EXAMINATION OF POSSIBLE EFFECTS OF NEONICOTINOIDS USE ON US HONEY FARMS

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Introduction

Awareness and concern about the condition of bee populations in the US and many other countries have increased notably in recent years. Bees serve a critical role not only in the natural environment but as the primary source of pollination for many types of agricultural products as well as producers of honey in their own right. Food products from blueberries, to almonds, to mead, depending on the work of bees. At the same time, an alarm has spread about declining bee populations and the implications that it could have for the agricultural sector of the economy and food security more broadly. However, without developing a better understanding of the relevant stressors on bee populations, it is not possible to determine appropriate and effective interventions to mitigate damage to this essential species. Our research attempts to examine one of those possible stressors--agricultural application of neonicotinoids--and its potential merit as avenue through which potential interventions might be considered to shore up bee populations and their productivity.

Hypothesis and Methodology

Our original inquiry focused primarily on the relationship between observed changes in climate indicators and the decline in honey production over the past two decades. However, the initial investigations did not yield promising leads for highlighting significant correlations between climate and honey production data. We have since pivoted to examining the use of neonicotinoids--an agricultural insecticide--and its possible effects on honey production in the US. In particular, we are interested in comparing variation in each of the variables between states over time to develop a better sense of the strength of the correlation. By merging and examining data sets of honey production--as a proxy for bee population health and productivity--in the US with chemical use data, we posit that we will find varying levels of correlation (some significant) between those dynamics and the extreme decline in honey production.

Data Use and Transformation

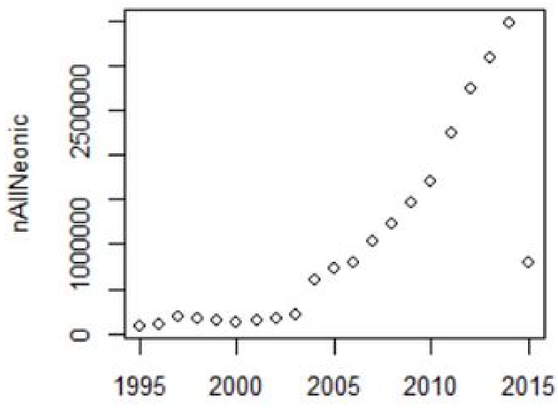
The data used in our project is based on US Honey Production statistics by the National Agricultural Statistics Service (NASS) from the years 1991 and 2017. Our dataset was augmented with statistics by USGS, to view statistical patterns across neonicotinoid pesticides and honey production. We used the ‘aggregate’ function in R to group honey production and neonicotinoid use per year by state. Data wrangling was performed to clean the dataset. The dataset has been cleaned up by removing “NAs” from column 12 to column 17.

Useful metadata on certain variables of the honey production dataset is below:

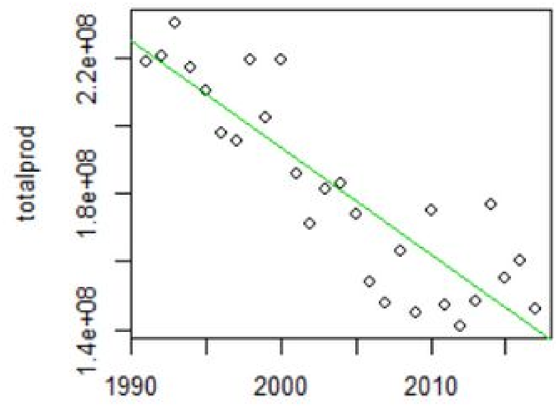
1. totalprod: Total production (numcol x yieldpercol). Unit is pounds
2. priceperlb: Refers to the average price per pound based on expanded sales. The unit is dollars.
3. numcol: Number of honey-producing colonies. Honey producing colonies are the maximum number of colonies from which honey was taken during the year. It is possible to take honey from colonies that did not survive the entire year.

Data Analysis

Our first probe into the data looked at the overall national trend in neonicotinoid use and honey production and found a reason to suspect a significant association between the application of the pesticide and declines in honey production. As the graphs below show, over the nearly 30 year period of observation, total national neonicotinoid use has clearly and significantly increased, while total honey production has dramatically declined.



Neonicitinoid Use in America



Honey Production in America

Further regression analysis reveals a negative relationship between neonicotinoids use and total honey production with a very high statistical significance level exceeding 0.001%. The model shows that a one-kilogram increase in neonicotinoid use was associated with a 7.6-pound decline in honey production.

```
Call:
lm(formula = totalprod ~ . - StateName - FIPS - Region - state -
    year, data = Honey3)

Residuals:
     Min       1Q   Median       3Q      Max
-8289812  -598361   -12544   532227 10498459

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -3.242e+06  2.076e+05 -15.613  < 2e-16 ***
numcol       5.629e+01  1.347e+00  41.795  < 2e-16 ***
yieldpercol  4.949e+04  2.580e+03  19.183  < 2e-16 ***
stocks       5.532e-01  4.121e-02  13.425  < 2e-16 ***
priceperlb   1.135e+05  5.775e+04   1.966   0.0496 *
prodvalue    6.011e-02  1.227e-02   4.897 1.12e-06 ***
nAllNeonic  -7.598e+00  1.171e+00  -6.488 1.30e-10 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1581000 on 1125 degrees of freedom
Multiple R-squared:  0.9487,    Adjusted R-squared:  0.9484
F-statistic:  3469 on 6 and 1125 DF,  p-value: < 2.2e-16
```

We then interrogated the data to look for the states that used the most and least neonicotinoids, finding those states to be Iowa and Wyoming respectively, with Iowa using more neonicotinoids than Wyoming by a factor of almost 150 (see Appendix). The lower left graph shows a considerable increase in neonicotinoid use in Iowa over the observed time period, while Wyoming's use was stable and minimal. The lower right graph shows that honey production over the same time period declined in Iowa, thus displaying a similar dual trend as we demonstrated on a national level. By contrast, Wyoming's honey production declined only slightly during this time. Thus, our initial state-level analysis did seem to reinforce the narrative on pesticide use and honey production derived from the aggregated national data.

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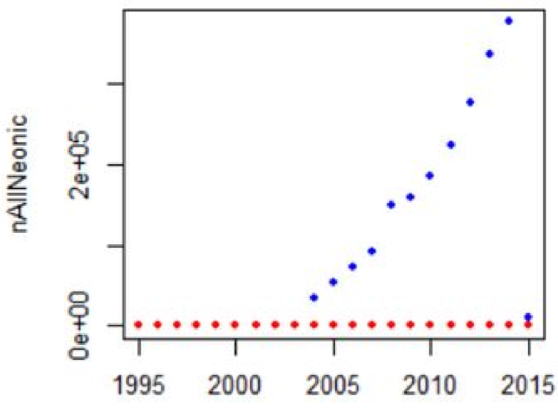
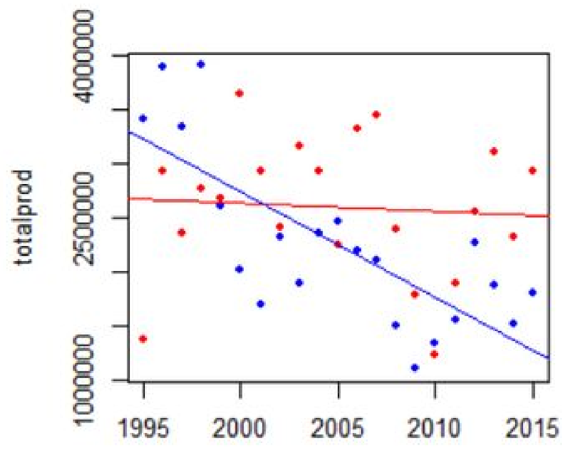


Neonicitinoid usage in (blue=Iowa) & (red=Wyoming

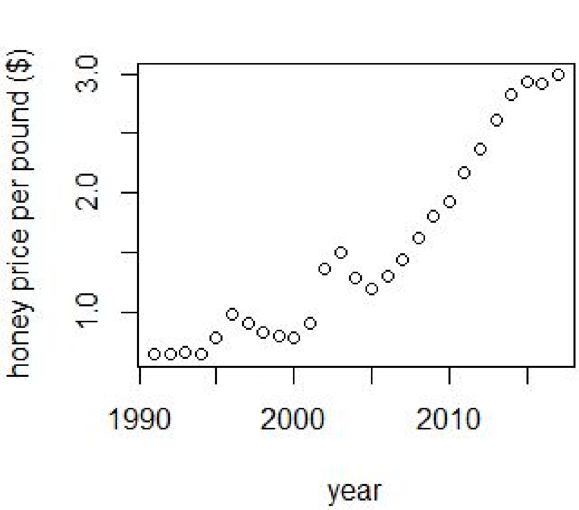


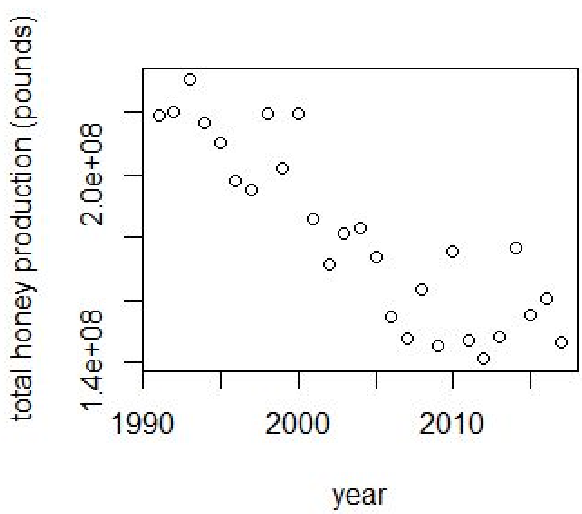
Honey Production in (blue=Iowa) & (red=Wyoming

We would also note that these two states seemed particularly useful for comparison as they have nearly the same number of colonies and began with similar levels of neonicotinoid use and honey production in the late 1990s. In fact, Iowa used to produce somewhat more honey than Wyoming but now produces markedly less. These initial similarities and the distinct change in neonicotinoid use in Iowa in the early 2000s, in our initial view, made this comparison somewhat closer to a natural experiment--though we, of course, do not know why Iowa pesticide use increased so much starting in the early 2000s.

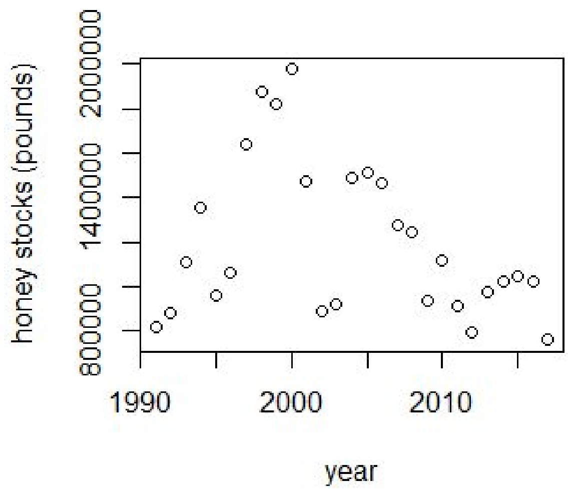
Of note, while there are certain indicators that neonicotinoid use and honey production declines are related, our initial analysis also showed that honey production declines preceded the rise in neonicotinoid use by at least a few years. This further bolstered the possibility that there may be confounding variables at play.

One variable of interest to us within the data was the price per pound of honey, which has a statistically significant (exceeding 0.05%), positive association with honey production. The model showed that a one-dollar increase in the price per pound of honey was associated with a 113,500-pound increase in total honey production nationally. It could be that honey production was driven by changes in the market price that producers were able to obtain for their honey and that changes in price were driven by factors exogenous to our model, such as changes in consumer demand. If demand-side factors were affecting honey production, we would expect to the price per pound of honey declining over time, since that would disincentivize honey production. Instead, however, we find that prices have increased over time suggesting that it is actually supply that is driving price. As honey has become more scarce with declining production, the price per pound has increased.





This observation of price trends also helps to invalidate the possibility that declining production is related to oversupply in the form of stocks of stored honey. It is further worth noting that these stocks have also been declining since 2000.



In order to more comprehensively control for omitted variable bias, we followed up our initial analysis with regressions using panel data taking into account both interstate and time fixed effects. We additionally applied Wald t-tests with clustered standard errors to our panel regressions in order to correct for any autocorrelation and heteroskedasticity in our regression residuals. Our panel regression produced the following results:

```
Twoways effects Within Model

Call:
plm(formula = totalprod ~ nAllNeonic, data = Honey3, effect = "twoways",
    model = "within", index = c("state", "year"))

Unbalanced Panel: n = 44, T = 7-21, N = 876

Residuals:
     Min.   1st Qu.    Median      Mean   3rd Qu.      Max.
-11994370   -527447      4274         0    462889  15330037

Coefficients:
           Estimate Std. Error t-value  Pr(>|t|)
nAllNeonic  -8.6013     2.2755 -3.7799 0.0001684 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Total Sum of Squares:    3.634e+15
Residual Sum of Squares: 3.5711e+15
R-Squared:      0.017312
Adj. R-Squared: -0.060237
F-statistic: 14.2874 on 1 and 811 DF, p-value: 0.00016841
```

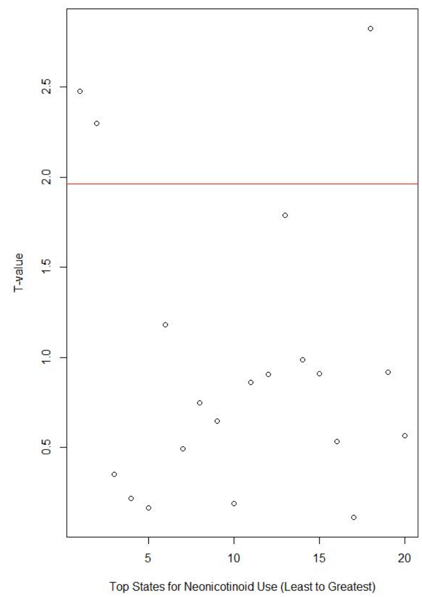
The panel regression continued to show a negative relationship with a statistical significance level exceeding 0.001%. A one-kilogram increase in neonicotinoid use was associated with an 8.6-pound decrease in total honey production. However, after running a Wald t-test with clustered standard errors we found that the relationship between neonicotinoid use and total honey production to no longer be statistically significant with a p-value of 0.23.

```
t test of coefficients:

           Estimate Std. Error t value Pr(>|t|)
nAllNeonic  -8.6013     7.1706 -1.1995   0.2307
```

This result held even when only controlling for heteroskedasticity. This suggests a significant correlation between the magnitude of our regression residuals and variation in neonicotinoid use, thus violating a critical OLS assumption and invalidating our alternative hypothesis that neonicotinoid use is significantly affecting total honey production.

We also investigated the possibility that there might be some threshold for neonicotinoid use beyond which application of neonicotinoids would have a statistically significant association with honey production. To do this we ran regressions with time fixed effects and Wald t-tests on individual states within the top 20 states for neonicotinoids. However, we not only found that the large majority of those states did not have statistically significant relationships between honey production and neonicotinoid use, but that there was no clear pattern for the few states that did show indications of a possible relationship. The graph below shows the t-values from each of the top 20 neonicotinoid using states we conducted this analysis on. It shows that only three of those states had t-values above 1.96 and they were the two smallest users of the group (Wyoming and Montana) and the third largest (Arkansas).



Conclusion and Recommendations for Further Inquiry

To conclude, we first ran our regression on a national level looking at neonicotinoid use and its association honey production in the United States over the same time period. With 30 years of data to observe, we saw that while neonicotinoid use has risen rapidly over the past few years, honey production has declined. Our initial analysis showed that this relationship had a very high statistical significance level exceeding 0.001%. After running this regression, we wanted to dive deeper and take a look at the neonicotinoid usage in relation to honey production, but on a state level. By singling out Iowa and Wisconsin as described above in our analysis, we were able to conclude that these individual state observations reinforced our main theme that an increase in neonicotinoid usage had a negative effect on honey production.

Another statistically significant observation we found was that honey price per pound and honey production are correlated. However, trends in the data appeared to show that supply was driving price rather than the other way around. As honey production declined, honey price per pound rose, suggesting that increasing honey scarcity resulted in higher honey prices.

Finally, we ran panel regressions on our model to take into account time and interstate fixed effects. The panel regression still proved to be significantly similar to our initial regression. However, when running a Wald T-Test, the test proved that honey production vs. neonicotinoid usage was not statistically significant with a p-value of 0.23.

Our examination of the data show that while a face value look aggregate data for neonicotinoid use and honey production might lead one to conclude that there is a significant relationship between the two, a more rigorous analysis applying robust standard errors prevents such a conclusion with reasonable certainty. This result suggests that other possible factors might be more salient to bee population health and productivity (such as parasites, disease, or habitat destruction) and warrant further investigation themselves.

Appendix

List of states using significant quantities of neonicotinoids (least to greatest)

	state	nAllNeonic	numcol	AvgUse
44	WY	491.3259	1073000	0.0004578993
22	MT	3471.7704	3528000	0.0009840619
24	ND	25317.7037	9560000	0.0026482954
32	OR	4330.6815	1453000	0.0029805103
10	ID	12087.8370	2845000	0.0042488004
6	FL	24662.6074	5618000	0.0043899266
35	SD	30899.7741	6604000	0.0046789482
29	NY	10149.7037	1630000	0.0062268121
4	CA	73834.3370	10790000	0.0068428487
3	AZ	8975.0630	1008000	0.0089038323
7	GA	16881.3667	1877000	0.0089938022
18	MI	20372.1630	2161000	0.0094271925
42	WI	19843.4333	1904000	0.0104219713
41	WA	17641.0111	1668000	0.0105761458
15	LA	13384.5444	1081000	0.0123816322
19	MN	47711.7519	3748000	0.0127299231
37	TX	42445.2074	2812000	0.0150943127
2	AR	17849.1111	1004000	0.0177779991
25	NE	45603.7296	1483000	0.0307509977
9	IA	73112.5519	1057000	0.0691698693