POLLINATING PRICES: 
ESTIMATING THE RELATIONSHIP BETWEEN 
HONEYBEE POPULATION AND ALMOND PRICES

Seth Taylor

Abstract

This paper examines the potential effect of decreasing honeybee population on crop prices by estimating the relationship between honeybee population and the price of almonds over time. As a declining honeybee population becomes an increasingly salient issue, the public must be aware of the potential impacts that honeybee population loss can have on society, including rising crop prices. Understanding the economic impact that honeybee loss can have on consumers and industry is critical to limiting the severity of that impact over time. Using data on honeybee population and almond prices from the USDA National Agricultural Statistics Service, we conduct both an ordinary least squares (OLS) and instrumental variable regression of almond prices using honeybee population. Our approach also includes controls for weather, almond yield and crop area, and transportation costs. Results are analyzed at the 95 percent confidence level. Our OLS regression presents a positive, significant relationship between honeybee population and almond prices, while our instrumental variable regressions are insignificant. The confidence of our findings is constrained by a small sample size, which suggests that further research is necessary to achieve more robust findings.

Introduction

Our first recorded use of honeybees for commercial pollination was in New Jersey in 1909, when they were rented for the pollination of apple crops (Morse and Calderone 2000). In 2000, there were 2.9 million colonies in the

SETH TAYLOR was a student of International Studies and Economics. He graduated in May of 2015. School of International Service (SIS)/College of Arts and Sciences (CAS) American University Email: st0362a@american.edu

United States and over 2 million of those colonies were being transported around the nation to serve as pollinators for different crops (Morse and Calderone 2000). A Cornell University study estimated that the value of honeybee pollination in increasing yield and quality results in $14.6 billion in value (Morse and Calderone 2000). Roughly another $180 million of raw honey is produced each year. Bees are also responsible for about 80 percent of all crop pollination in the United States (The Nature Conservancy 2015). The value of honeybees as both producers of honey and as pollinators is well recognized, and honeybees have been instrumental in increasing yields and quality in a variety of crops. It was particularly alarming then, when in October of 2006, some beekeepers reported losses of 30 to 90 percent of their hives (“Honey Bee Health and Colony Collapse Disorder 2015). This phenomena has become known as “Colony Collapse Disorder,” or CCD. The cause of CCD is a subject of ongoing research. Culprits range from insecticide used on crops that honeybees get nectar from (particularly neonicotinoids), the introduction of pathogens or parasites into the hive, to environmental stressors like lack of diversity in nectar and pollen (“Honey Bee Health and Colony Collapse Disorder 2015). Generally, however, there has been a lack of consensus on what causes CCD, and there seems to be no single smoking gun.

What is clear is that the number of managed honey bee colonies has decreased dramatically in the past decade. The total number of managed honey bee colonies has decreased from 5 million in the 1940s to only 2.5 million today (“Honey Bee Health and Colony Collapse Disorder 2015). From 2006 to 2011, winter honeybee losses averaged about 33 percent per year, with about one-third of these losses being attributed to CCD (“Honey Bee Health and Colony Collapse Disorder 2015). Continued losses of honeybee colonies could threaten the commercial bee pollination industry. At the very least, the loss of honeybees can lead to the cost of pollination services rising, which would induce a general rise in the price of crops that rely on honeybees. This paper attempts to examine the relationship between honeybee population decline and increasing crop prices.

This paper specifically analyzes the relationship between honeybee population and almond prices using both ordinary least squares (OLS) regression and instrumental variable regression. Almonds are used in this analysis for several reasons. First, pollination by honeybees is essential for almond production as almond trees cannot cross-pollinate between varieties on their own. Instead, almond producers rent bee colonies from commercial apiarists in early spring to pollinate their trees for them. Pollination services are so critical for almond production that almond pollination fees accounted for 45 percent of total collected pollination fees in 2011 (Bond et al. 2014). The approximate crop value for almonds from honeybee pollination is $2.84 billion (“Beyond Pesticides” 2015).
This represents almost 19.5 percent of the total value to crop production from honeybee pollination.

Almonds are also used in this analysis because all of their production in the United States is localized to one region. One hundred percent of American almond production occurs in California ("Almond Almanac 2014" 2014). This makes controlling for variables in almond production much easier than choosing a crop that is produced in many locations throughout the United States. Specific control variables in this study include data on temperature, precipitation, and drought, as well as yield and crop area characteristics and transportation costs. If this analysis used other crops, such as watermelons or cotton, controls would have to factor in variation in regions across the United States, which would open up our analysis to significant error in omitted-variable bias. Choosing a crop that is both pollination-essential and is localized is crucial for producing an analysis that is both accurate and relevant for more general discussion of the relationship between declining honeybee population and crop prices.

Hypothesis

Our null hypothesis for this study is as follows:

\[ H_0: \text{There is no relationship between honeybee population and almond prices.} \]

Our alternative hypothesis is:

\[ H_a: \text{There is an inverse relationship between honeybee population and almond prices.} \]

The law of supply dictates that as honeybee population falls there should be an increase in the cost for pollination services. We hypothesize that this increased cost for pollination services will result in higher prices for almonds. If a large enough decline in honeybee population occurs, then we should also see a decrease in total yield of almonds as firms are priced out of optimal levels of pollination services by the rapidly rising cost of pollination services. This decline in yield should also cause an increase in almond prices as the supply of almonds falls. All variables in this study will be analyzed at a 95 percent confidence level.

Literature Review

Substantial amounts of literature have been published on the
relationship between pollinators and crop yields and food security. Research has also been done on the economic valuation of pollinators and the loss in value from their decline. Little work, however, has been done on directly estimating the relationship between pollinator population and crop prices.

Dana Bauer and Ian Sue Wing, of Boston University, have attempted to analyze the relationship between global pollinator loss, reduction in value of global production, and food security by creating a general equilibrium model (Bauer, Dana, and Wing 2010). Their study finds compelling evidence that local or regional pollination shortages could negatively affect the value of production in both crop and non-crop sectors (Bauer, Dana, and Wing 2010). Certain regions like Sub-Saharan Africa suffer much heavier burdens of pollinator loss on production than others under their model and are at heightened risk of food security issues (Bauer, Dana, and Wing 2010, 378). A study published by the Society for Conservation Biology found evidence of declines in yield and crop loss in almonds, blueberries, and alfalfa seed being attributable to pollinator declines (Meffe 1997). This study presents further evidence that pollinator declines can result in food shortages and food instability. The Society finds that further research into the domestication of alternative pollinators as well as action to protect genetic stocks of honey bees is necessary to reduce variation in annual yield of crops (Meffe 1997, 15). These studies present evidence that the decline of pollinators can have a drastic effect on the future of food stability, and present possible solutions to these issues. However, these studies do not make attempts to assess changes in price, instead preferring to discuss qualitative changes in crops based on pollinator decline (i.e. Society study) or create global models that quantitatively discuss changes in the value of production.

Other studies also attempt to assess the value of pollinators by analyzing their relationship with crop yield or by attempting to calculate the loss in total agricultural production if a complete loss of pollinators occurred. One particular study was conducted by researchers Aizen, Garibaldi, Cunningham, and Klein in 2009. Using data from the Food and Agriculture Organization, they gathered data on the production and cultivated area of 87 important crops. Using aggregate measures of the effects of pollinator dependence for various crops, they were able to estimate the reduction in total agricultural production and the relative increase in cultivated land area to make up for it (Aizen et al. 2009). The researchers found that in the absence of animal pollination there would be a 3 to 8 percent reduction in total agricultural production, but that the needed increase in cultivated area to compensate would be many times higher (Aizen et al. 2009). Another study by the same team in 2009 addressed how pollinator shortages would affect annual growth rate in yield as well as growth rate in cultivated area. The researchers did not find
evidence of their prediction that there would be a lower annual growth rate in yield, but did find that there was a higher annual growth rate in cultivated area for pollinator-dependent crops (Garibaldi et al. 2009). They propose that pollination management techniques like renting more hives or hand pollination might have compensated for any limitation to yield (Garibaldi et al. 2009, 37). These conclusions may be useful when attempting to interpret the results from our analysis. Additionally, our analysis should account for strategies such as renting hives because we are attempting to estimate price, which should be directly influenced by pollination services pricing that is in turn affected by honeybee population.

A 2014 study conducted a field experiment to attempt to answer the question of how pollinator contribution affects crop yield and quality. After establishing an experimental zone and identifying the types of pollinators in their zone, they carefully controlled insect pollination in the field to create an experiment and control group (Bartomeus et al. 2014). Results from the study show that insect pollination enhanced crop yield between 18 to 71 percent, depending on the crop (Bartomeus et al. 2014). This study presents a unique method for determining the impact of pollinators on crops and confirms what previous studies have found. Another 2014 study, by European researchers, on supply and demand for pollination services found that for 41 European countries, the recommended number of honeybees for crop pollination rose 4.9 times as fast as honeybee population between 2005 and 2010 (Breeze et al. 2014). For 22 of these countries, the number of honeybees was not sufficient to supply greater than 90 percent of the demand for their services (Breeze et al. 2014).

These studies are very useful for establishing a baseline of knowledge from which to build our OLS and IV regression models. Additionally, the abundance of literature supporting the impact of pollinators on crop yields and quality gives early indication that we should expect to see an inverse relationship between honeybee population and almond prices. Since pollination has a demonstrated positive effect on supply of crops, we should expect that as the supply of almonds increases in direct proportion with honeybee population there will be a fall in almond prices. Because studies in the literature primarily focus on the impact of pollinators on yield and food security, this analysis also fills a gap in the literature. By directly estimating the price of a crop from honeybee population we enable discussion surrounding direct effects on consumers’ and producers’ bottom lines. We also provide a basis for future research interested in pricing effects of pollinators.
Data and Method

This paper uses two separate methods of analysis and two specifications to analyze the relationship between honeybees and almond prices. Our first method is the standard ordinary least squares (OLS) regression with almond price serving as our dependent variable and honeybee population as our independent variable. Control variables in this regression include the average United States temperature anomaly, average California rainfall, an index for drought in California, yield of almonds per acre, the amount of acres of almond trees, and the price of peanuts. This model attempts to estimate a linear relationship between honeybee population and almond prices while controlling for factors that may influence the production of almonds or their price. Rainfall, temperature, and the drought index control partially for growing conditions that may affect the yield of almonds every year, while yield per acre and acres bearing control for variation in the amount of sellable almonds every year. Temperature being a U.S. average means that its correlation with almond price will likely be weaker than if we used California averages, but this variable’s use in our second method requires that U.S. averages be used as will be discussed later. The price of peanuts in this model is used on the assumption that peanuts are a substitute good for almonds. In other words, peanut price is included because changes in the price of peanuts may have an effect on the price of almonds as demand shifts with changes in price. Finally, gasoline price is included as a rough proxy for transportation costs of honeybees used as pollination for almond crops. Significantly more factors go into the cost of transporting bees nationwide, but due to the complexity and multitude of factors data is hard to quantify or collect.

Our second method in this analysis is an instrumental variable regression using a two-stage least squares estimator. Instrumental variable analysis is used when our explanatory variables are correlated with the error of our regression. In the case of our analysis we use instrumental variable analysis because the price of almonds is determined by the interaction of both supply and demand. Using OLS regression in this case may result in the regression coefficients not being close to their true value. To have a non-biased result we must use a method that isolates shifts in price due to changes in supply and demand. Instrumental variable analysis allows us to use instruments, or variables that are both correlated with our independent variable and uncorrelated with the error term, to estimate our independent variable and determine if it is valid. The two stage least squares estimator, in particular, breaks down the process into two stages that use least squares regression. First, we use our instrument to estimate our independent variable, and then we use that estimate of our independent variable to estimate the coefficient of our dependent variable. By using this method we know that our
estimate of our independent variable will be uncorrelated with the error term.

Our instrumental variable analysis uses two instruments; one to control for demand and the other to control for supply. Our demand-based instrument is peanut price under the assumption that peanuts are a substitute good for almonds and as their price changes it has an effect on the demand for almonds. Our supply-based instrument is U.S. average temperature anomaly. Temperature is used because temperatures that are too hot or cold can have a negative effect on the survival of bees. Too hot or cold temperatures can also negatively affect the growth of almonds, and therefore temperature anomaly as an instrument is plausibly correlated with both our independent variable and dependent variable. Additionally, it is unlikely that honeybee population or almond prices has any reverse causality with temperature, and therefore is unlikely to be correlated with the error of our regression. National temperature anomalies are used because our honeybee data is also reported nationally, and California-only averages would not accurately correlate with national honeybee population. By using these two instruments in conjunction, we eliminate variation in the price of almonds from both supply and demand, and attempt an accurate estimate of the supply/demand function for almonds. All control variables for this model are the same, with the exclusion of U.S. temperature anomaly and peanut prices since they are used as instruments.

The two specifications used in our methods are the linear-linear and log-linear specification. The linear-linear specification is our base specification, and simply means that both our independent and dependent variables are linear in nature. The log-linear specification means our models are run using the natural log of almond price while honeybee population is left linear. This specification is used because logarithmic scales have a progression based on orders of magnitude (i.e. 10, 100, 1000). In the case of prices, using a logarithmic specification can help further linearize data if there is a wide range in values. By using this specification it is possible to increase the goodness of fit of our estimations.

This analysis makes use of yearly data from a variety of sources for a 20 year period from 1995 to 2014. Data on honeybee population was gathered from the U.S. Department of Agriculture’s National Agricultural Statistics Service (NASS) annual “Honey” publication, which reports the annual number of colonies producing honey on both the state and national level (“Honey Report” 2015). NASS’s “Honey” report represents the best available data on the number of managed honeybee colonies in the United States. A graph of the number of honeybee colonies over time is reported in Figure 1. Data on
almond price, acres bearing almonds, and yield per acre is gathered from the 2014 California Almond Price Report (“California Almond Price Report” 2014). The price for almonds is reported in terms of the average return to growers in U.S. dollars per pound. Yield per acre is also reported in terms of pounds. This data is gathered and reported annually by NASS’s Pacific Regional Office, and the 2014 report is a continuation of a long series of almond price surveys. A scatterplot of almond price vs. honeybee population is presented in Figure 2. Data on yearly peanut price is reported as the return to growers in U.S. Dollars per pound and is gathered from the USDA’s Farm Price report.

Data on temperature, precipitation, and drought is gathered from the National Climactic Data Center at the National Oceanic and Atmospheric Administration (“Climate Normals” 2015). Data on temperature is reported in terms of the annual average temperature anomaly for the contiguous United States. Temperature anomaly is the departure in degrees from the long-term average for a region. Temperature anomaly is used instead of absolute temperature measurements because anomalies more accurately describe climate variability over large areas (“Global Surface Temperature Anomalies” 2015). Additionally, we are primarily concerned with variation from the average because of particularly hot or cold temperatures’ effects on bee population and crop growth. Data on precipitation is reported in yearly averages in inches for the state of California. The measure of drought used in this study is the Palmer Drought Severity Index (PDSI), which is an index that attempts to assess moisture status comprehensively (“Palmer Drought Severity Index” 2015). It uses data on both temperature and precipitation to calculate water supply and demand, as well as incorporating soil moisture. Including this measure in our study attempts to account for climate variables relevant to crop growth that are not easily collected independently. Data on PDSI is reported in yearly terms for the state of California.

Finally, data on gasoline prices is gathered from the U.S. Energy Information Administration (“U.S. All Grades All Formulations Retail Gasoline Prices” 2015). This data is specifically for retail prices for all grades and all formulations of U.S. gasoline. Including data on all grades and all formulations attempts to account for a variety of transportation methods used for the transport of honeybees for pollination. The price for gasoline is reported in dollars per gallon. Summary statistics of all variables used in our analysis are presented in Table 1.

Results and Analysis

The results of all four regressions are presented in Table 2. Our first regression is an ordinary least squares regression using a linear-linear specification.
Our results from this regression report that our honeybee population variable is both positive and significant at the 99 percent confidence level. Specifically, the coefficient of this variable shows that for every 1000 extra honeybee colonies almond prices increase by roughly .004 cents per pound. These findings do not support our hypothesis. We expected to see that as honeybee population rose the price for almonds would fall, but this analysis estimates that as honeybee population rises so do almond prices. However, the change in price is minute. By this model’s estimate it would take an increase of nearly 250,000 honeybee colonies to increase almond prices by a single dollar, independent of other factors. Explanations for this apparent relationship will be discussed in our conclusion.

Other significant variables in this model are yield per acre and the price of gasoline. Yield per acre has a negative relationship with almond price and is significant at the 95 percent confidence level. This analysis estimates that for every extra pound of almonds per acre, almond price decreases by roughly .0015 cents. This is in line with what the law of supply would dictate: as the supply of almonds increases, the price of almonds should decrease, all else equal. The price of gasoline has both a very large positive and significant effect (at the 99.9 percent confidence level) on almond prices. Our model estimates that for every dollar increase in the price of gasoline per gallon almond price increases by roughly $1.69 per pound. This relationship and its magnitude are logical. Not only does gasoline necessarily influence the cost of pollination services, but gasoline is also used to run various agricultural equipment and also likely factors into the process of preparing and transporting almonds for consumption after harvest. The large increase in price of almonds per dollar increase in gasoline price is reflective of this relationship. Other variables in this model are not significant at our established 95 percent confidence level, but contribute to the explanatory power of our model. This models R-squared value is 0.742, which means roughly 74 percent of the variation in almond price is explained by our independent variables.

Our second OLS model, using the log-linear specification, produces similar results to our first model. In this model, honeybee population is once against significant and positive, but only at the 95 percent confidence level, suggesting that the log-linear specification is a worse fit for our data. This is further supported by the fact that our R-squared value for this model is .719, meaning that roughly 72 percent of the variation in almond price is explained by our independent variables. The interpretation of our honeybee population coefficient in this model estimates that for every extra 1000 honeybee colonies almond price will increase by .17 percent. Under this estimate, to increase
almond prices by one percent you would require an extra 5,880 honeybee colonies. Yield per acre and gasoline price in this model are both still significant at their previous significance level. In this model, a one pound increase in yield per acre would result in a .068 percent increase in almond price, and a 1 dollar increase in gas price would increase almond price by 89.6 percent.

The next two models are our instrumental variable regression models. For both of these models we used U.S. temperature anomaly and peanut prices as our instruments, and included all other control variables. All variables in these models are non-significant, but the signs on our variables make more sense in the context of our hypothesis and other literature on pollinators’ effect on crops. Under these models an increase in honeybee population has a negative effect on almond price, but these estimates are not significant at the 95 percent confidence level meaning we cannot say that these results are not simply an error or artifact of the data. The explanatory power of these models is also much lower at R-squared values of .344 and .374, respectively. Interestingly, it seems that the log-linear specification results in a stronger model for our instrumental variable regressions, but not for our ordinary least squares regressions. Overall, it seems that while our instruments did have some affect on controlling for effects on price from supply and demand factors, there is something missing from the model that prevents our results from being significant. As a result, no useful conclusions can be drawn from these two models. Deficiencies and possible adjustments to these models will be discussed in the next section.

Conclusions and Avenues for Future Research

Our findings did not establish a substantial relationship between honeybees and almond prices, and conclusions drawn from the analysis will naturally be weak. Both of our ordinary least squares models present results that are the opposite of our hypothesis, and although honeybee population in both models is significant, the validity of these results is suspect. First, the sample size in our model is lower than is generally required for OLS and instrumental variable estimators to be unbiased. At small sample sizes (particularly below 30) many of the assumptions that can be made about the validity of statistical analysis using these methods break down. Having access to more frequently recorded (i.e. quarterly) data would increase our sample size significantly and eliminate much of the bias that is likely present in our current analysis. Another issue in our results comes from examining Figure 2, which graphs almond prices vs. honeybee population. When examining this graph it becomes immediately clear that the relationship between
almond prices and honeybee population is weak at best and can only tenuously be called positive. Although our OLS models show significance for honeybee population, it seems that the elimination of only one or two data points could shift the linear regression from positive to negative. If we had access to more data or data across a longer period of time it would be easier conclusively to say if the relationship between honeybee population and almond prices is positive or negative. From the results of our regressions, we can say at best that the relationship between honeybees and almond prices is inconclusive.

Another possible and equally valid conclusion is that honeybee population is not as large of a factor in the final price of almonds as we would like to think. A multitude of factors go into the production of almonds, and the variables used in our analysis are only a subset of the larger ones. The direct effect of honeybee population on almond prices may filter out to be negligible in the long run, although this does not seem to be likely since almonds are considered a crop that greatly benefits from pollination. It seems more likely that the amount of data we currently have available is insufficient. OLS regression is also likely to be inaccurate because of the reasons stated in our methods section, hence our use of instrumental variable analysis as well.

An important control variable that is missing from our analysis is the cost for pollination services for almond growers. Data on pollination service costs are not centralized and seem to be collected sporadically by different beekeeping associations. Having good data on the price that almond growers pay for pollination services would allow us to further control for effects on almond price that honeybees cause. As it stands currently, our honeybee population variable is doing the work of the omitted pollination cost variable, which results in weaker overall explanatory power.

When examining Figure 1, which reports honeybee population over time, there also seems to be a discrepancy in our data and the commonly reported honeybee loss due to colony collapse disorder. The USDA reports that from 2006 to 2011, winter honeybee losses averaged about 33 percent of total colonies in the United States. However, when examining the period from 2006 to 2008 there is only a slight decrease in the reported number of managed colonies, and from 2009 to 2010 there is a large jump in the number of colonies. Despite the NASS “Honey” report having well aggregated and consistent yearly data, there is perhaps a discrepancy in the number of honey producing colonies and in the total number of managed colonies in the United States. If this is the case, and the total number of colonies has been decreasing in accordance with USDA reports, then this is a large source of error in our
analysis. Further research into finding accurate honeybee population data is needed.

Our instrumental variable regressions are non-conclusive for a variety of reasons. As stated above, the sample size we have for this analysis is too low for the assumptions that make IV regression a useful method to hold true. Having a larger sample size would help eliminate these sources of errors and make our models stronger. Additionally, it is likely the case that our instruments are weak and do not fully capture the supply/demand function for almonds. The Consumer Price Index may be a useful instrument to use alongside other instruments. Non-linear specifications for quantity should also be explored to estimate for a nonlinear demand curve. With better data and more complex and better suited instruments a significant IV regression should be possible.

Another possible explanation for our results is that rising prices of honeybee pollination services (unaccounted for in our data) has increased the viability of using alternative pollination methods, thereby offsetting some of the effect of declining honeybee pollination. Some research has been done on agricultural techniques that make use of native insect pollinators as alternatives to honeybees (Scardina 2012), and it is possible that rising costs of pollination services has reduced the opportunity cost of transitioning to alternative pollination methods. This has been seen in China, where honeybee loss has caused farmers to shift to hand pollination of apple trees (Liess 2015).

Generally, even though our OLS regressions show significance, we cannot reject the null hypothesis or confirm our alternative hypothesis. This is primarily due to the lack of sample size, and inherent bias in our estimators as a result. Additionally our instrumental variable regressions are insignificant which are supposed to control for bias that is still inherent in OLS regression for this type of analysis. Further research is clearly needed to determine if a relationship between honeybee population and almond prices exists.

There are a variety of avenues for further research on this topic. For future research on almonds and honeybees better data is needed. If data on almonds can be gathered pre-1995, and better instruments can be found then the models laid out in this paper can serve as a starting point for analysis. Future research can also focus on other crops that benefit from honeybee pollination. Almonds are a useful crop to focus on because almost all of the U.S. production in located in California, and therefore variables in production are easier to control for, but other crops may have better data which would produce a more conclusive result. Research on commercial crops instead of food crops would be particularly interesting. Future analysis on this topic should also make attempts to gather data on the price of honeybee pollination services for the specific crop they are analyzing.
Bibliography


Bartomeus et al. (2014), Contribution of insect pollinators to crop yield and quality varies with agricultural intensification


Appendix A: Tables and Figures

Figure 1

Honeybee Population vs. Time

Figure 2

Almond Price vs. Honeybee Population
### Table 1

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* p<0.05, ** p<0.01, *** p<0.001