,000 colonies. The exception to this was the 2014 almond pollination season when considerably fewer colonies were shipped into California widening the gap to roughly 450,000 colonies. The gap between the number of colonies shipped and demand could imply that using two colonies per acre is a substantial overestimate of the demand for colonies. Due to the wide use of the industry rule of thumb, our assessment is that errors in demand estimates are minor. Because the migratory nature of beekeeping operations does not lead to accurate estimates of the number of colonies remaining in California year round, we posit most of the remaining demand is met by colonies which do not leave the state of California.

Figures 7 and 8 depict the number of colonies shipped from each contiguous U.S. state in the almond pollination seasons 2008 and 2018, respectively. Figure 9 shows the shipments over almond pollination seasons 2008 to 2018 from the eight states which provided the largest number of colonies to California in 2018. The top three providers in 2018, namely, Idaho, North Dakota and Florida, shipped 769, 633 and 430 truckloads into California, respectively. North Dakota, South Dakota and Montana, which are consistently some of the largest providers of colonies for almond pollination, were the top three honey producing states in the U.S in 2016 (USDA, 2017b). Until 2018, the largest number of colonies each almond pollination season was shipped from North Dakota—over 200,000 colonies were shipped from North Dakota to California in every almond pollination season but 2014. In 2018, Idaho moved to the top, shipping over 320,000 colonies for almond pollination. In 2018, Florida came close to North Dakota with 195,000 shipped to California. As can be seen from a comparison of figures 7 and 8, the number of colonies shipped has increased for most states since 2008. The number of colonies shipped from the southeastern states have increased in particular. For example, shipments from Georgia and Florida increased by 1000% and 500%, respectively, over the time period.

4 Analysis

Due to the regional variation in beekeeping regions, to analyze supply elasticities we use a Geographically Weighted Regression (GWR). GWR accounts for spatial heterogeneity and estimates geographically varying coefficients (Fotheringham, Brunson, and Charlton, 2002). The GWR model can be represented generally as follows (Brunson, Fotheringham, and Charlton, 1998):

$$Y_{it} = \beta_0(x_i, y_i) + \sum_k \beta_k(x_i, y_i)X_{it} + \mu_{it}$$

where Y_{it} is the dependent variable, X_{it} is a matrix of explanatory variables, x_i and y_i are geographic coordinates, and μ_{it} is the error term. The GWR coefficients are estimated as follows:

$$\hat{\beta}(x_i, y_i) = (X'W(x_i, y_i)X)^{-1} X'W(x_i, y_i)Y_{it}$$

where $W(x_i, y_i)$ is a distance based weighting matrix. We use a Gaussian weighting matrix where distance is measured as $w_i = \exp[-\frac{1}{2} \frac{d(x_i, y_i)}{h}]^2$ where $d(x_i, y_i)$ is Euclidean Distance and h is a bandwidth parameter. The bandwidth is chosen through a cross-validation process (Fotheringham, Brunsdon, and Charlton, 2002).

We estimate the following models using GWR:

Model 1:

$$\begin{aligned} Shipment_{it} = & \beta_0(x_i, y_i) + \beta_1(x_i, y_i)NetShipPrice_{it} + \beta_2(x_i, y_i)HPCol_{it-1} + \beta_3(x_i, y_i)WM_{it} \\ & + \beta_4(x_i, y_i)Diesel_t + \mu_{it} \end{aligned}$$

Model 2:

$$\begin{aligned} ColShipped_{it} = & \beta_0(x_i, y_i) + \beta_1(x_i, y_i)NetPerColPrice_{it} + \beta_2(x_i, y_i)HPCol_{it-1} + \beta_3(x_i, y_i)WM_{it} \\ & + \beta_4(x_i, y_i)Diesel_t + \mu_{it} \end{aligned}$$

where $Shipment_{it}$ is the number of apiary shipments into California from state i in year t , and $ColShipped_{it}$ is the total number of colonies shipped into California from state i in year t . The geographic coordinates x_i and y_i are respectively the longitude and latitude values of the centroid of state i . Centroids for each state were obtained from Rogerson (2015). $NetShipPrice_{it}$ and $NetPerColPrice_{it}$ respectively are the net prices received per shipment and per colony in state i in year t after round trip shipment costs are accounted for. To calculate these values we assume a cost per shipment of \$3 per mile and a uniform 400 colonies per shipment, which is not far from the 2008-2018 average of 394 colonies per shipment. The shipment cost estimate came from conversations with commercial beekeepers, shipment companies, and pollination

brokers. Industry participants have stated that apiary shipment costs have not changed substantially since 2007, and have remained around \$3/mile. One-way distance was calculated using the minimum road mileage from Google maps between the the state’s centroid and a location in Madera, CA.¹⁹

$NetShipPrice_{it}$ and $NetPerColPrice_{it}$ are calculated as follows:

$$NetShipPrice_{it} = \left(AlmondPollinationFee(\$ / Col)_t \times \frac{400 \text{ colonies}}{Shipment} \right) - (2 \times MilesFromMadera_i \times \$3/mile)$$

$$NetPerColPrice_{it} = AlmondPollinationFee(\$ / Col)_t - \left(2 \times MilesFromMadera_i \times \$3/mile \div \frac{400 \text{ colonies}}{Shipment} \right)$$

These net prices are then normalized using GDP deflators to 2009 dollars. $HPCol_{it-1}$ is the maximum number of honey-producing colonies in state i in the year prior to almond pollination year t according to the USDA Honey Report. WM_{it} is the average winter mortality rate in state i in the winter prior to almond bloom collected from the Bee Informed Partnership. $Diesel_t$ is the average U.S. diesel price from October to February prior to almond bloom in year t , collected from the Energy Information Administration.

As the net price of shipping colonies to California increases, we would expect the number of colonies (shipments) to increase as well. Due to the geographical variation of honey bee colonies in the U.S., we believe this will vary significantly across states. The number of honey producing colonies and winter mortality rates are included to control for the supply of colonies from a specific state. As the number of honey producing colonies increases in a given year, there will be more colonies available to supply for almond bloom, so we predict the number of colonies supplied (shipments) will increase. Similarly, as the average winter mortality rate in a state increases, there will be fewer colonies available to supply to almonds so we predict a negative relationship between winter mortality rates and the number of colonies shipped (shipments). Because our shipment cost does not vary over time, we control for time varying shipment costs using average diesel prices in the months leading up to almond bloom. We predict that as diesel prices increase and it becomes more costly to ship colonies, the numbers of colonies shipped (shipments) will decrease.

Table 4 shows summary statistics for the variables used in this analysis.²⁰ We estimate the GWR model using the *spgwr* package in R (Bivand et al., 2017).

4.1 Results

Table 5 shows results from estimating Models 1 and 2 using ordinary least squares (OLS) regression. As expected, the net shipment price and net per-colony price have a positive and significant effect on the

¹⁹Of course, transportation costs would be more precisely estimated if we had the exact locations where the colonies originated and were delivered.

²⁰We dropped observations for total of 14 states from the analysis due to either insufficient data regarding winter mortality rates and maximum honey producing colonies throughout the 11 years, or a lack of participation in almond pollination altogether.

number of shipments and colonies shipped, respectively. As predicted, the maximum number of honey producing colonies increases the shipments and total number of colonies shipped, whereas winter mortality rates decrease shipments and numbers of colonies. Contrary to our predictions, an increase in diesel prices seems to increase shipments, and has no significant effects on the number of colonies.

Tables 6-9 show results of the GWR for Models 1 and 2. Tables 6 and 8 display the variation in coefficient estimates, and compare those with the OLS estimates (Global). The coefficient estimates on the Net Shipment Price range from -0.01 to 0.03 in GWR, compared with 0.01 in the OLS regression. Similarly, coefficient estimates on the Net Per-Colony Price range from -1,611 to 4,701 compared with the OLS estimate of 1,414. These suggest significant spatial variation in the responsiveness of beekeepers to price changes in almond pollination fees. Interestingly enough, the negative coefficients imply that some states have supply elasticities inconsistent with economic theory.

In both Models 1 and 2, the sum of squared residuals in the GWR model are lower than the sum of squared residuals from OLS (Tables 6 and 8). This implies that GWR is a better fit (Fotheringham, Brunson, and Charlton, 2002). Tables 7 and 9 display results from tests according to Leung, Mei, and Zhang (2000), in which the null hypothesis holds coefficients equal across all states. From these tests we can conclude that there is significant regional variation in all of the variables.

Figures 10 and 11 display elasticity estimates for each state that were calculated using state-level 2008 net prices and quantities.²¹ Testing for significance of coefficients in the GWR model leads to a large number of simultaneous t-tests (Edayu and Syerrina, 2018). Thus, we use a Bonferroni correction to adjust the significance values for each test.²² In figures 10 and 11, a circle denotes statistical significance at 10% using the Bonferroni adjustment, i.e., each two tailed t-test is significant at $0.1\% = \frac{10\%}{34}$.

Supply elasticities, which range from -2 to 27, seem to be spatially related. Parts of the northern Plains, Southeast and Southwest have negative supply elasticities, while areas such as the Pacific Northwest, and most of the Southeast have relatively large supply elasticities. We believe the negative elasticities result from the migratory nature of beekeeping operations. Transporting colonies to California in early January and February may not be ideal due to winter weather conditions in a beekeeper's state of origin. Often colonies are not allowed to be placed too early in almond orchards because almond growers must adjust pesticide applications while bees are in the orchard. Thus, in California access to locations where colonies may be placed for an extended period of time (without too much pesticide exposure) is in high demand leading up to almond bloom and therefore is scarce. From Oct 1, 2017 to November 30, 2017 over 665,000

²¹New Jersey, Tennessee, and Mississippi did not participate in 2008 almond pollination, so the prices and quantities from the first year in which they participated were used.

²²We use a significance level of $\alpha_B = \frac{\alpha}{m}$, where m is the number of states in the analysis, to guarantee an overall significance level of α .

colonies entered California in addition to the 680,000 colonies which were already there on October 1, 2017. This influx of bee colonies which are not yet allowed in almond orchards may necessitate beekeepers to place colonies in nearby states. Tables 10 and 11 display colony shipments and populations in the Pacific Northwest states in 2016 and 2017. The number of colonies shipped from each of those states is often double or triple the colony populations at various times leading up to almond bloom. Thus, it is likely that beekeepers from other states are sending colonies to the Pacific Northwest to overwinter before almond pollination.

In addition to the lack of locations for bee colonies in California, the industry has moved towards cold storage of bee colonies (Koenig, 2017; O'Connell, 2017). Bees are stored in temperature-controlled buildings throughout the winter to regulate varroa mite populations and cut down on winter mortality rates. According to conversations with industry participants, cold-storage locations seem to be concentrated in California and the Pacific Northwest states.

One important aspect of figures 10 and 11 is that large supply elasticities are concentrated in the eastern U.S., and particularly the southeastern states. Beekeepers in these regions have seemingly been more responsive to changes in almond pollination fees over the time period. This responsiveness shows the tendency for the marginal supplier to move further from California where transportation costs are high. Should the demand for almond pollination increase, more and more colonies will likely come from this region.

4.2 Origin of Future Shipments

Increasing almond acreage has created a particular interest in the number of colonies that will be available to meet additional increases in demand for pollination services. Using the 2017 USDA almond acreage report, we estimate by 2020 an additional 148,000 colonies will be needed from almond acreage coming to bearing age.²³ According to OLS estimates in Table 5, almond pollination fees would need to increase by 1.6% from 2017 to 2020 to bring in enough colonies to meet this additional demand. When we take the spatial nature of colony supply into account, i.e., using the GWR Model 2 estimates, almond pollination fees will have to increase by 7.9% to access the additional numbers of colonies. This shows the importance of factoring in the spatial nature of the market for pollination services.

Figure 12 displays the estimated number of colonies which did not participate in 2017 almond pollination by each state. To calculate this number, we subtracted the number of colonies that were shipped to California for the 2017 pollination season from the maximum number of honey bee colonies in each state in October-December 2016 reported by the USDA (USDA, 2017a). It should be noted that the map does not account

²³The estimated increase in colonies from bearing acreage is calculated by: 2 colonies/acre * 64,406 bearing acres of traditional almond varieties +1 colony/acre * 19,519 bearing acres of Independence and Shasta varieties (self-fertile so require fewer colonies per acre see Doll (2012)).

for any colony losses over the winter 2016-2017, so the estimated number of colonies that remain in the state not participating in almond pollination are likely overestimated in figure 12. Despite this potential overestimation, many states in the western U.S. (Utah, Colorado, Idaho, Oregon, and Washington) shipped more colonies to California than their colony populations, i.e., the number of colonies not participating in almond pollination was negative. This discrepancy supports the discussion earlier that colonies from more distant states may be held briefly or over the winter in states which are close to California before entering the state for almond pollination. Figure 12 shows that most colonies not sent to California are concentrated in southern states of Florida, Texas, Georgia and Louisiana where opportunities for honey production during this time may compete with revenues from almond pollination. South Dakota and some of the North Central states (Michigan and Minnesota) may also have some colonies which remain in-state and could potentially be shipped to California to participate in almond pollination, although these may be colonies which are shipped through other states before entering California.

5 Conclusion

In 2018, most of the honey bee colonies throughout the U.S. were shipped into California to perform pollination services, a necessary input to almond production. Many prior analyses of pollination services have considered determinants of almond pollination fees, but have ignored the spatial nature of honey bee colonies in the U.S. This paper explores spatial relationships within the supply of almond pollination services, using a dataset of apiary shipments from each state into California from 2007 through 2018.

By pairing apiary shipments with almond pollination fee data and estimated transportation costs from each state, we were able to estimate supply elasticities for each state using a geographically weighted regression. We determined that beekeepers in the eastern U.S. have been more responsive to increases in almond pollination fees than in states closer to California. Due to the fact that we focus on shipments, rather than prices alone, we were able to verify that the marginal supplier of almond pollination services has moved further from California as almond acreage has increased. Without shipment data with the state of origin, we could only have surmised this finding. Using shipment data along with colony population data, we estimated each state's number of colonies which remain available to participate in almond pollination. Should almond acreage continue growing, this information will be very important to almond growers, as almond pollination fees must rise to attract these colonies to California.

This paper highlights the importance of the spatial nature of the U.S. beekeeping industry in the supply of pollination services. Probably, such complex spatial relationships are present in many other commodities. It is rare in many other commodities to know the flows into a destination market—Barrett and Li (2002) is

the exception that demonstrates that point. Even rarer is to know the origin of those flows, and practices within a specialized transportation sector. The data from inspection reports on California’s border provide such information for bees, providing an illustrative example of spatial relationships in commodity shipment.

Table 1: U.S. Regional Honey Bee Colony Populations, 1978 and 2015

Region	December 31, 1978		Maximum Oct-Dec 2015 [†]	
	Colonies	Percentage of U.S.	Colonies	Percentage of U.S.
California	477,013	18.7%	750,000	26.1%
Pacific Northwest	130,589	5.1%	203,000	7.1%
Mountainous	309,174	12.1%	345,000	12.0%
Southwest	166,021	6.5%	295,000	10.3%
Plains	403,838	15.8%	571,500	19.9%
North Central	483,772	18.9%	319,000	11.1%
Southeast	465,389	18.2%	603,000	21.0%
Northeast	111,290	4.4%	95,400	3.3%
Total U.S.	2,554,390		2,874,760	

[†] For California, the colony population as of October 1, 2015 is used because colonies are moved to California from other regions during this time period. Colony movement and mortality during this time period result in discrepancies between the sum of regional colony numbers and the U.S. total (and corresponding regional percentages sum to over 100).

Sources: USDA 1978 Census of Agriculture; USDA May 2016 Honey Bee Colonies Report

Table 2: Average Distance and Per-Colony Shipment Costs by Region[†]

Region	Average Distance (Miles)	Minimum (\$/Colony)	Average (\$/Colony)	Maximum (\$/Colony)
Pacific Northwest	781	9.62	11.71	13.81
Mountainous	896	6.30	13.44	18.32
Southwest	1,049	10.08	15.73	22.12
Plains	1,560	22.17	23.41	25.55
North Central	2,125	27.73	31.88	36.27
Southeast	2,349	26.85	35.23	41.85
Northeast	2,960	40.68	44.40	49.16

[†] Average Distance calculated from averaging the distance from the centroid of each state to Madera, CA. Per-Colony Shipment Costs calculated using a per-mile shipment cost of \$3, and 400 colonies per truck shipment from the centroid of each state to Madera, CA (See Section 4).

Table 3: Annual Summaries of Apiary Shipments into California, Seasons 2008-2018

Almond Pollination			Colonies per Shipment		
Season [†]	Shipments	Colonies Shipped	Average	10th Percentile	90th Percentile
2008	2,812	1,095,217	389	172	480
2009	2,992	1,164,012	389	196	480
2010	2,999	1,171,812	391	200	480
2011	3,179	1,247,001	392	192	480
2012	3,340	1,324,366	397	224	480
2013	3,408	1,332,157	391	193	480
2014	3,267	1,291,693	395	238	480
2015	3,791	1,506,661	397	250	480
2016	3,966	1,567,699	395	244	480
2017	4,267	1,684,413	395	216	480
2018	4,633	1,844,901	398	225	480

[†] Almond pollination season defined as April 1 of the previous year through March 31 of the almond pollination season year.
Source: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services

Table 4: Summary Statistics of State Apiary Shipments for Almond Pollination, Seasons 2008-2018

Statistic	N	Mean	St. Dev.	Min	Max
Shipments	341	102.00	153.66	0.00	769.00
Colonies Shipped	341	40,629.11	61,712.58	0.00	329,432.00
Net Shipment Price	341	51,951.03	5,174.84	41,703.93	64,233.19
Net Per-Colony Price	341	129.88	12.94	104.26	160.58
Max Honey Producing Colonies	341	66,973.61	94,299.88	4,000.00	510,000.00
Winter Mortality Rate	341	0.31	0.13	0.06	0.73
Diesel (Avg \$/gal Oct-Feb)	11	3.19	0.58	2.28	4.02

$$NetShipPrice_{it} = (AlmondPollinationFee(\$ / Col)_t \times \frac{400 \text{ colonies}}{Shipment}) - (2 \times MilesFromMadera_i \times \$3/mile)$$

$$NetPerColPrice_{it} = AlmondPollinationFee(\$ / Col)_t - (2 \times MilesFromMadera_i \times \$3/mile \div \frac{400 \text{ colonies}}{Shipment})$$

Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services;
CSBA Pollination Fee Surveys 2008-2018; USDA Honey Report 2007-2017; BIP Colony Loss Surveys 2007-2008 through 2017-2018;
EIA Gasoline and Diesel Fuel Update October 2007-February 2018

Table 5: Ordinary Least Squares Regressions of Apiary Shipments on Net Prices for Almond Pollination

	<i>Dependent variable:</i>	
	Shipments	Colonies Shipped
	(1)	(2)
Net Shipment Price	0.01*** (0.001)	
Net Per-Colony Price		1,414.87*** (144.48)
Max Honey Producing Colonies	0.001*** (0.0000)	0.50*** (0.02)
Winter Mortality Rate	-96.0*** (35.43)	-35,674*** (13,508.10)
Diesel (Avg \$/gal Oct-Feb)	15.4* (8.52)	4,996 (3,247.95)
Constant	-512.1*** (69.10)	-181,218*** (26,344.55)
Observations	341	341
R ²	0.72	0.75
Adjusted R ²	0.72	0.74
Residual Std. Error (df = 336)	81.9	31,236.8
F Statistic (df = 4; 336)	215.0***	247.8***

Note: *p<0.1; **p<0.05; ***p<0.01

Table 6: Summary of Geographically Weighted Regression Coefficients, Model 1

	Min	1st Quartile	Median	3rd Quartile	Max	Global
Intercept	-1,278.01	-67.93	-27.34	-3.82	729.34	-512.08
Net Shipment Price	-0.01	-0.00	0.00	0.00	0.03	0.01
Diesel (Avg \$/gal Oct-Feb)	-61.80	-1.36	-0.46	1.21	30.17	15.35
Max Honey Producing Colonies	0.000	0.001	0.001	0.001	0.005	0.001
Winter Mortality Rate	-356.82	-13.10	-4.47	2.17	36.62	-95.97
Brunsdon, Fotheringham and Charlton (2002) ANOVA						
SS OLS residuals (in 1000s)	SS GWR residuals (in 1000s)					
2,255.51	208.16					
F = 10.84, df1 = 336.0, df2 = 229.3, p-value < 0.000						

Note: Global is equivalent to OLS

Table 7: Leung et al (2000) F_3 test results for GWR coefficients, Model 1

	F statistic (1000s)	Numerator d.f.	Denominator d.f.
(Intercept)	10,155***	58.56	244.27
Net Shipment Price	17,757***	82.41	244.27
Diesel (Avg \$/gal Oct-Feb)	2,270***	78.80	244.27
Max Honey Producing Colonies	482,655***	37.47	244.27
Winter Mortality Rate	3,644***	34.41	244.27
Null Hypothesis: All GWR coefficients equal		*p<0.1; **p<0.05; ***p<0.01	

Table 8: Summary of Geographically Weighted Regression Coefficients, Model 2

	Min	1st Quartile	Median	3rd Quartile	Max	Global
Intercept	-617,868.80	-22,101.78	-5,182.71	686.59	304,933.30	-181,218.40
Net Per-Colony Price	-1,610.54	-14.98	49.55	204.94	4,701.29	1,413.87
Diesel (Avg \$/gal Oct-Feb)	-23,364.93	-539.59	-133.84	216.69	13,667.94	4,996.45
Max Honey Producing Colonies	0.01	0.25	0.41	0.53	2.02	0.50
Winter Mortality Rate	-174,662.70	-4,897.29	-1,724.50	680.78	11,337.49	-35,674.37
Brunsdon, Fotheringham and Charlton (2002) ANOVA						
SS OLS residuals (in 1000s)			SS GWR residuals (in 1000s)			
327,846.935			36,392.891			
F = 9.01, df1 = 336.0, df2 = 226.5, p-value < 0.000						

Note: Global is equivalent to OLS

Table 9: Leung et al (2000) F_3 test results for GWR coefficients, Model 2

	F statistic (1000s)	Numerator d.f.	Denominator d.f.
(Intercept)	9,602***	58.58	240.79
Net Per-Colony Price	15,304***	82.43	240.79
Diesel (Avg \$/gal Oct-Feb)	1,946***	78.83	240.79
Max Honey Producing Colonies	520,505,940***	37.47	240.79
Winter Mortality Rate	3,675***	34.41	240.79
Null Hypothesis: All GWR coefficients equal		*p<0.1; **p<0.05; ***p<0.01	

Table 10: Pacific Northwest State Colony Populations and Colony Shipments into California for the 2016 Almond Bloom

State	Shipments	Colonies Shipped	Number of Colonies		
			July 1, 2015	October 1, 2015	January 1, 2016
Idaho	504	209,150	80,000	121,000	90,000
Oregon	422	137,941	68,000	100,000	70,000
Washington	329	115,036	84,000	87,000	78,000

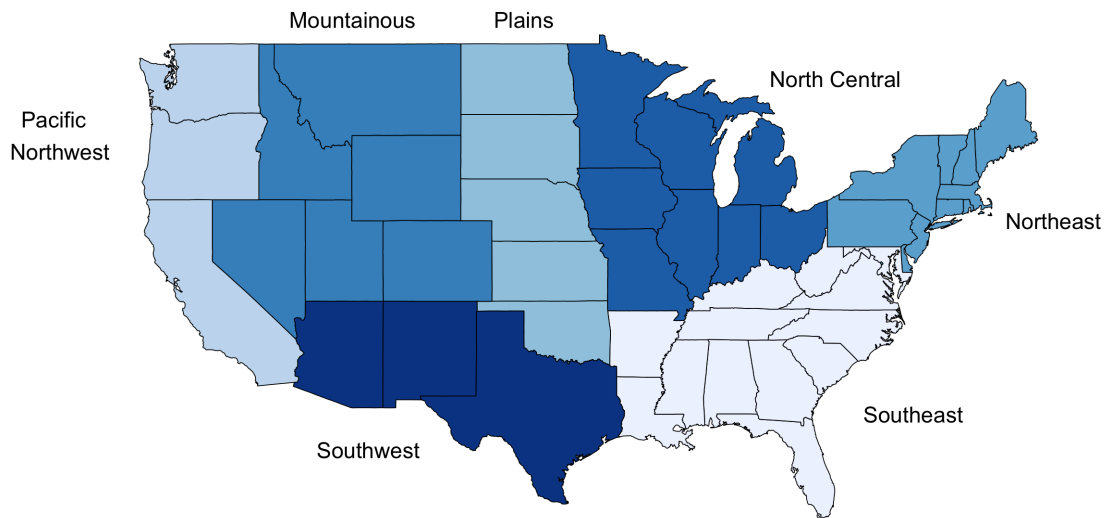
Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; USDA Honey Bee Colonies Report 2016

Table 11: Pacific Northwest State Colony Populations and Colony Shipments into California for the 2017 Almond Bloom

State	Shipments	Colonies Shipped	Number of Colonies		
			July 1, 2016	October 1, 2016	January 1, 2017
Idaho	560	235,695	79,000	121,000	95,000
Oregon	485	154,161	107,000	98,000	71,000
Washington	341	114,892	57,000	65,000	68,000

Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; USDA Honey Bee Colonies Report 2017

Figure 1: Beekeeping Regions in the United States



Source: Nye (1980)

Figure 2: Conceptual Representation of Supply and Demand of Honey Bee Colonies for Almond Pollination

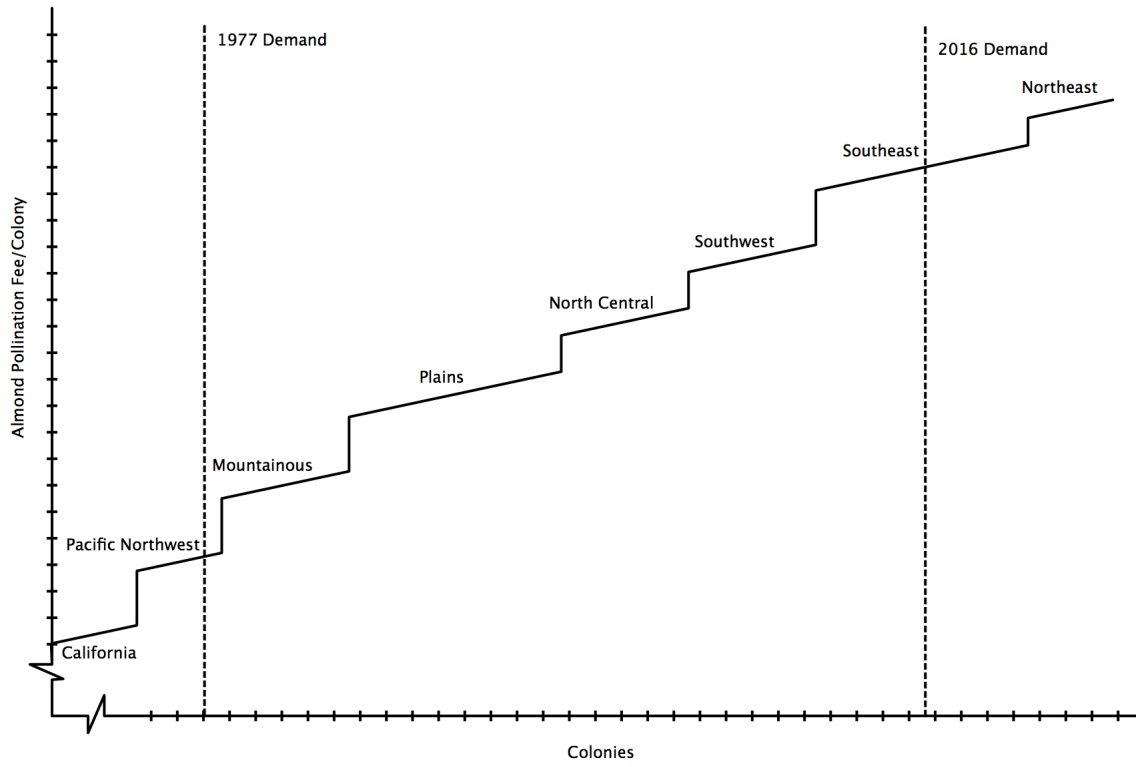


Figure 3: California Department of Food and Agriculture Border Stations

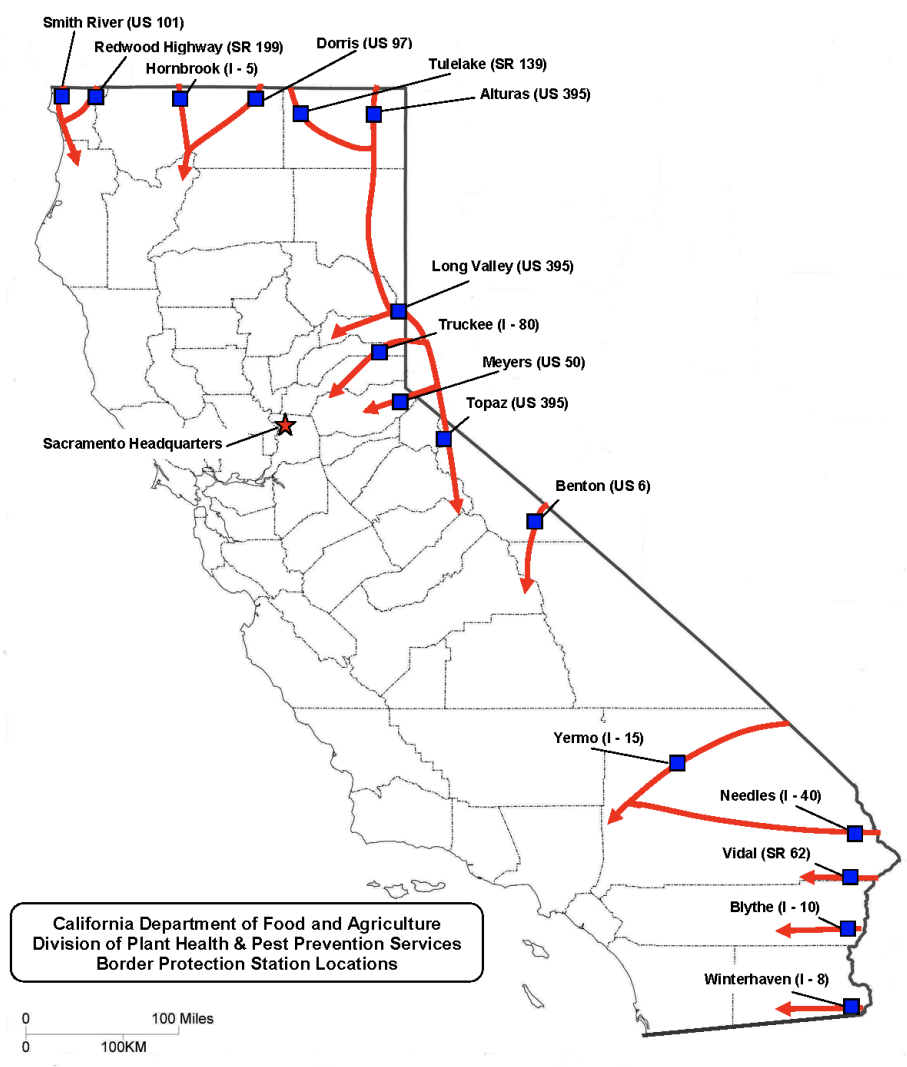
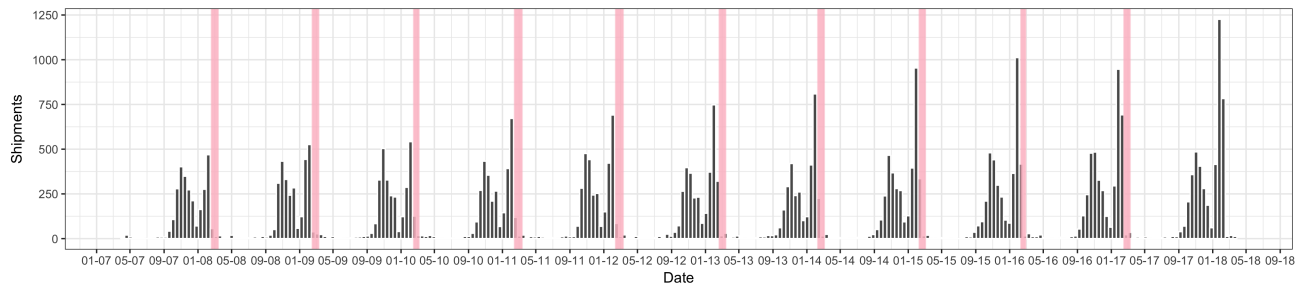
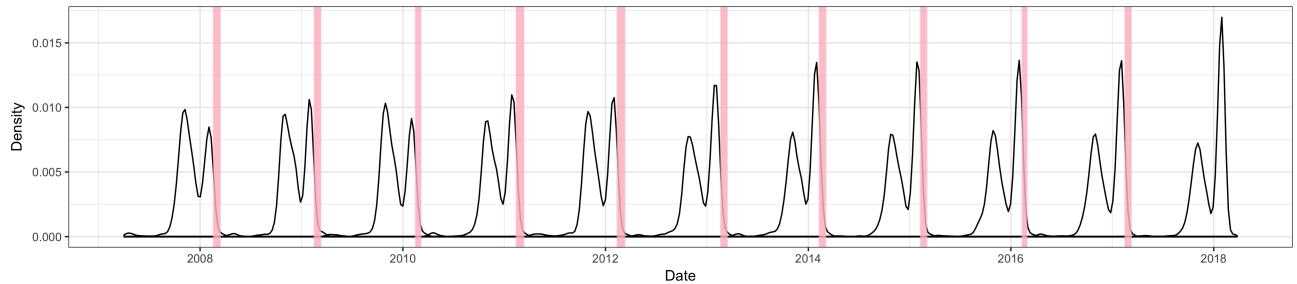


Figure 4: Histogram of Bi-Weekly Apiary Shipments into California, March 2007- April 2018 (Almond Bloom Period for Central California Highlighted)



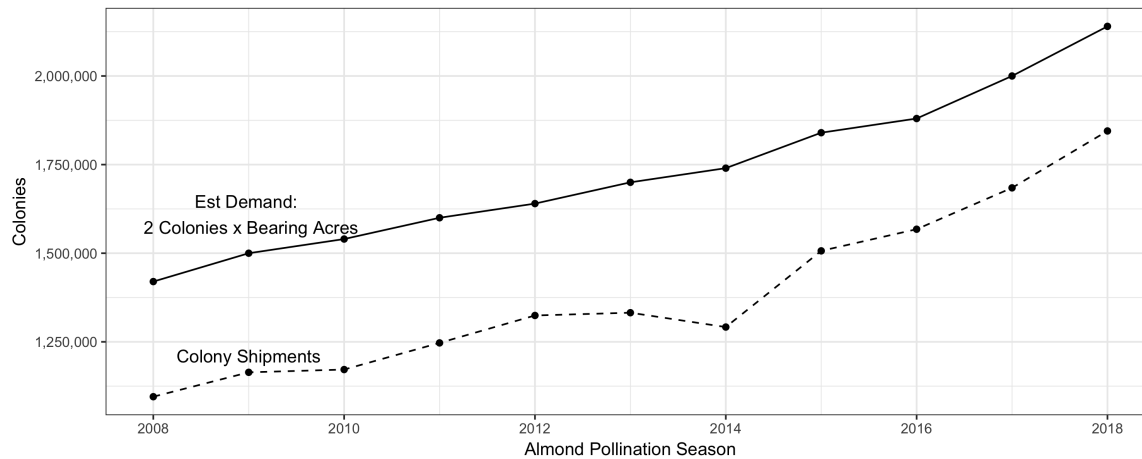
Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; Blue Diamond Grower's Crop Progress Reports

Figure 5: Density of Colonies Shipped into California by Almond Pollination Season, Seasons 2008-2018 (Almond Bloom Period for Central California Highlighted)[†]



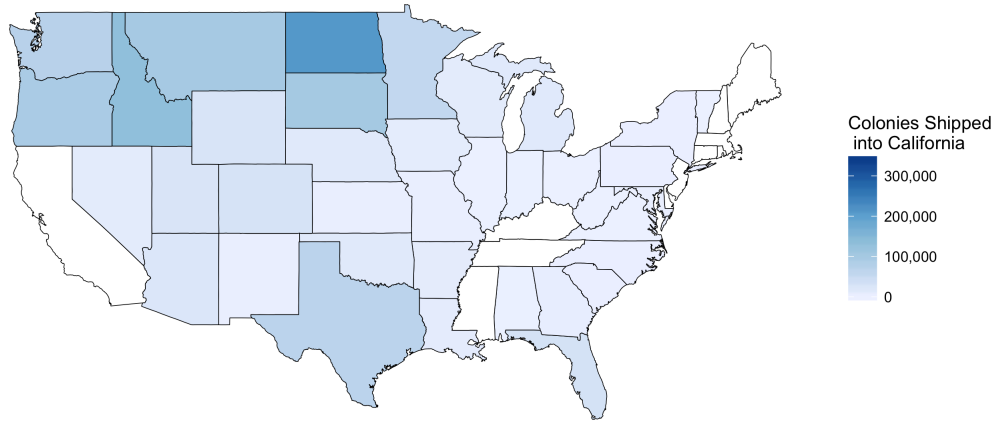
[†]Densities are calculated for each almond pollination season which we define as April 1 of the previous year through March 31 of the almond pollination season year.
Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; Blue Diamond Grower's Crop Progress Reports

Figure 6: Colonies Shipped into California and the Estimated Demand for Almond Pollination, Seasons 2008-2018[†]



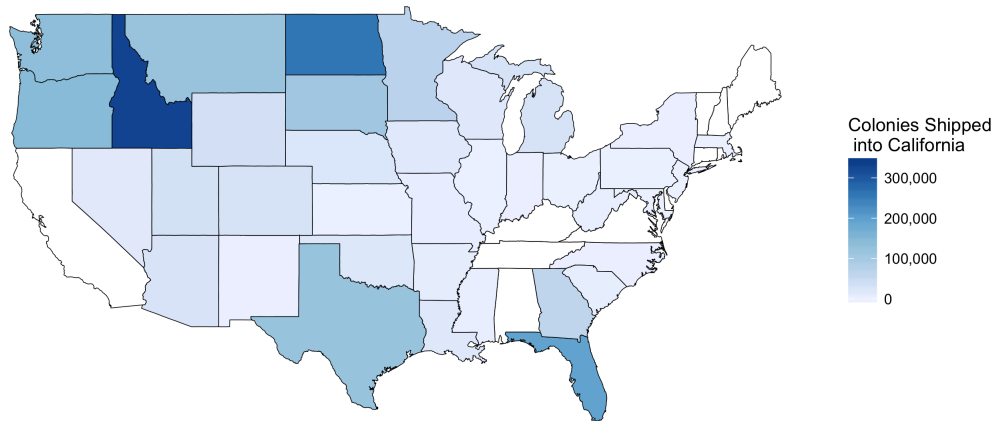
[†]Colony shipments are summed for each almond pollination season which we define as April 1 of the previous year through March 31 of the almond pollination season year.
Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; USDA NASS 2008-2017 Almond Acreage Reports; 2018 California Almond Objective Measurement Report

Figure 7: Honey Bee Colony Shipments into California for Almond Pollination by State of Origin, Season 2008



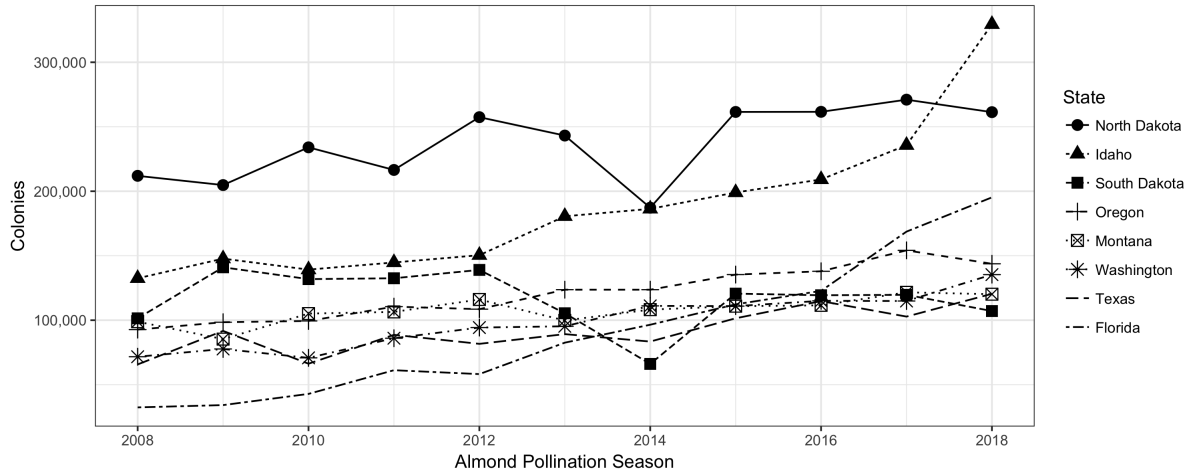
Source: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services

Figure 8: Honey Bee Colony Shipments into California for Almond Pollination by State of Origin, Season 2018



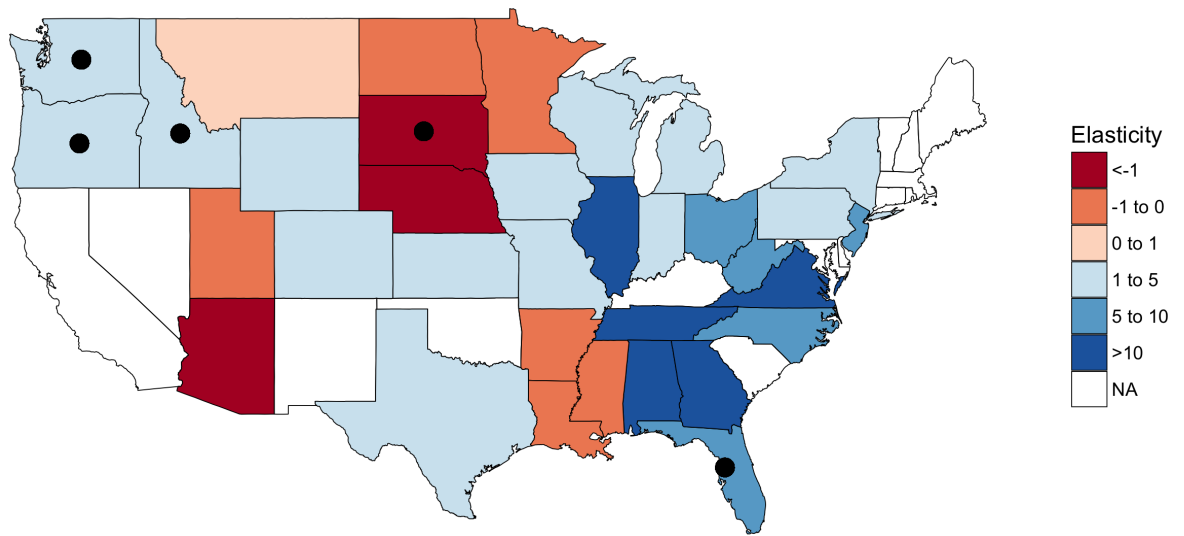
Source: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services

Figure 9: Honey Bee Colony Shipments into California for Almond Pollination from Eight States with Largest Number of Colonies Shipped in 2018, Seasons 2008-2018



Source: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services

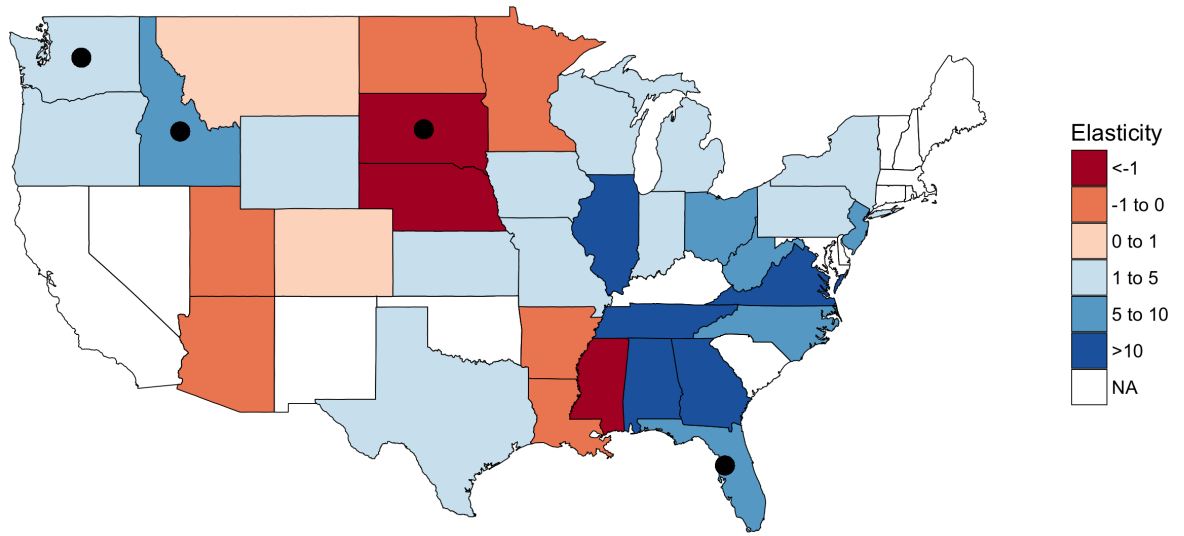
Figure 10: Supply Elasticity Estimates for Truck Shipments into California for Almond Pollination using GWR Coefficients, Model 1[†]



● denotes statistical significance at the 90% level using a Bonferroni adjustment for multiple hypothesis tests

[†]Elasticities were calculated using 2008 prices and quantities

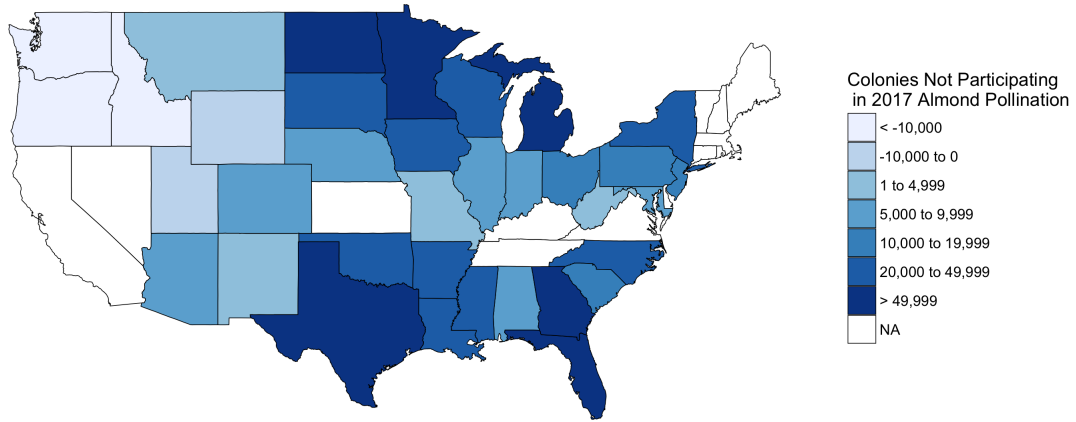
Figure 11: Supply Elasticity Estimates for Colonies Shipped into California for Almond Pollination using GWR Coefficients, Model 2[†]



● denotes statistical significance at the 90% level using a Bonferroni adjustment for multiple hypothesis tests

[†]Elasticities were calculated using 2008 prices and quantities

Figure 12: State Estimates of the Number of Honey Bee Colonies that did not Participate in 2017 Almond Pollination[†]



[†]NAs exist for Delaware, Nevada, New Hampshire, and Rhode Island because USDA does not publish honey bee populations for these states.
 Sources: Apiary Shipments through California Border Protection Stations, CDFA Plant Health and Pest Prevention Services; USDA Honey Bee Colonies Report May 2017

References

- Aizen, M.A., and L.D. Harder. 2009. "The global stock of domesticated honey bees is growing slower than agricultural demand for pollination." *Current biology* 19:915–918.
- Alger, S.A., P.A. Burnham, Z.S. Lamas, A.K. Brody, and L.L. Richardson. 2018. "Home sick: impacts of migratory beekeeping on honey bee (*Apis mellifera*) pests, pathogens, and colony size." *PeerJ* 6:e5812.
- American Bee Journal. 2017. "U.S. Honey Crops and Markets." Available at: <https://americanbeejournal.com/category/departments/u-s-honey-crops-and-markets/>.
- Barrett, C.B., and J.R. Li. 2002. "Distinguishing between equilibrium and integration in spatial price analysis." *American Journal of Agricultural Economics* 84:292–307.
- Bee Culture Magazine. 2018. "Regional Honey Price Report." Available at: <https://www.beeculture.com/regional-honey-price-report-9/>.
- Bivand, R., D. Yu, T. Nakaya, and M.A. Garcia-Lopez. 2017. "Package 'spgwr' Geographically Weighted Regression." R Package.
- Bond, J., K. Plattner, and K. Hunt. 2014. "Fruit and Tree Nuts Outlook: Economic Insight. US Pollination-Services Market." USDA Economic Research Service Situation and Outlook FTS-357SA.
- Brunsdon, C., S. Fotheringham, and M. Charlton. 1998. "Geographically weighted regression." *Journal of the Royal Statistical Society: Series D (The Statistician)* 47:431–443.
- California Department of Food and Agriculture. 2018. "California Border Protection Stations Apiary Shipments." Unpublished, Unpublished raw data.
- . 2015. "CDFA: Plant Health and Pest Prevention Services Entering CA: Border Protection Stations (BPS)." Available at: <https://www.cdffa.ca.gov/plant/pollinators/inspections.html>.
- Carman, H. 2011. "The Estimated Impact of Bee Colony Collapse Disorder on Almond Pollination Fees." *Agricultural and Resource Economics Update* 14:9–11.
- Champetier, A., D.A. Sumner, and J.E. Wilen. 2015. "The bioeconomics of honey bees and pollination." *Environmental and Resource Economics* 60:143–164.
- Daberkow, S., P. Korb, and F. Hoff. 2009. "Structure of the US beekeeping industry: 1982–2002." *Journal of Economic Entomology* 102:868–886.
- Doll, D. 2012. "Independence Almond—Some Observations." Available at: <http://thealmonddoctor.com/2012/06/30/independence-almond-some-observations/>.
- Edayu, Z.N., and Z. Syerrina. 2018. "A statistical analysis for geographical weighted regression." In *IOP Conference Series: Earth and Environmental Science*. IOP Publishing, vol. 169, p. 012105.
- Ellis, J., and C. Zettel Nalen. 2010. *Florida Beekeeping Management Calendar*. ENY156, University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, EDIS.
- ETBA. 2000. "East Texas Beekeepers Monthly Guidebook." Available at: <http://www.etba.info/ETBA>
- Fackler, P.L., and B.K. Goodwin. 2001. "Spatial price analysis." *Handbook of Agricultural Economics* 1B:971–1024.
- Faminow, M.D., and B.L. Benson. 1990. "Integration of spatial markets." *American Journal of Agricultural Economics* 72:49–62.
- Ferrier, P.M., R.R. Rucker, W.N. Thurman, and M. Burgett. 2018. "Economic Effects and Responses to Changes in Honey Bee Health." *USDA Economic Research Service ERR-246:1–38*.

- Fotheringham, A.S., C. Brunsdon, and M. Charlton. 2002. *Geographically Weighted Regression: The Analysis of Spatially Varying Relationships*. John Wiley and Sons.
- Goodrich, B., and R.E. Goodhue. 2016. "Honey bee colony strength in the California Almond Pollination Market." *ARE Update* 19:5–8.
- Goodrich, B.K. 2017. *The California Almond Pollination Market: Contracts and Honey Bee Colony Health*. University of California, Davis.
- Goodwin, B.K. 2006. "Spatial and vertical price transmission in meat markets." In *Market Integration and Vertical and Spatial Price Transmission, Agricultural Markets Workshop*. University of Kentucky.
- Goodwin, B.K., and N.E. Piggott. 2001. "Spatial market integration in the presence of threshold effects." *American Journal of Agricultural Economics* 83:302–317.
- Jones Ritten, C., D. Peck, M. Ehmke, and M.B. Patalee. 2018. "Firm Efficiency and Returns-to-Scale in the Honey Bee Pollination Services Industry." *Journal of Economic Entomology* 111:1014–1022.
- Khachatryan, H., J. Yan, and K. Casavant. 2011. "Spatial Differences in Price Elasticity of Demand for Ethanol." In *Journal of the Transportation Research Forum*. vol. 50, pp. 43–61.
- Koenig, P. 2017. "Wintering Sheds: Why are more North American beekeepers overwintering their bees in cold storage?" Bee Informed Partnership Blog. Available at: <https://beeinformed.org/2017/12/05/wintering-sheds-why-are-more-north-american-beekeepers-overwintering-their-bees-in-cold-storage/>.
- Lee, H., D.A. Sumner, and A. Champetier. 2019. "Pollination Markets and the Coupled Futures of Almonds and Honey Bees: Simulating Impacts of Shifts in Demands and Costs." *American Journal of Agricultural Economics* 101:230–249.
- Leung, Y., C.L. Mei, and W.X. Zhang. 2000. "Statistical tests for spatial nonstationarity based on the geographically weighted regression model." *Environment and Planning A* 32:9–32.
- McNew, K., and D. Griffith. 2005. "Measuring the impact of ethanol plants on local grain prices." *Review of Agricultural Economics* 27:164–180.
- National Honey Board. 2007. "Honey Varietal Guide." Available at: <https://www.bjcp.org/mead/varietaiguide.pdf>.
- Nickeson, J., and R. Wolfe. 2017. "Honey Bee Forage Map." Available at: <https://honeybeenet.gsfc.nasa.gov/Honeybees/Forage.htm>.
- Nye, W. 1980. "Beekeeping regions in the United States." *Beekeeping in the United States. USDA Agriculture Handbook* 335:10–15.
- O'Connell, J. 2017. "Beekeepers build high-tech storage to improve hive survival." Available at: <http://www.capitalpress.com/Profit/20170519/beekeepers-build-high-tech-storage-to-improve-hive-survival>.
- Rogerson, P.A. 2015. "A new method for finding geographic centers with application to U.S. states." *The Professional Geographer* 67:686–694.
- Rucker, R.R., W.N. Thurman, and M. Burgett. 2012. "Honey bee pollination markets and the internalization of reciprocal benefits." *American Journal of Agricultural Economics* 94:956–977.
- Sumner, D.A., and H. Boriss. 2006. "Bee-economics and the leap in pollination fees." *Agricultural and Resource Economics Update* 9:9–11.
- USDA. 2017a. "Honey Bee Colonies (August 2017)." USDA National Agricultural Statistics Service ISSN: 2470-993X.

- . 2018. “Honey Bee Colonies (August 2018).” USDA National Agricultural Statistics Service ISSN: 2470-993X.
- . 2017b. “Honey (March 2017).” USDA National Agricultural Statistics Service ISSN: 1949-1492.
- USDA Agricultural Marketing Service. 1985. “Extracted Honey Grading Manual.” Available at: <https://www.ams.usda.gov/grades-standards/extracted-honey-grades-and-standards>.
- Ward, R., A. Whyte, and R. James. 2010. “A tale of two bees: Looking at pollination fees for almonds and sweet cherries.” *American Entomologist* 56:170–177.
- Wyns, D. 2018. “The Long Haul.” Bee Informed Partnership Blog. Available at: <https://beeinformed.org/2018/02/08/the-long-haul/>.