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Honey Bees' Impact on the U.S. Economy

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Abstract

Since Colony Collapse Disorder became front-page news in 2006, popular literature ranging from news articles to White House documents has cited the value that honey bees provide. These numbers in articles often are inconsistent and rarely cite the origin of the stated value. This paper examines the major studies on the economic impact that honey bees have in the United States. Then it discusses the existing errors in these studies' methodologies and offers a preliminary model that incorporates the full economic effects of honey bees. It then offers some policy suggestions in order to better address the needs of honey bees in order to maintain this valuable natural resource.

Honey Bees' Impact on the U.S. Economy

Introduction

The European honey bee, *Apis Mellifera,* is critical to food production in the United States. Products such as fruits, nuts, vegetables, as well as meat and dairy products, through pollination of animal feed such as alfalfa, are pollinated by insects (Losey & Vaughan, 2006, p. 315). Of the several species of insects that pollinate crops, the European honey bee is the species used commercially since they can be semi-domesticated and honey bees are valued for their products of honey and wax ("Status of Pollination in North America," 2007, p. 12). Humans have been keeping honey bees for thousands of years for both their products and pollination services. Records of honey bee domestication date back to ancient Egypt over 6000 years ago ("Status of Pollination in North America," 2007, p. 12). Recently, honey bees have been plagued by drastic declines in their populations in Europe, and the United States is following a similar disturbing trend. Between 1947 and 2005, the total number of hives has declined 59 percent (Potts et al., 2010, p. 345). While many factors are responsible for the decline, a major contributor was the rise of mite infestations that began in the 1980s and has continued to this day ("Status of Pollination in North America," 2007a, p. 40-41). This decline is compounded by an increase in demand for pollination services by over 300 percent since 1961 (Aizen, & Harder, 2009, p. 915).

After 2005, a new type of honey bee disease named Colony Collapse Disorder (CCD) has only exasperated the decline in managed honey bee colonies. CCD is caused by multiple factors ranging from pesticide exposure, to disease, and loss of genetic diversity; however, an exact cause is unknown ("Fact Sheet," 2014). This combination decreases the ability for beekeepers to hibernate their bees over winter and that leads to high mortality rates of hives during the hibernation period (Potts et al., 2010, p. 349). In addition to CCD, there is the parasite *Varroa destructor*, which is only one of many diseases the honey bees have been exposed to in recent decades (Potts et al., 2010, p. 349).[1] Another category of pathogens is *Nosema*, which is effectively bee dysentery (Potts et al., 2010, p. 349). Both *Varroa* and *Nosema* weaken the honey bees' immune systems and make them susceptible to secondary infections. In addition, the exposure of honey bees to chemicals from agriculture, such as neonictinoids, cause non-lethal neurological and genetic damage (Sass, 2015). Agrichemicals that provide these non-lethal doses hinder the honey bees' ability to reproduce and forage for pollen and nectar (Sass, 2015). The new decline due to CCD has created a dialogue within multiple disciplines on what a world without managed honey bee colonies would look like. In the field of economics, specifically agricultural economics, the discussion has centered around what would the consequences of such a loss be.

Few studies exist that attempt to calculate the aggregate impact that pollinators, let alone honey bees, have on the United States economy. In the past 35 years, only four major attempts at assessing the value of honey bees have been published, and two of the four use similar methodology of assessing honey bees value on the United States economy. **Table 1** shows the pronounced discrepancy in the valuation of honey bees, in 2015 dollars, ranging from $54 billion to only $620 million. This paper uses 2015 as a base year in order to have

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[1] Varroa destructor is an external parasite, which feeds on honey bees. They were discovered in the United States in 1987 after coming from East Asia. Varroa feed on the bees' blood and weaken their host, shortening the honey bees' lifespan. As infestation grows, the hive weakens and is more susceptible to other diseases. Honey bees that are infected with Varroa are treated with medication biannually. For more information, see *The ABC & XYZ of Bee Culture pgs. 547-558*.

a comparative value between the studies.[2] The base year maintains a consistency of values between the studies in order to factor inflation changes. Since there are relatively few studies, and, of those studies, a wide dollar discrepancy exists, establishing a clear value of honey bees currently is problematic. Without having a clear estimate of honey bees' services, it is difficult for people and government agencies to see how much honey bees impact their daily lives. For example, if honey bees' impact is underestimated, and if they become scarce, it can have costly impacts for the farmer, who pays for the pollination, the beekeeper who relies on bees for their livelihood, and ultimately the consumer, who buys products that have been produced by honey bees. It is important to understand how much honey bees are worth so this valuable resource can be protected.

Table 1 Value of Honey Bees in Agriculture in the United States

Study	Data Year	2015 Dollar Value (in billions)
Levin	1980	54.75
Southwick & Southwick	1992	34.48
Morse & Calderone	1996-2000	21.22*
Rucker et al.	2009	.62

2015 Dollar Value is calculated as a base year for the different studies

*Average inflation over the 5 year period tested, does not account for changes in output since the initial dollar year

The variation in **Table 1** comes from widely ranging methodologies that the authors of the studies use in order to assess the values of honey bees. This paper will discuss the current environment that honey bees face and then it will evaluate four methods that have been used to assess the economic value that honey bees have in the United States. The focus of this meta-analysis will be the assessment of the existing studies and how the current research environment is missing key factors in establishing honey bees' value. It will then offer a preliminary model as a

[2] Inflation is calculated from data provided by the United States Bureau of Labor Statistics. http://www.bls.gov/data/inflation_calculator.htm

solution to this existing research gap. Finally, this paper will discuss the current policy environment and offer suggestions for how to improve the environment for honey bees in the future in order to maintain this critical component of production in the United States.

How Honey Bees Factor into the Agricultural Economy

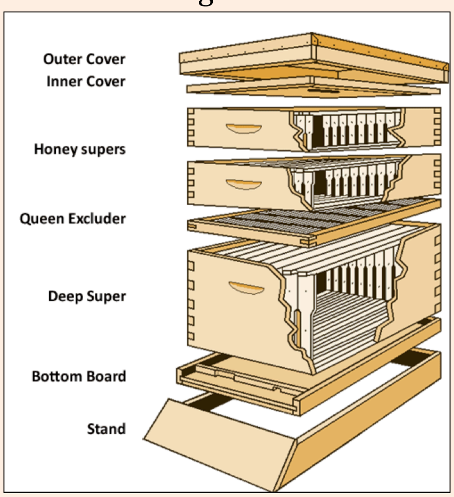
Not all crops are pollinated by bees. Most cereal grains as well as the leading commodity crops are not pollinated by honey bees, but rather wind and other passive methods (Klein et al., 2007, p. 306). In the United States, approximately 15-30 percent of a person's diet comes from crops that are pollinated by animals, chiefly among those animals being the honey bee (Losey & Vaughan, 2006, p. 315). Some studies, such as Gallai, Salles, Settele, and Vaissiere's 2009 paper on global pollinator decline, factor in native pollinators as well as managed bee colonies; Losey and Vaughan's analysis is another example of assessing the value of native, as well as managed, pollinators. Native pollinators provide their own substantial economic service; however, they are not as relevant in areas, such as most of the United States that rely heavily on monoculture production (Rucker et al., 2012, p. 956). [3] Honey bees are used due to the ease in which they can be transformed into a commercial agricultural service. Some other species of managed pollinators are used by farmers instead of honey bees; however, they are for specialized purposes. For example, for tomato plants to be pollinated, in order to increase yields over passive pollination, they must be sonicated by bumblebees to open the plants' anthers (Losey & Vaughan, 2006, p. 316). Anther type of crop that often relies on managed pollinators is alfalfa, where alfalfa

[3] Honey bees are not native to North America, most native bees are solitary, such as the mason bee, or live in small colonies, such as bumblebees. For more information, see *Insect Pollination of Cultivated Crop Plants* section on "Wild Bees and Wild Bee Culture."

leafcutter bees, typically imported from Canada, are used to pollinate the crop ("Status of Pollination in North America," 2007b, p. 86-87). In addition to native and managed bees, feral honey bee colonies pollinate crops. However, the impact of feral honey bees is no longer a reliable source of pollination due to the damage of Varroa mites, which decimated feral honey bee colonies in the late 1980s (Rucker et al., 2012, p. 956). As a result of the limitations of other bee species, commercial beekeepers continue to use honey bees.

Beekeeping can readily be scaled up from the hobby and enthusiast level to that of commercialization, where an individual commercial beekeeper has between 300-60,000 hives ("Status of Pollination in North America," 2007b, p. 12). Beekeeping is subject to economies of scale where as an individual takes on more hives, they are able to decrease their per-unit costs by increasing efficiency of resource distribution. A major factor of the honey bees being receptive to economies of scale is due to the Langstroth hive. The hive was developed in 1862 and it allowed bees to be moved and manipulated by people easily to increase the productivity of the hives ("Status of Pollination in North America," 2007b, p. 12). This hive design has remained unchanged for the most part since Langstroth's created the hive (See **Box 1**) . The start up costs to the beekeeper are modest for an agricultural industry.

Box 1 The Langstroth Hive



This is the general structure of a Langstroth hive. Components can be added or subtracted based on the needs of the bees and the size of the colony. Typically, commercial pollinators use an 8-frame variant placed on pallets. For more information, see *The ABC & XYZ of Bee Culture pgs. 312-314, 234*.

**Adapted from the Pierce County Beekeepers Association Apprenticeship Program*

The United States' beekeeping industry is similar to a competitive market system. The products that beekeepers produce: honey, wax, and pollination are almost identical among various beekeepers. In addition, the inputs of production, the equipment that beekeepers use, from the woodenware to the transportation of hives are similar across beekeepers as well. With regards to barriers to entry, a potential supplier needs only to possess the necessary knowledge to raise bees, which can be obtained at little cost. Online information is free and minimal education on how to raise bees is needed. For example, the State of Washington offers an education program for only $20 ("Apprentice," 2015). Finally, an investment of approximately $125,000 for 3,000 hives is needed for a person to establish a commercial beekeeping operation (Business Practices and Profitability, 2010, p. 732).

Approximately, one percent, about 1,350 persons, of beekeepers are considered commercial, whereas 94 percent are hobbyists who have 1-25 colonies, and the remaining five percent are sideliners who manage 25-300 colonies ("Status of Pollination in North America," 2007a, p. 19). Commercial beekeepers typically need an average of 2,000 hives to sustain themselves financially, however, operations with approximately 700 to 1,000 hives had the lowest costs per unit (Business Practices and Profitability, 2010, p. 742).[4] Hobbyists and sideliners already possess many of the tools that commercial beekeepers have, and, as a result, they face little barriers to entry in the commercial beekeeping industry.

A major component of commercial beekeeping that differs from smaller operations is transportation. Honey bees are transported to fields when crops are in bloom, where the

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[4] For a complete breakdown of fixed and variable costs to a commercial beekeeper, see **Table 2** in the *Hive and the Honey Bee* on page 732.

hives are left for the bees to forage and aid in the sexual reproduction of plants for either seeds to be eaten by people, or for use in future seasons' plantings (Aizen et al., 2009, p. 1579). In exchange for the use of a beekeeper's colonies, the proprietor of the farm will pay a rental fee on a per hive basis. Hive rental fees have been rising dramatically since the 1990s. For example, the average fee was $54 in 2004 and in 2006, the average fee was $136, and fees can go even higher depending on the crop being pollinated ("Status of Pollination in North America," 2007b, p. 12; Sumner, D., & Boris, H., 2006, p. 9).

Analysis of Existing Studies

Estimating the value of honey bees can be difficult since other variables such as soil nutrients, microclimates, and pests in a particular year, or other limiting factors can hide the impact that honey bees can have on a particular crop (Klein et al., 2007, p. 309). The variety of a particular plant, along with its location in proximity to native pollinator habitats can change the demand for managed honey bee colonies (315). As a result, the four studies discussed below attempt to answer the same question, what impact do honey bees have on the United States' economy, but with varying methods. Each method has its merits, but also flaws, moreover, the studies choose to focus on a different aspect of honey bees' services as opposed to the larger impact that honey bees have as a whole.

Value of Bee Pollination to U.S. Agriculture—M.D. Levin

The first study in assessing the value of honey bees is by M.D. Levin who relied on the data obtained through a book written by S. E. McGregor and published by the United States Department of Agriculture (USDA) in 1976 titled *Insect Pollination of Cultivated Crop*

Plants (811). McGregor's publication is also a major source of information in the other studies, Morse and Calderone and Southwick and Southwick. Levin established the value of crops pollinated by honey bees at $54.75 billion dollars. He breaks this number down by crops that need bee production for human consumption such as fruits and nuts, then crops that need bees to seed, such as broccoli and carrots, then secondary crops of beef and milk (51). This method is inherently flawed since it does not separate the value of the actual crop from the value of the pollination service itself. This is due to the lack of dependency ratios in Levin's research. In order to isolate the impact that honey bees have on crop yields, later researchers developed dependency ratios that allow them to measure how much yield can be attributed to pollination services (Losey & Vaughan, 2006, p. 317). How the dependency ratios are created and interpreted yields significant variation in estimating an accurate economic impact that honey bees, and other pollinators have on agriculture. By not using dependency ratios at all, Levin does not capture how much crops would be reduced without honey bees. For most crops, with the absence of honey bees, the crops would still produce, but at a reduced quantity output.

While his analysis does include the secondary crops of beef and milk from cows, since alfalfa is a pollinated crop, it is based on outdated farming practices. Increasingly in modern apiculture, alfalfa leafcutter bees are being reared to pollinate alfalfa since they are more efficient than honey bees for the crop's specialized pollination needs ("Status of Pollination in North America," 2007, p. 24, 168). One place where Levin's analysis maintains some merit is the inclusion of other honey bee products, namely honey and wax. He estimates it is worth $404 million, in 2015 dollars. As the rise of natural beekeeping cosmetic products has continued since Levin's study in the early 1980s, this value will have increased as well. The value of honey and wax would also be considered a secondary market since the products can be turned into consumable goods for cosmetic and home use. Burt's Bees, arguably the most popular for its beeswax lip balm, sold to Clorox for $925 million in 2007 is an example of a company that relies on this secondary market (Farrell, 2007).

Honey Bee Pollination Markets and the Internalization of Reciprocal Benefits — Rucker, Thurman, and Burgett

Recently in 2012, Rucker, Thurman, and Burgett employ an entirely different method for assessing the value of honey bees within the United States using a value added approach. They examine the fees paid by farmers to beekeepers for the services of pollination. Rucker et al. create a pollination market to explain how their estimate of $390 million of pollination fees fit into a competitive market structure (957). In addition, Rucker et al. include $230 million of honey sales in their model (957). Pollination markets exist due to contracts between farmers and migratory beekeepers, who travel routes together to pollinate multiple crops in a year (Rucker et al., 2012, p. 958). The farmer hires the beekeeper, or goes through a bee broker, and, because of hiring the beekeeper, the farmer gains the increase in crop yield through pollination and the beekeeper then gains honey in exchange for their bees (Rucker et al., 2012, p. 959, 962). The honey gained by the beekeeper can be harvested and sold for a profit, or it can be used as food stores for the colonies in the winter. Since crops are in bloom at different times of the year, a single beekeeper can pollinate many crops within the same growing season creating large economies of scale (Rucker et al., 2012, p. 958).

Rucker et al. (2012) establish that demand for the individual beekeeper's bees is equal to the total value marginal product of bees ($TVMP_B$). This value is also considered the bee wage (w) where $TVMP_B$ equals the variable marginal product (VMP) of honey ($_{H/B}$) and fruit ($_{F/B}$) (960). The stocking density, which determines the per acre output of honey and fruit is expressed as acres (A) divided by bee colonies used (B). This value is interpreted as:

$$b \equiv \frac{A}{B}$$

For an individual beekeeper b* is the stocking density for his/her $TVMP_B$. Therefore, $TVMP_B$ can be interpreted as:

$$TVMP_B \equiv VMP_{\frac{H}{B}}(b^*) + VMP_{\frac{F}{B}}(b^*) = w$$

The aggregate demand of the market for pollination is created by multiplying $TVMP_B$ by the aggregate equilibrium of the number of acres pollinated (A). Rucker et al. (2012) then create the market supply by establishing that supply is a function of the cost of beekeeping to the beekeeper (k), price of honey (P_H), and the bee wage (w). This cost (k) includes all costs of production both fixed and variable (960).

$$S = f(k, P_H, w)$$

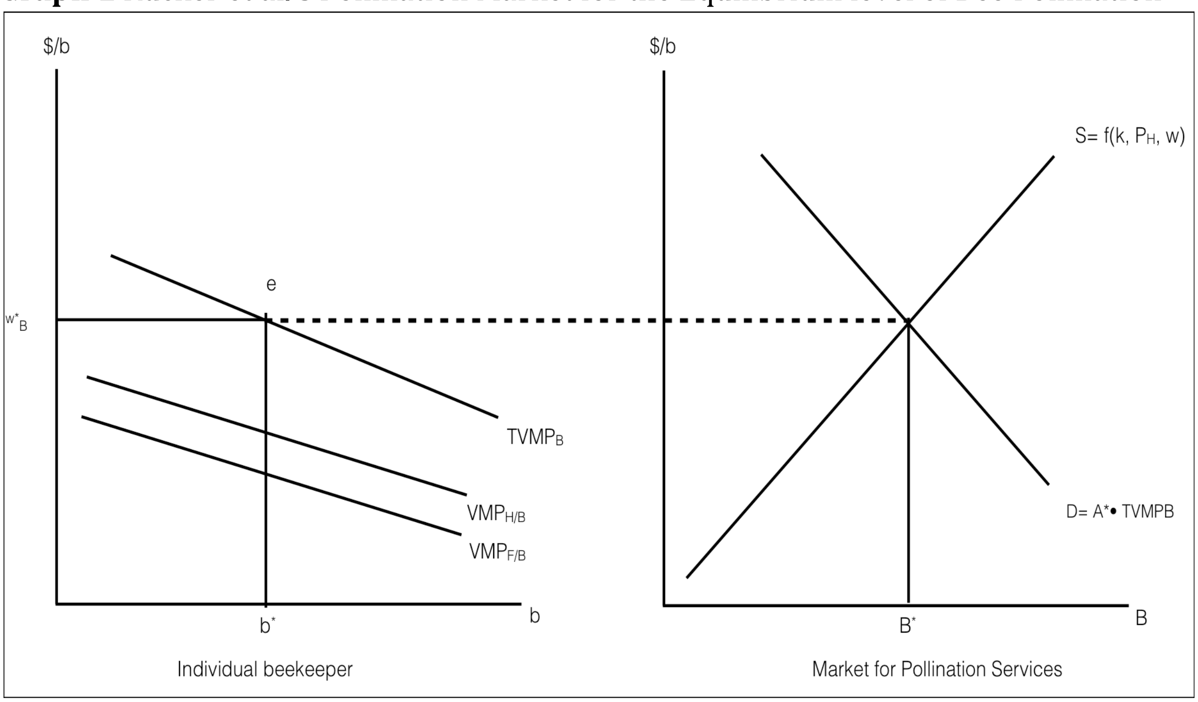
This market is expressed in **Graph 1** where it shows the market at equilibrium. Equilibrium is defined as the point where aggregate demand is the sum of the optimal density function of b* across the same number of acres pollinated (A^*). This is seen in the equation

$$A^* \bullet b^*(k, P_H, w) = Q_S(k, P_H, w)$$

This result corresponds to the bee wage, or the market value of pollination services, which Rucker et al. (2012) estimate at $390 million (957). With the market at equilibrium as shown in **Graph 1,** the price is equal to the marginal cost, which means that in the long run the beekeeper will be producing at the minimum average total cost (ATC) of production. With the creation of a competitive market for pollination services, the market can operate at both production efficiency and allocative efficiency.

While this creates an accurate model for the market of pollination, much like Levin's model it fails to capture the full impact that honey bees have on the United States economy. Levin did note that honey bees increased yields of crops, however he was incorrect in attributing all of the crops' value to honey bee production in his model. Rucker et al.'s model fails to include that honey bees add increased yields to crops. A more accurate model would include not only the products that bees produce, pollen services, wax, and honey, but

Graph 1 Rucker et al.'s Pollination Market for the Equilibrium level of Bee Pollination



This graph shows that the two variable marginal product curves are added together to form a total marginal product curve for the individual beekeeper, which is then aggregated by the number of acres. Equilibrium is at w^*_B and B^*. Supply is the sum of the marginal cost for all the individual beekeepers.
*Adapted from Rucker et al. 2012, p. 961

what value they add to crops in general. The next two studies by Morse and Calderone and Southwick and Southwick attempt to estimate the value of honey bee pollination services on crop value by incorporating dependency variables.

The Value of Honey Bees as Pollinators of U.S. Crops in 2000—Morse and Calderone

Morse and Calderone's model is similar to Levin's in that it attempts to estimate the total value that honey bees have on the United States agricultural economy by focusing on the crops, and not, as in Rucker et al.'s case, on the actual transactions between beekeepers and farmers. Morse and Calderone (2000) also acknowledge that free pollination exists from beekeepers who are willing to pollinate a farmer's crop with no compensation for pollination since they gain a high return for honey produced (3-4). Additional services provided that are not compensated by farmers to beekeepers include pollination from nearby hobby beekeepers or bees that are moved nearby for queen rearing (4). Morse and Calderone also note that honey bees provide other services which create positive externalities to the surrounding ecosystem including: pollination of plants that prevent erosion, pollination of gardens, pollination of native plants that provide food for wildlife (4). These externalities would be very difficult to measure accurately but they do provide an important service to the environment, and therefore an economic service to humans. For pollination markets, Morse and Calderone focus on the actual crop dependency of pollination since it is key to getting an accurate result on honey bees' economic impact regarding pollination.

In order to create a model of the value honey bees add to agriculture, Morse and Calderone employ dependency variables in order to estimate how dependent a crop is to pollination. Their dependency ratios are meant to measure the economic loss that results from a total loss of pollinators for a particular crop in quantifiable terms (Gallai, et al., 2009, p. 811). The dependency ratios are calculated based on their analysis of how much pollination is needed for each crop used in the model (Morse & Calderone, 2000, p. 8). Morse and Calderone then created an equation used to estimate how much value honey bees were responsible for an individual crop:

$$V_P = V \bullet D \bullet P$$

Where the value of pollination (V_P) is equal to the value of the crop (V) multiplied by the dependency ratio (D) and the proportion of honey bees needed to pollinate a crop (P). The variable "P" is similar to the variable "b" used by Rucker et al. in their model. This model can then be aggregated so:

$$V_T = \sum(V \bullet D \bullet P)$$

where the total value of pollination (V_T), is equal to the value of the sum of all the crops that honey bees pollinate (Losey & Vaughan, 2006, p. 315). Morse and Calderone estimate the value that honey bees have on agriculture is $21.22 billion (8). This value is significantly higher than Rucker et al. value and lower than Levin's value, which also included the honey and wax sales.

Morse and Calderone's methodology falls short in several places. They underestimate aspects of honey bees' impact, such as the positive externalities mentioned above, the actual transaction cost of pollination services, honey, and wax products, as well as the secondary market for bee equipment and products, which are not included in this analysis. These shortcomings are partially addressed in the final study by Southwick and

Southwick who use a similar method to attempt to solve the issue of a partial loss and partial replacement of honey bee stocks in their analysis.

Estimating the Value of Honey Bees as Agricultural Pollinators in the United States—Southwick and Southwick

Southwick and Southwick specifically incorporate losses of honey bees stemming from mites, pesticides, and diseases (622). They also include Africanized honey bees as a potential source of bad press, and declination of honey bee stocks (622).[5] Much like Morse and Calderone, Southwick and Southwick acknowledge that there are benefits that honey bees provide outside of pollination, honey, and wax, but they leave the positive externalities out of their analysis. They create a model of the crop pollination market for honey bees. They assume a perfectly elastic supply curve where a farmer's opportunity cost is the same for a variety of crops, so it is easy to switch to a different crop (Southwick & Southwick, 1992, p. 622). This can be seen in **Graph 2** where "S_0" is perfectly elastic, and when farmers employ managed honey bees, the "S_0" curve moves downwards to "S_1" since their productivity increases. Southwick and Southwick assume a typical demand curve for the graph.

To establish the increase in consumer surplus of the model, Southwick and Southwick use the equation:

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[5] *Apis Mellifera Scutellata* was imported into the Americas in 1956 and escaped a research facility. They have migrated into the United States, but are limited in their progression northward due to the climate. They can crossbreed with European honey bees. Africanized bees are known for their aggressive behavior. They will pursue a person for up to a mile if agitated, as opposed to European honey bees, which will pursue a person for a few feet. This makes them almost impossible to domesticate safely. For more information, see *The ABC & XYZ of Bee Culture pgs. 4-11*.

$$\text{Gain} = (P_0Q_0 - P_1Q_1) + \int_{Q_0}^{Q_1} [P(\text{Demand})]dQ$$

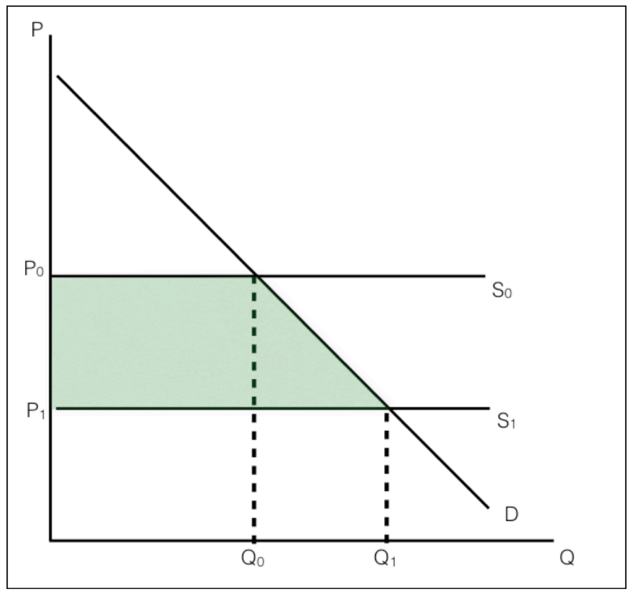
Where the difference in revenue for the farmers with and without honey bees (P_0Q_0-P_1Q_1) and the value placed on the particular crop by the consumers willing to buy the product at the lower price as a result of honey bee pollination (Southwick & Southwick, 1992, p. 623). This increase in consumer surplus is seen in green on **Graph 2**.

In order to estimate the dependency variables for the crops that honey bees pollinate, Southwick and Southwick first create an econometric model of demand based on a Box and Cox form:

$$P^b = a_0 + a_1Q^b + a_2Y^b$$

Where "P" is the price, "Q" is the quantity, and "Y" represents the income to the beekeeper. The parameters "b" and "a" are added as well. Each demand function for the crops is considered independent of each other (Southwick & Southwick, 1992, p. 625).

Graph 2 Southwick and Southwick Model of Consumer Surplus Gain from Honey Bee Pollination Services



This model shows the additional CS (in Green) that consumers' gain from pollination services which lower the cost of agriculture.
*Adapted from Southwick and Southwick 1992 p. 622

Southwick and Southwick then calculate the production loss if honey bees were eliminated from each crop's production, and they give several levels in order to estimate a variety of scenarios of partial to full loss (Southwick & Southwick, 1992, p. 627,629). Finally, Southwick and Southwick incorporate two levels of dependency ratios into their analysis, the "no replacement value" level is to estimate what would happen if there was a total collapse of honey bee populations in the United States (Southwick & Southwick, 1992, p. 629). This would be a worst-case scenario where there are no longer any managed honey bee hives to be used in commercial agriculture. Their second and lower level of dependency ratios, "expected" are assuming the use of other managed bee stocks, even proposing using the Africanized honey bee to compensate for the loss of honey bees (629). These ratios are calculated by interpreting a wide variety of references and no particular formula or equation is given. This value would be $12.37 billion if the "expected" loss scenario were to happen. However, the actual value of honey bees' pollination to crops would be the total value lost if they were no honey bees left to pollinate. As a result, Southwick and Southwick (1992) estimate the value much higher at $34.48 billion (630). This model still has many of the same deficiencies that Morse and Calderone's analysis has. It does not factor in externalities, nor does it factor in the honey, wax, and secondary markets. The creation of the market for crop pollination does not have the same depth as Rucker et al.'s; it does not go in-depth into the economic rationale for the perfectly elastic supply curve.

A Note on Dependency Ratios

All of the studies that this paper analyzes do not capture the entirety of honey bees' economic impact in the United States. Levin's (1983) study did not include dependency ratios, and as a result, he overestimated the impact that honey bees have in their pollination services. With regards to Southwick and Southwick and Morse and Calderone's studies, a major flaw in them is how they derive their dependency ratios. Despite both

Southwick and Southwick and Morse and Calderone using dependency ratios, their actual results differ greatly. Dependency ratios in particular, largely rely on the personal communications of researchers or individual interpretation instead of an accepted and tested model (Gallai, et al., 2009, p. 811). This is a notable criticism by Gallai et al. when they attempted to estimate the global impact of pollinators on agriculture by using dependency ratios for crops. In addition, the source material for the dependency ratios often stems from the same book, *Insect Pollination of Cultivated Crop Plants,* written by McGregor (811).

If one reviews the pollination requirements that are mentioned in McGregor's publication, it does not give specifics on how dependent a crop is, but instead discusses in general terms the kind of pollination needed. As a result, even when using a partial loss estimate and drawing on the same source material, variations within the dependency ratios persist. Gallai et al. (2009) favor a more complex approach that takes into account partial losses, a methodology created by Klein et al. (811).

This methodology is newer than both Morse and Calderone and Southwick and Southwick and is more comprehensive in its source material. Klein et al. (2007) used the United Nations Food and Agriculture Organization (FAO) data (304). They established that 12 crops are entirely dependent on honey bee pollination and there are 107 additional crops that honey bees pollinate (Klein et al., 2007, p. 309). The dependency ratios that Klein et al. created were divided into five levels from "essential" to "none" as shown in **Table 2**.

While also drawing on McGregor's publication for source material, Klein et al.'s (2007) data utilizes current information in agricultural practices resulting in a more

Table 2 Levels of Pollinator Dependency Based on FAO Data

Level of Dependency	Percent Dependent*
Essential	90
High	40-90
Modest	10-40
Low	>10
None	0

*Percent Dependent is the percent that the crop output would be reduced in the absence of pollinators

thorough analysis of the how dependent crops are on pollinators than previous research. In addition, Klein et al. (2007) relies on many more sources in their analysis of the dependency that crop production is tied to honey bees. This methodology has been used as the core dependency ratios in Gallai et al.; however, no studies in the United States have been published since Klein et al.'s research so the existing studies on the economic impact of honey bees rely on older and less accurate methodology for establishing the dependency ratios. A comparison of five crops' dependency ratios is shown in **Table 3** to illustrate the disparity in results of the three different methodologies discussed. While there are similarities, only Klein et al. (2007) capture the variability of the other factors in crop production. Losey and Vaughan (2006) note that a place for a discrepancy in value of pollinators from study-to-study is the regional differences that arise concerning discrepancies in the environment of where crops are grown (315). By creating a spectrum for dependency ratios to, Klein et al. can more accurately capture the production increase that honey bees have on crops.

Shortcomings of the Four Existing Models

All the current models suffer from deficiencies. In order to estimate the value of honey bees, several factors have to be examined in order to create a comprehensive model. None of the models above accurately determine the value of honey bees' impact. A complete analysis would combine aspects from the discussed models and expand in order

Table 3 Comparison of Five Major Crops between Southwick & Southwick, Morse & Calderone, and Klein et al.

Crop	Southwick & Southwick "No replacement" [a]	Southwick & Southwick "Expected"	Morse & Calderone [b]	Klein et al. [c]
Almonds	0.9	0.5	1	0.4-0.9
Strawberry	0.3	0.2	0.2	0.1-0.4
Cottonseed	0.3	0.2	0.2	0.1-.04
Cucumber	0.6	0.3	0.9	0.4-0.9
Orange	0.3	0.1	0.3	0-0.1

Expected is assuming a 50 percent loss of honey bee stocks in the United States and then replacing them with other means of pollination. Klein et al. is included as a comparison of updated dependency ratios

Sources:
[a] Southwick & Southwick, 1992, p. 628; [b] Morse & Calderone, 2000, p. 8; [c] Klein et al. Figure 2, 2007, p. 2-14; Table design from Gallai et al., 2009, p. 811

to establish a more accurate estimate of honey bee impact. While this model is beyond the scope of this paper, it would incorporate five elements. First, it would use a similar methodology to Rucker et al. (2012) and create a transaction market for pollination services between farmers and beekeepers. Second, it would factor in the value added, through use of Klein et al.'s (2007) dependency ratios for the crops that honey bees pollinate in the United States. Third, it would also incorporate honey and wax sales as with Levin (1983). Fourth, the model would be able to incorporate the secondary markets such as cosmetic goods from bee products and the hardware used in beekeeping, such as hive woodenware. Fifth, the externalities that honey bees provide that provide that Morse and Calderone (2000) noted would be added. Using the existing data from these studies, a preliminary estimate of the impact that honey bees have on the United States economy can be interpreted as:

$$V_{HB} = \Sigma(V_P) + P_F + (V_H + V_W) + \Sigma(P_{HB}) + \Sigma(Ext)$$

where the total sum of honey bees' value (V_{HB}) is equal to the sum of the value of pollination on crops (V_p). Then pollination fees (P_f), honey (V_H) and wax (V_w) sales would be added. Next, the sum of the value honey bees add to secondary products (P_{HB}) is included, and finally adding the sum of all known positive externalities (Ext).

The "V_p" would not change significantly from what Southwick and Southwick estimated for their "no replacement" level. However, by using Klein et al.'s (2007) more comprehensive data and averaging each of Klein et al.'s (2007) dependency ratios, which is similar to Gallai et al. (2009) method, the value of the impact of honey bees' pollination on crops would be improved. For "P_f" based on Rucker et al. (2012) analysis of the value of pollination transaction fees model would keep the value consistent with what they already estimated. For "V_H" and "V_w" using existing USDA data would be sufficient on recorded sales for commercial beekeepers, but what would also need to be included would be the value of honey and wax for all hobbyists who are not recorded in USDA data (McConnell, M, 2007, Table 46). The addition of including the "P_{HB}" which is the secondary markets of cosmetic products and supporting industries, companies that manufacture equipment as well as transportation firms for migratory beekeeping, would substantially increase the value that honey bees have. Finally, finding and assessing the value of the externalities that honey bees provide to people in the United States, would also raise the value substantially.

This value would be significantly higher than the existing estimates for honey bee's impact on the United States' economy. In addition, the values in **Table 1** only take into account for inflation and not increases in production demand, which has increased over 300 percent in the last 50 years (Aizen, & Harder, 2009, p. 915). As a result, the value that honey bees provide to the United States economy each year would be greater than even Levin's estimate. With honey bees being able to contribute over $50 billion per year in services, they are undoubtedly an important resource.

Policy Recommendations

This paper has established that while there is a considerable impact that honey bees have economically, there is not a wealth of research on the topic. As far as the status of honey bees in the United States, they are in decline at the same time the demand for their services is increasing. At the Federal level, it is important for the USDA and its branch the Agriculture Research Service (ARS) to increase its data collection of beekeepers and improve its accuracy for smaller scale beekeepers such as hobbyists. Washington State already does this by requiring beekeepers to register their hives with its Department of Agriculture. Increasing data of how many people are beekeepers in addition to how many hives are used for honey and pollination services would therefore increase the ability for researchers to establish a value of honey bees ("Status of Pollination in North America," 2007a, p. 198). This would also yield an improved value of per-hive pollination fees.

In addition, the Federal Honeybee Act must be revised. The Honeybee Act of 1922 which granted the Animal and Plant Inspection Service (APHIS) leeway in regulating honey bee imports prevents much of the importation of honey bees into the United States ("Status of Pollination in North America," 2007a, p. 167). As honey bees are not native to the United States, their gene pool has been shrinking for almost a century. While the act was imposed to protect United States honey bee colonies from diseases abroad, it needs to easily permit the transfer of drone semen and queens from Europe in order to increase genetic diversity.

Finally, at the Federal level, improved regulations of pesticides and herbicides are needed to ensure honey bees as an agricultural stock are protected. Neonicotinoid (neonics) pesticides are a type of systemic pesticide that has risen in popularity since the

1990s and it is the most used type of pesticide in the United States (Sass, 2015, p. 2). Neonics are systemic, they penetrate the entire plant, and the nectar and pollen of the plant have trace elements of the toxic substance in them (Sass, 2015, p. 2). This toxin provides a sub-lethal dose to the bees and after a few generations, the honey bees suffer genetic damage and compromised immune systems that render them more susceptible to other diseases (Sass, 2015, p. 3). Improving the regulatory structure of how pesticides, and to a lesser extent herbicides are approved by the Environmental Protection Agency (EPA) is key to maintaining existing stocks of honey bees in the United States. While in 2015 Barack Obama budgeted $50 million for improving research and regulation on honey bees, it is an inadequate amount to yield any meaningful changes to the beekeeping industry ("Fact Sheet," 2014).

In addition, additional research is needed to address combating existing diseases such as *Varroa* mites, *Nosema*, foulbrood, and CCD. These diseases are lethal to colonies, and for many, such as foulbrood and Varroa, drug resistance is a significant concern ("Status of Pollination in North America," 2007a, p. 199-200). Then there is the problem of Africanized honey bees that are encroaching in the Southern United States, a region that is a major source of queens for beekeepers nationwide ("Status of Pollination in North America," 2007a, p. 199). Without the habitat for honey bees to be bred in the Southwest being free of the invasive bee species, queen stocks could interbreed with the Africanized bees and become aggressive.

Conclusion

This paper set out to analyze the shortcomings of the existing research on honey bees' economic impact and offer a preliminary model for a comprehensive structure of honey bees' economic effect. It showed that the existing methods fail to take into account the larger economic impact that honey bees have. With regards to the studies, Levin (1983) failed to take into account the portion of crop value bees add, instead he aggregated the value of crops pollinated by bees. Rucker et al. (2012) created a pollination market, but that did not capture the value added to crops, or any of the secondary market effects that honey and wax have, let alone any externalities that honey bees provide. Morse and Calderone (2000) acknowledged externalities but did not quantify them. Finally, Southwick and Southwick's research on dependency ratios, which gave two levels of dependence, were not sufficient to offer the spectrum that Klein et al. (2007) managed to create. Further research is needed to create a comprehensive analysis of all aspects of how honey bees contribute important economic services to the United States.

Some shortcomings of this paper are with the economic models used by the case studies authors, most notably Rucker et al. (2012), which is largely beyond the scope of the author's economic understanding. Further study in economics at a graduate level would improve the understanding of how to not only analyze the models, but also construct a more accurate one. The preliminary equation that was given to create a more accurate estimate of the impact that honey bees have needs to be expanded for each component in order to create the complete model where agricultural and economic data could be input in order to create the estimate. This would take more time than what is allotted for this research project as well as better data collection on the part of the USDA ARS.

Honey bees are important to every person who consumes the products of their pollination. Be that wax, through cosmetics and household products, honey, or any of the plants that honey bees pollinate. Honey bees are in decline losing 59 percent of colonies in North America before 2005 (Potts et al., 2010, p. 345). This statistic predates the newest decline in honey bees, which is caused by CCD. CCD is an early indicator that honey bees are no longer on the decline, but are on the edge of a critical population collapse. Since CCD was discovered, beekeepers have been losing 30 percent or more of their hives each year to disease ("Fact Sheet," 2014). In addition to the decline in stocks, pollination demand has increased, over 300 percent in the past 50 years, which has raised the pollination fees from $50 per hive in 2003 to $175 per hive in 2009 (Aizen, & Harder, 2009, p. 915; "Fact Sheet," 2014). The cost increases are born by the farmer, who funnels the increase to the consumer who will continue to see food prices rise.

Apiculture is an industry and a practice that was not designed for industrial agriculture. The Langstroth hive dates back to 1862 and has not changed much since then, except for the use of plastic foundation as opposed to wire ("Status of Pollination in North America," 2007b, p. 12). The industry has not been able to adapt to the modern needs of a monoculture agricultural system as in the United States. Increasing use of systemic pesticides, and herbicides weaken honey bees, and yet they are still widely used. Part of understanding the economic impact that honey bees have is understanding the loss to society there would be if they were no longer a feasible source of honey, wax, and pollination. This paper argues that the dollar value is much higher than the estimates that the authors of the current literature give. Now it is time for that cost to sink in and changes to the industry to be made to prevent total population collapse of *Apis Mellifera.*

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