An Empirical Analysis of Honeybee Pollination Markets

by

Randal R. Rucker
Department of Agricultural Economics and Economics
Montana State University

Walter N. Thurman
Department of Agricultural and Resource Economics
North Carolina State University

and

Michael Burgett
Department of Entomology
Oregon State University

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I. INTRODUCTION

Pollination services provided by beekeepers represent an important input into the production of many U.S. agricultural commodities. Arguments made in Congressional subcommittee hearings in recent years suggest that the value of these services may be as high as $9 billion (see Robinson et al., 1989). Recent updates to that figure (see Morse and Calderone) peg the value at $14.6 billion in 1999 dollars. While these estimates almost certainly are greatly overstated,[1] there is no doubt that the pollination services provided by beekeepers are extremely important for the production of certain crops. Given this importance, it is surprising that little economic analysis of pollination markets has been undertaken.

To our knowledge, publications on the workings of pollination markets are just three: Cheung (1973), Johnson (1973), and Olmstead and Wooten (1987).[2] Cheung's 1973 paper recounted the history of what he termed "the fable of the bees" in economic thought. Pigou (1912 and 1920) is credited with first discussing the divergence between private and social cost, but the popularization of the notion in the economic literature is credited to Meade (1952) whose central, and fictional, example is one of an apple farmer and a beekeeper. He describes a situation where beekeeping and apple farming occur side by side, apple blossom nectar provides food for the bees, and bee pollination increases the yield of apples. The stipulated fact that the apple farmer and beekeeper do not transact implies an externality and an under provision of both

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[1] See Muth and Thurman (1995) for a critique of these estimates.

[2] Siebert (1980) discusses pesticide use in California agriculture and its bee mortality effects, which reduce the profitability of almond and citrus production. He does not address specifically the market for pollination services.

nectar and pollination.

The central point made by both Cheung and Johnson is that the stipulated facts (and therefore the claim of externalities) described by Meade and later by Bator (1958) are fictional—there are, in fact, well-developed markets in which beekeepers and growers of pollination-requiring and nectar-producing crops transact regularly. Cheung examines the market for bee services and nectar in Washington state, analyzing data from a small number of beekeepers in 1971. He concludes that the markets for pollination services function well: that the observed fees in the market reflect both the pollination value of the bees' activities and the value of honey produced.

Cheung's empirical analysis of the Washington beekeeping industry sounded a caution against the use of blackboard economics for policy analysis. He illustrates what can be taken to be a central point of Coase's celebrated 1960 paper: that the transactions costs of market exchange determine the existence and extent of externalities and that to understand transactions costs (hence externalities) one must understand the particular institutional details of the market under consideration. A later contribution by Olmstead and Wooten (1987) studies a particular pollination market in a different context. They tell the economic history of the development of the pollination market for the alfalfa seed crop in California in the 1940s and 1950s.

In this paper, we extend and update the analysis of pollination markets by analyzing a considerably larger and richer data set on pollination markets than the data set examined by Cheung. Empirical results based on several years of data are described in section III below.

These results support Cheung's findings that pollination markets seem to operate efficiently.[3]

II. POLLINATION MARKETS

Pollination is an essential input in the production of numerous agricultural commodities. Notably, almonds, kiwifruit, tree fruit, blueberries, and various vegetables require pollination for uniform product quality as well as enhanced yield. Further, while honeybees have been used in North American commercial agriculture since colonial days, their importance has grown in recent years for at least two reasons. First, as modern agricultural production has come to rely on large monocropped farms, dependence for pollination on wild insects living on the periphery of fields has become less feasible. The purposeful pollination of crops, primarily through the use of honeybees, is increasingly essential. Second, wild bees have been decimated in recent years by the twin scourges of *Varroa* and tracheal mites. While both can be controlled (at a cost) by beekeepers in domesticated colonies, feral bees have reportedly been wiped out in many areas. There now is less "natural" pollination to be relied upon.

In addition to providing pollination services, bees also (of course) produce honey. The joint production process has made honeybee pollination a favorite textbook example of reciprocal externalities. The joint nature of the production process also means that the study of pollination markets contributes to an understanding of the honey commodity market.

Pollination service has been a standard example of positive externality for good reason. The physical facts of crop pollination imply that transactions are difficult to monitor and enforce. Crops require pollination for only a brief period each year and different crops and different

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[3]Our data also allow us to investigate the interaction between honey subsidies and pollination fees, a public policy topic that is analyzed in Muth *et al.* (2001).

altitudes and latitudes require pollination at different times. This fact implies that there are great economies of scale available to mobile pollinators, who use the same bees to pollinate several crops during a crop year. But the competitive pressure toward mobility also makes market transactions more costly. Combine the above with evolving scientific views of the efficacy of honeybee pollination, and different levels of grower acceptance of the importance of bees, and the difficulty of private contracting for pollination becomes clear.

Nevertheless, private parties do provide pollination services and markets do emerge. In North America, Johnson (1973) claims that the first recorded renting of colonies for pollination occurred in 1910. Prior to that, farmers either relied upon wild insects and the wind to pollinate or kept bees themselves.

Several developments led to the emergence of markets for pollination services. Many sources refer to the invention of the Langstroth movable-frame hive as defining the beginning of modern beekeeping. The Langstroth hive, invented in 1853, allowed more intensive management of the bees and lower cost extraction of honey.

Another development important to pollination markets in North America was the development of infrastructure that allowed bees to be moved easily. Migratory beekeeping was made possible by the development of the internal combustion engine and the building of a system of roads. The early 20th century history of beekeeping in California included some episodes of migratory beekeeping by rail car (see Pellett) but the important migration happened by flatbed trucks.

A more gradual development, but one critical to the development of pollination markets, is the growth of knowledge about bee pollination by bees and its benefits. Crane dates the fundamental science as occurring between 1670 and 1880 (p. 473). Knowledge grew after that time, however, as the details of pollination requirements of particular crops came to be known. For example, Olmstead and Wooten tell the story of how the benefits of pollination to alfalfa seed production came to be known in the late 1940's. The development continues today with active research on pollination by solitary bees.

Finally, and most recently, development of pollination markets has been spurred by changes in the availability and quality of natural pollination. Examples here are Varroa and tracheal mites. These honey bee diseases have done two things: raised the costs of commercial beekeeping and diminished–perhaps eliminated–feral bee colonies. The elimination of feral bee colonies could be construed to be a rightward shift in the demand for commercial pollination services and a spur to contracting and markets. The increase in the costs of commercial beekeeping also could be a force leading to developments of contracts inasmuch as they reduce the numbers of bee colonies used to produce honey and so reduce the supply of inadvertent pollination.

Much of the modern market for pollination services consists of contracts between farmers and migratory beekeepers. In a 1994 survey of American beekeepers, Hoff and Willett found that 22% of the surveyed beekeepers were migratory, who annually transported their bees from 37,500 to 40,000 miles. There are several large-scale migration routes traveled by these bees. An important one is the route that begins with the pollination of almond trees in southern California in March and April. Almonds as currently grown are highly dependent on honeybee pollination and beekeepers are paid around $40 per colony to place their bees in almond orchards during the bloom. Also during the early spring, the same bee colonies are put into citrus orchards, where the pollination benefits are not great but the nectar is plentiful for the production of honey. Beekeepers move their colonies north on flatbed trailers stopping to pollinate vegetable and fruit crops along the way. After several weeks, the migratory beekeepers arrive in Oregon and Washington where they are paid to pollinate apples, pears, and cherries. The pollination fees they collect vary with the value of the honeybee pollination, the value of the crop's nectar in honey production, and with the prices of the crop and of honey.

After the blooming season, beekeepers find summer range for their colonies, often in the Northern Plains states of North and South Dakota and Minnesota. There the hives stay put and the bees visit sunflowers, clover, basswood trees, and other nectar sources, producing honey for consumption by the hive and extraction for sale by the beekeeper. As winter approaches, the bees are loaded up again, this time to winter in the south or in southern California. A parallel migratory route moves up the Atlantic coast, from fruit and vegetable crops in Florida to blueberry bushes in Maine. The markets that connect beekeepers with contracting farmers solve remarkable problems of information gathering and processing.

III. POLLINATION EXTERNALITIES

The argument has been made that the two-way externalities between beekeepers and orchard owners result in inefficiencies associated with the underproduction of orchard output and the under provision of pollination services.[4] Externalities exist because, and to the extent that, transactions costs are high. (See Coase.) If it were economical for farmers and beekeepers to

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[4] While this argument has been made in an academic context, similar arguments have been made in the context of agricultural policy regarding beekeepers. There it has been argued that markets undersupply pollination services and that subsidizing honey production will generate social surplus by increasing bee pollination. See Muth *et al.* (2001).

contract for pollination services, they would do so and there would be no under supply. In fact, pollination markets exist for many pollinated crops and so the relevant questions become: how well do they work and how widespread are the situations where they do not? (See Cheung.)

Pollination Markets in the Absence of Transactions Costs

As a starting point for addressing these questions, consider how markets for pollination would work in the absence of transactions costs, hence, externalities. Honey and fruit are the joint outputs of a production process that employs land and bees. The typical organization of production involves landowners who grow crops and hire beekeepers to pollinate their crops. Landowners receive the output of fruit while beekeepers receive the honey. In equilibrium, there is a side payment (possibly negative) from landowners to beekeepers.

To analyze the equilibrium pollination payment, consider a fictional industrial organization which, absent transactions costs, would replicate the same payments to inputs as the actual industry. In the fictional story there are orchard firms that produce honey and fruit by employing land and bee inputs, which they rent from the two classes of input owners. The orchard firms retain all honey and fruit output and pay beekeepers and landowners monetary wages.

The production technology is described by two constant returns to scale production functions. The two outputs are assumed here to be perfectly complementary: for a given employment of acres and bees the outputs of honey and fruit are fixed. That honey and fruit production follow constant returns to scale implies that the two production functions can be written in per-acre terms:

$H = F_H(A,B) = A\cdot f_H(B/A)$, and

$F = F_F(A,B) = A \cdot f_F(B/A)$,

where H, F, A, and B are honey, fruit, acres, and bees. The value of the output from a firm employing an arbitrary amount of the two inputs is:

$$\text{Total value} = A[P_H f_H(B/A) + P_F f_F(B/A)].$$

In a competitive equilibrium, orchard firms will pay each input its value marginal product, which comprises the value marginal product from both outputs. The equality of the total value marginal product of bees (total refers to the sum across honey and fruit) and the competitive wage for bees can be written as:

$$TVMP_B = A\left[P_H f'_H(B/A) \cdot 1/A + P_F f'_F(B/A) \cdot 1/A\right] = P_H f'_H(B/A) + P_F f'_F(B/A) = w_B,$$

where f'_H and f'_F are the per-acre marginal products with respect to the stocking rate, B/A. The same equilibrium condition for acres of land is:

$$TVMP_A = P_H f_H(B/A) + P_F f_F(B/A) - (B/A)[P_H f'_H(B/A) + P_F f'_F(B/A)]$$

$$= (\text{total value per acre}) - (B/A) \cdot TVMP_B = w_A.$$

In the expression for $TVMP_B$, notice that the return from adding bees is independent of how many acres to which the increment of bees is added. Only the stocking rate (B/A) matters. The same is true of the return to adding acres.[5]

A competitive market equilibrium requires that the total value marginal products for each of the two inputs equal their wages and, on the factor supply side, factor wages equal their

[5] Because the production functions are normalized on acres, the $TVMP_A$ expression appears different from that for bees. The interpretation of the $TVMP_A$ equation is that adding one acre yields the current total product on a single acre adjusted for the negative effect that reducing the stocking rate has on all other acres. The negative effect is due to the fact that bees must be spread more thinly and so the loss is proportional to $TVMP_B$. If the two marginal products, $f'_H(B/A)$ and $f'_F(B/A)$, decrease in B/A then $TVMP_B$ decreases and $TVMP_A$ increases in B/A.

marginal costs of supply. The two equilibrium conditions are:

$$TVMP_A(B/A) = w_A(A), \text{ and}$$

$$TVMP_B(B/A) = w_B(B).$$

The equilibrium just discussed is illustrated at the firm level in Figure 2. The diagrams show the equilibrium w_B and B for a given A. Not shown is the symmetric pair of diagrams depicting equilibrium w_A and A for a given B. The left panel shows the total value marginal product of bees, which is the vertical sum of the value marginal products in honey and fruit. Aggregating such $TVMP_B$ curves for all pollinated crops and across all acres cultivated, results in the market demand curve for bees. The equilibrium bee wage is determined in the right panel by the intersection of the market demand for bees and the market supply of bee services.

In the equilibrium just described, beekeepers and landowners earn rents if the industry marginal cost curves for the factors are upward sloping. Orchard firms earn no rents in equilibrium because they employ constant returns to scale technology and are assumed to possess no unique abilities.[6]

Now, dissolve the fictional orchard firms and consider the actual situation where landowners own the orchards and rent the services of beekeepers. Landowners typically pay beekeepers, partly in kind by allowing them to keep the honey produced on their land, and partly

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[6] Comparative static analysis of the bees and land equilibrium reveals the equilibrium dependence of the bee and land wages on the exogenous prices of honey and fruit. The comparative statics analysis is found in an appendix.

The prices of fruit and honey could be endogenized, first, by substituting the inverse demand equations $P_H(H)$ and $P_F(F)$ into the expressions for market equilibrium A and B and, second, substituting $Af_H(B/A)$ for H and $Af_F(B/A)$ for F into the demand equations. Paying the two inputs their value marginal products ensures that the equilibrium prices are marginal costs. This along with constant returns to scale ensures zero profits for the orchard firms.

by pollination fee. The landowners retain claim to the fruit produced by the joint efforts of bees and land. Presumably, the fact that the standard contractual agreement makes the beekeeper the owner of all honey produced is a result of monitoring costs. A contract in which the orchardist was due the honey would be more difficult to monitor than one in which the orchardist was due only the pollination services of a fixed number of easily observed bee colonies.

The remaining analytical task is to determine a pollination fee that will replicate the efficient equilibrium just described. The actual contractual arrangement stipulates that beekeepers receive honey and landowners receive fruit. In addition, landowners pay beekeepers a pollination fee of P_P per colony (which may be negative). To replicate the factor payments in the fictional equilibrium, it must be that total payments to beekeepers on an acre of land—in kind plus pollination fees—equal the fictional equilibrium per acre payments to bees:

$$\left(\frac{B^*}{A^*}\right) P_P + P_H f_H^* = \left(\frac{B^*}{A^*}\right) w_B^* = \left(\frac{B^*}{A^*}\right) TVMP_B(A^*, B^*),$$

where $f_H^* = f_H(B^*/A^*)$ and A^* and B^* are equilibrium values. This equation yields the solution:

$$P_P = TVMP_B - \frac{P_H f_H^*}{(B^*/A^*)}$$

or

$$\left(\frac{B^*}{A^*}\right) P_P = \left(\frac{B^*}{A^*}\right) TVMP_B - P_H f_H^* .$$

Figures 1 and 2 show the equilibrium payment to beekeepers per acre of land, $P_P(B/A)$, in two situations. The second panel shows the apparently uncommon case in which the equilibrium payment is negative, i.e. beekeepers pay landowners for the privilege of placing their bees on the cultivated land. The possibility of negative pollination fees can most easily be imagined for a crop with little or no marginal fruit product at the equilibrium stocking rate, such as oranges.

Pollination Markets with Transactions Costs

Having seen how pollination markets would work in the absence of transactions costs, introduce the reality of non-zero costs. Where transactions costs are not prohibitively high, then the same essential equilibrium as just described will occur. Further, the contractual in-kind payment of honey to beekeepers represents a response to certain types of transaction costs. But for some crops (or uncultivated situations) the costs of information, contracting, and enforcement are higher than the benefits. For such crops, only the value of bees in producing honey is transmitted to the market and bees are employed only with regard to their honey production. Among such crops, the VMPs of bees in producing honey are forced equal, regardless of their crop-specific pollination value. Bees are underutilized and deadweight welfare losses arise.

There are, then, two types of beekeeping situations. There are those where the welfare gains from contracting are less than the transactions costs of information acquisition and contracting. These are markets with pollination externalities—markets in which increases in pollination services would generate net welfare gains (ignoring the transaction costs of effecting the increase.) The other situations are markets in which farmers and beekeepers contract for pollination services, transactions costs apparently being less than the gains from an optimal provision of pollination.

In the markets with externalities, the effective demand for bee services is the value marginal product of bees in producing honey only. Such markets are represented in the left panel of Figure 4, where VMP_E^H refers to the value marginal product of bees in the production of honey aggregated across acres in externality markets. The subscript E refers to externalities. $TVMP_E$ refers to the social value marginal product from those markets, or the aggregate of vertically summed VMP curves in the production of honey and pollination.

In markets with pollination contracts, depicted in the middle panel of Figure 4, the effective demand for bee services is the $TVMP_C$ curve, subscript C standing for contracts. The equilibrium price and quantity of bee services is found in the right panel of Figure 4. There, VMP_E^H and $TVMP_C$ are horizontally summed to obtain the market demand curve for bee services, D_B. Its intersection with the market supply of bee services, S_B, determines an equilibrium bee wage of w^o. At that wage, B_E^o units (colony months per month) are demanded in the markets with externalities and B_C^o units are demanded in the markets with contracts. The aggregate quantity of bee services consumed is $B^o = B_E^o + B_C^o$.

In the equilibrium just described there is an obvious inefficiency, ignoring transactions costs. While the net marginal social value of bee services in the markets with contracts is zero, the net marginal social value in the markets with externalities equals the distance de, which is the value marginal product of bees in their roles as pollinators. There is an allocational inefficiency in that social welfare would increase by a transfer of bees from the markets with contracts to the markets with externalities. After a transfer that equalized TVMP between the two types of markets, there may be an additional adjustment in the aggregate numbers of bees that would be welfare increasing.

In this context, one can imagine a Pigovian subsidy schedule that would bring about a social optimum. It would subsidize bee placement in the markets with externalities by the marginal schedule $TVMP_E - VMP_E^H$. A subsidy on honey production, like the U. S. honey support program, is different from such a schedule in two important ways.[7] First, it subsidizes only one of the two joint outputs from beekeeping. To the extent that honey production and pollination are not perfect complements, a honey subsidy shifts the ratio of output produced in favor of honey production. If the outputs are net substitutes, a subsidy on honey production will move pollination away from the desired result. (If this is the case, then the welfare improving action is a honey tax.)

But assume here that honey and pollination are produced in fixed proportions. Then the second important way in which a honey subsidy does not resemble the Pigovian subsidy is that the subsidy applies to both kinds of markets: ones where private and social costs diverge and ones where contracting causes private and social costs to be equal. A subsidy on honey, then, is not necessarily welfare improving. It will induce too much pollination in markets with contracts while it generates its welfare gains in the markets with externalities.

The welfare accounting of a honey subsidy can be described with the help of Figure 3. Suppose that a per unit subsidy of σ is paid on the production of bee services (equivalent to a per unit subsidy on honey because of the assumption of fixed proportions in output.) The right panel of Figure 4 shows that the equilibrium price of bee services will fall to w^1 while the per unit return to beekeepers will rise to $w^1+\sigma$. Equilibrium quantities of services consumed in the two types of markets rise to B_E^1 and B_C^1.

The gain to honey producers (and consumers) in the externality markets is the increase in consumer surplus behind the derived demand for bees in the production of honey: abcd. The gain to orchardists in the externality markets is the incremental product of pollination services:

[7] The question of why honey is subsidized rather than pollination services is addressed in Muth *et al.*

edcf. In the markets with contracts, the total gain to the honey sector and pollination demanders is the increase in derived demand consumer surplus, hijk.

The gain to beekeepers can be seen in the right panel. It is the increase in producer surplus, mnop. Taxpayer costs can also be seen in the right panel to be msrp.

The indeterminate sign of the net social welfare change can be seen by disaggregating taxpayer costs into three components: msrp = abcg + hijl + mnqp. The net welfare gain, then, is:

$$\begin{aligned}\Delta W &= abcd + edcf + hijk + mnop - msrp \\ &= abcd + edcf + hijk + mnop - (abcg + hijl + mnqp) \\ &= (abcd + edcf - abcg) + (hijk - hijl) + (mnop - mnqp) \\ &= edgf - kjl - oqp.\end{aligned}$$

The last three components of ΔW are readily identified and interpreted in the three panels of Figure 4. The possibility of net welfare gain comes from edgf, the trapezoid that nets the consumers' component of subsidy cost from the benefits to orchardists in externality markets. The second component, -kjl, arises from the inefficiency induced by encouraging pollination in markets with contracts. The third component, -oqp, arises from the fact that the supply price of beekeeping services is above its marginal value in the subsidized equilibrium. There is no way, *a priori*, to say if ΔW is positive or negative. It will be positive if the conditions described in the left panel predominate.

It is in situations where transactions costs are high relative to the externality loss that subsidizing pollination can increase social surplus. The question is: where are those situations? Where are the externalities? Consider three categories of beneficiaries from honey bee pollination: crops (including fruit), home gardens, and uncultivated areas.

Should we expect to find significant externalities in crop production? This seems unlikely in most instances. For crops that benefit from honey bee pollination and that are grown in large fields or orchards, full benefit from bee colonies requires their placement within the field or orchard or on the periphery. It is relatively easy for farmers to monitor the placement of colonies on their own fields and any significant potential surplus should be captured through contracting. Evidence on this comes from the active markets for honey bee pollination services.

Should we expect to find significant externalities in home gardens? Perhaps. Transactions costs would be high to organize neighbors and contract with a beekeeper for the placement of his bees in the neighborhood. Free rider problems would abound. Further, many people, rationally or not, are afraid of bee stings and would oppose the plan. Bee stings are, in fact, a life-threatening hazard to some, with approximately 50 fatalities a year in the United States. The fear of bee stings by some would, no doubt, raise transactions costs. But it would also introduce a negative externality into the social calculation that is as legitimate as the interests of gardeners seeking higher yields. It is not clear that the obvious positive effects of bees located in crop-producing areas would outweigh the negative effects of their increased presence in residential areas.[8]

Finally, should we expect to find significant externalities in uncultivated areas? The *prima facie* argument here suggests yes. Uncultivated areas provide public goods: wildlife, scenery, water filtering, and others. Public goods are under provided privately, in general, and augmenting plant production would increase the supply of these types of goods. The case for the

[8] The issue of whether a honey subsidy encourages useful pollination is particularly appropriate in consideration of home gardens. It seems most unlikely that a producer attempting to maximize honey production would place his colonies near home gardens with their low density of blossoms.

agronomic benefits of honey bees in uncultivated areas is, however, much less well documented than it is for cultivated crops.

In the preceding discussion of externalities, the link between a honey subsidy and the provision of pollination services has been assumed. But that link is not clear and the complementarity of honey and pollination has not, to our knowledge, been measured. Honey and pollination can be produced in variable proportions. Bee colonies are mobile, are regularly transported great distances, and there is much that a beekeeper can do to redirect his colonies' activity from one output to the other.[9] Therefore, a subsidy on one output is not equivalent to a subsidy on both. Nonetheless, there may be sufficient complementarity between honey and pollination in certain situations that production of the latter is increased by a subsidy to the former.

While honeybees produce both honey and pollination, in practice, beekeepers often use a colony for only one commercial purpose at a time. Effective pollination requires a higher density of bees than does honey production. If colonies are placed in a field to effectively pollinate, there are so many bees relative to the food supply that they consume all the honey they produce. The issue is somewhat complicated by the fact that beekeepers produce several honey or pollination "crops" in a year. At a particular time, however, beekeepers either rent out colonies for pollination or strategically place them for best honey production. Therefore, a higher price of honey may actually decrease the incentive for beekeepers to provide pollination.

The important issue is whether pollination and honey are substitute or complementary outputs. Arguments made in favor of the U.S. honey support program nearly always assume

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[9] For descriptions of beekeepers' mobile lifestyle, see Whynott (1991) and Mairson (1993).

complementarity. Data on colony populations by state, however, suggest substitutability and specialization. Over time, bee populations have shifted from states with crops requiring pollination to states with crops producing nectar for honey. For example, colony numbers in North Dakota and South Dakota, states with few crops requiring pollination, have doubled several times in recent decades. A 1985 U.S. General Accounting Office Report noted that, with the exception of Florida, the states with increased colony populations grow few crops that require supplemental pollination. These changes cannot be attributed entirely to the honey support program because it had very little effect on the industry until 1981. However, the increases in bee populations in honey producing states continued throughout the period when the honey price support was effective.

IV. EXTENDING CHEUNG: THE EMPIRICAL DETERMINANTS OF POLLINATION FEES

For our empirical analysis of pollination markets, we use information from an annual survey of Oregon and Washington beekeepers. The survey is conducted by Professor. Michael Burgett of the Department of Entomology at Oregon State University. The data set we have constructed includes information on average annual pollination fees by crop of the survey respondents for the years 1987-1995.[10] To conduct our empirical analysis, we augment the survey data with annual data from other sources on Oregon crop prices and Oregon honey prices.

A straightforward empirical specification is

(1) $$FEE_{it} = f\left(CROP\ PRICE_{it},\ HONEY\ PRICE_{it}\right),$$

[10]Several additional years of data are currently being entered into computer files and will be included in future analysis.

where for crop i in year t, FEE_{it} is the average pollination fee (in dollars per colony) reported in the survey, CROP PRICE is the average crop price in Oregon (in dollars per pound), and HONEY PRICE is the average price of honey received by producers in Oregon (in dollars per pound).[11]

The expected sign of the estimated coefficient on CROP PRICE is positive—an increase in the price of a pollinated crop increases the value marginal product of pollination services, which should increase pollination fees. The sign of the estimated coefficient on HONEY PRICE provides insights into the validity of the arguments made by proponents of the honey program. A negative sign is consistent with the argument that an increase in honey prices increases the number of bees available for pollination, and that this increase in supply of pollination services leads to a reduction in pollination fees and an increase in the equilibrium quantity of pollination services. A positive sign suggests that an increase in honey prices causes beekeepers to shift more of their colonies from providing pollination services to producing honey, thereby reducing the supply of pollination services and increasing pollination fees. The former result is consistent with honey and pollination being complements and with the arguments made by supporters of the honey program, whereas the latter is consistent with honey and pollination being substitutes.

Beekeepers and landowners agree on pollination fees at the time colonies are placed in orchards and fields, typically in the spring or early summer months. Because the fees are determined prior to the time that actual crop prices for the year are known, fees must be based on expectations of what crop prices will be. Accordingly, in our empirical analysis, our simple

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[11] Pollination fees, crop prices, and honey prices are deflated (base year = 1991) for the empirical analysis.

proxy for the expected crop price is the crop price from the previous year. Similarly, Oregon honey prices for year t are determined after pollination fees are specified. In the presence of the honey price support program, however, each year's honey price support level was known at the time that pollination fees were specified. Accordingly, to account for the presence of the honey program during a portion of the period of our analysis, we use the honey price for year t when the program was in effect (until 1993) and thereafter, we use the honey price in year t−1 as a proxy for the expected honey price at the time pollination fees were specified in year t.[12]

The data set we use for our empirical analysis includes 88 observations on crop-average pollination fees from the surveys. The data span the years 1987–1995 and include information on eleven crops.[13]

An obvious problem with the specification in equation (1) arises from the cross section-time series nature of our pollination fee data set. The dependent variable, FEE_{it}, is measured in dollars per colony, whereas the units for crop prices and honey prices are dollars per pound. Because of differences in crop yields and bee colony placement densities, there is no reason to believe that a given change in crop prices will have the same effect on pollination fees for all crops. Similarly, because of differences in the characteristics and volume of honey produced from different crops, there is no reason to believe that a given change in the price of honey will

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[12]Note that we use the actual average honey price rather than the support price. Given that there were different support prices for different grades of honey, and given that support prices were binding during the period of our analysis, we assume that the observed average honey price was an appropriately weighted average of the various support prices.

[13]The survey responses do not include fee information for all of the eleven crops for every year. Our data set is comprised of the following: 9 observations on pears, sweet cherries, apples, cucumbers, blueberries, and radish seed; 8 observations on vetch seed; 7 observations on crimson clover seed and squash; and 6 observations on red clover seed and cranberries.

have the same effects on fees for all crops. A semi-log empirical specification that accounts for these effects is:

$$\text{(2)}\quad FEE_{it} = \beta_0 + \beta_1 \ln\left(\frac{CROP\ PRICE_{it} \cdot CROP\ YIELD_i}{PLACEMENT\ DENSITY_i}\right) + \beta_2 \ln(HONEY\ PRICE_t \cdot DISCOUNT_i \cdot HONEY\ YIELD_i) + \beta_3 CROP\ DUMMY_i + \epsilon_{it},$$

The transformation for crop prices adjusts for crop yields and bee colony placement densities, while the transformation for honey prices adjusts for honey quality and honey yield per colony. Crop dummies (0–1 variables) are included to account for any additional fixed effects across crops. It can be seen that the units of the adjusted crop price are $/colony = [($/lb)(lb/acre)]/(colonies/acre). Similarly, the units of the adjusted honey price are $/colony = $/lb·lb/colony.[14] Noting that two of the three terms in the expressions for both the adjusted crop and honey prices vary only across crops, equation (2) can be rewritten as

$$\text{(3)}\quad FEE_{it} = \beta_0 + \beta_1 \ln(CROP\ PRICE_{it} \cdot k_i) + \beta_2 \ln(HONEY\ PRICE_t \cdot m_i) + \beta_3 CROP\ DUMMY_i + \epsilon_{it}.$$

$$= \beta_0 + \beta_1 \ln(CROP\ PRICE_{it}) + \beta_2 \ln(HONEY\ PRICE_t) + (\beta_1 \ln k_i + \beta_2 \ln m_i + \beta_3 CROP\ DUMMY_i) + \epsilon_{it}.$$

$$= \beta_0 + \beta_1 \ln(CROP\ PRICE_{it}) + \beta_2 \ln(HONEY\ PRICE_t) + \beta_3^* D_i + \epsilon_{it},$$

[14]Here, DISCOUNT is a unitless measure of the proportionate discount or premium in the price of honey from the ith crop relative to the price of honey from some base crop.

where D_i is a crop specific dummy variable that subsumes the impacts of the separate crop-specific effects listed above.

OLS estimates of equation (3) and variants are presented in table 1. Regression 1 includes the crop price, the price of honey, and ten individual 0–1 crop dummy variables.[15] Although the estimated coefficient on the crop price is positive, it is not significantly different from zero. The estimated coefficient on the honey price is negative and significant, which supports the pro-honey price support argument that an increase in the price of honey increases the availability of pollination services, thereby driving down pollination fees. The crop dummy variables are jointly significant.[16]

With a full set of crop dummies, the crop price variable represents only the effects from time series price variation. It cannot represent the possible effects of inter-crop variation in value. To examine such an effect, regression 2 replaces the individual crop dummy variables with a 0–1 dummy variable that is assigned a value of one if honey typically is produced when colonies are placed with the crop.[17] Because revenues are obtained from the honey produced, the fees charged for placing colonies with these crops are predicted to be less than for crops that yield no income to the beekeeper. Thus, we predict a negative estimated coefficient for the HONEY CROP variable. As can be seen from table 1, this prediction is borne out by the highly significant coefficient on this variable. Further, the estimated coefficient on the CROP PRICE

[15]The squash dummy variable is omitted.

[16]The only three crop dummy variables whose estimated coefficients are significantly different from zero are those for red and crimson clover seed and vetch seed. The estimated coefficients for all three of these are negative.

[17]Crops that are designated as honey producing crops were vegetable seed, red clover seed, crimson clover seed, vetch seed, raspberries, blueberries, and radish seed.

variable becomes positive and significant and the coefficient on the HONEY PRICE remains negative and significant. The coefficient on the HONEY CROP variable suggests that the pollination fee for crops that produce honey is about $17 per colony less than for crops that produce no honey. The results also suggest that a ten percent increase in average honey prices causes a decrease in pollination fees of about $2.50 per colony and that a ten percent increase in crop prices causes pollination fees to increase by about $.40 per colony.

In our data set, the price of honey is constant across all crops for each year. Because of this structure, it is conceivable that the honey price variable is picking up the effects of other (non-honey price) factors that vary yearly. If so, then the effects of other factors are confounding our estimates of the impacts of changes in crop prices on pollination fees. Regression 3 accounts for this possible source of bias by replacing the honey price variable in Regression 2 with annual 0–1 year dummy variables. As can be seen, the year dummy variables are jointly significant. Further, neither the crop price nor the honey crop variable is much affected—either in terms of statistical significance or the value of the estimated coefficient.

Another measurable factor that should influence pollination fees is related to the impacts of honeybees on crop output. The more reliant a crop's output is on pollination by honeybees, the greater will be the value of a colony of bees. For a subset of the crops in our sample, we obtained an index of pollination from Robinson, et al. as a proxy for this factor. The inclusion of this variable reduces our data sample from 88 to 58 observations. Regression 4 in table 1 has the same specification as Regression 2 and is presented to indicate the impacts of the change in sample size (as distinct from the introduction of the pollination index). The results of the two regressions are substantively the same in terms of statistical significance (although the magnitude of the coefficients is altered somewhat). Regression 5 includes the index of pollination. The estimated coefficient on this variable is positive as predicted and significant at the .10 level. The estimated coefficients on the other three variables remain statistically significant with the same signs.

The empirical results presented in table 1 support the notion, first developed by Cheung, that there is a well-developed market for beekeepers' services. As predicted by a competitive model, increases in crop prices and in the productivity of honey bees tend to increase pollination fees, and pollination fees for honey crops are less than for crops that do not yield marketable honey to beekeepers. Finally, our results suggest that an increase in honey prices results in a reduction in pollination fees—a finding that is consistent with arguments made by proponents of the honey program. Our empirical results support Cheung's earlier findings and extend his work, both in terms of econometric methodology and richness of the data analyzed.

IV. SUMMARY AND CONCLUSIONS

Despite the importance of honeybee pollination for many agricultural crops, there has been little economic analysis of pollination markets. In this paper, we extend Cheung's three-decade-old treatment of pollination markets in several ways. First, we discuss some of the historical institutional developments that made possible the pollination markets studied by Cheung and discuss the effects of recent events related to bee disease. Second, we discuss the particular instance of the theory of the second best provided by the simultaneous existence of pollination markets and pollination externalities. In this context, we present a model of welfare analysis taking into account transaction costs. which we use to analyze the welfare effects of a subsidy on the production of honey. Third, we extend Cheung's empirical work by focusing on pollination markets that appear to work well and testing the predictions of an economic model of such markets. The empirical analysis we present, based on annual surveys of Oregon and Washington beekeepers, suggests that pollination markets are efficient in the sense that pollination fees respond in predictable ways to changes in a variety of economic factors.

Planned extensions to the current work are two. The first is a more disaggregated analysis–at the individual beekeeper level–of the pollination survey data to measure the determinants of pollination fees. The second is a historical study of the rise of pollination markets: the process of institutional evolution that transforms situations involving externalities into situations in which potential gains from trade have been captured through contracts.

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Table 1. Regression Results: Determinants of Pollination Fees

Dependent variable: Pollination Fee ($/colony).

Variable	Regression 1 Coefficient (t-value)	Regression 2 Coefficient (t-value)	Regression 3 Coefficient (t-value)	Regression 4 Coefficient (t-value)	Regression 5 Coefficient (t-value)
Constant	8.51 (1.13)	15.29 (2.01)**	29.33 (10.84)**	7.16 (1.12)	-0.89 (-0.10)
Crop Price	1.17 (0.48)	3.78 (3.43)**	4.14 (3.92)**	2.18 (2.66)**	2.01 (2.43)**
Honey Price	-28.16 (-3.32)**	-24.70 (-1.93)*	—	-33.14 (-3.09)**	-33.38 (-3.13)**
Honey Crop	—	-17.25 (-8.43)**	-17.37 (-8.84)**	-6.99 (-3.42)**	-7.62 (-3.66)**
Pollination Index	—	—	—	—	9.42 (1.34)*
Crop Dummy Variables#	33.20**	—	—	—	—
Year Dummy Variables#	—	—	2.51**	—	—
F Value	31.75	29.92	11.52	6.34	5.27
Adjusted R^2	0.809	0.499	0.547	0.219	0.231
No. of observations	88	88	88	58	58

**Significant at 0.05 level; * significant at 0.10 level (one-tailed test significance for Crop Price, Honey Crop, and Pollination Index; two-tailed for others).
[#] Number displayed is value of F-statistic for joint significance of the respective groups of dummy variables.

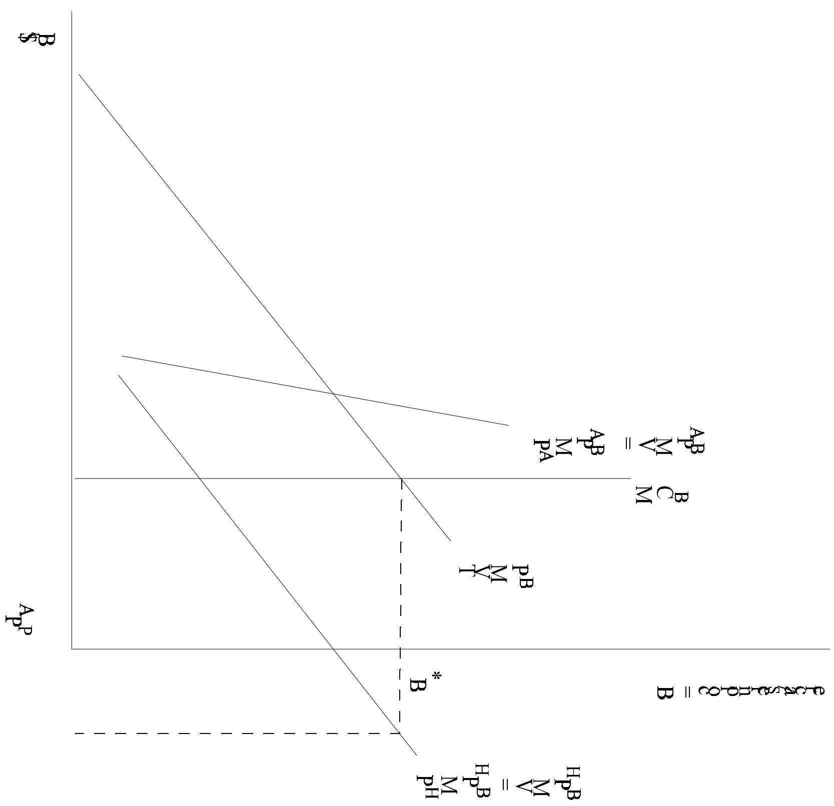


Figure 1 The Optimal Bee Stocking Rate in Apples

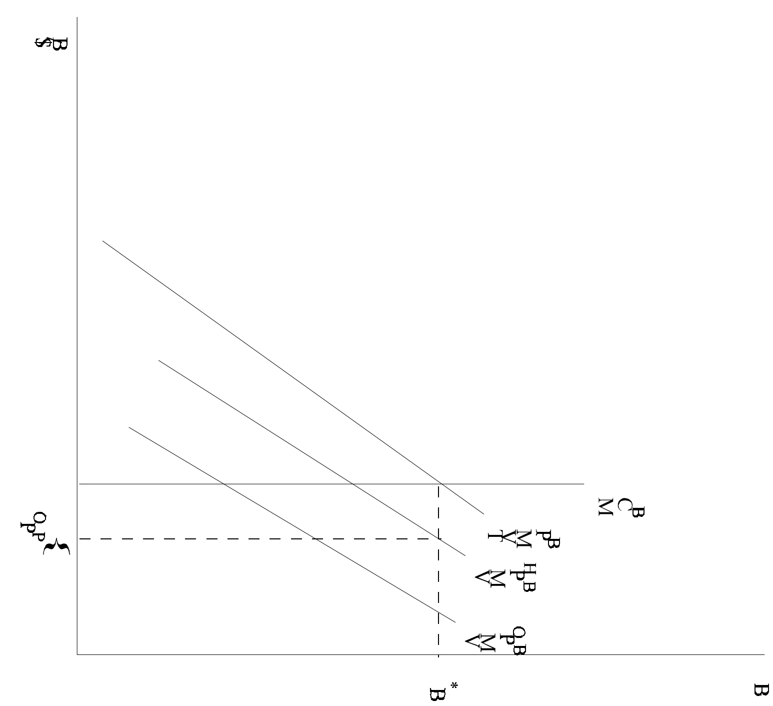
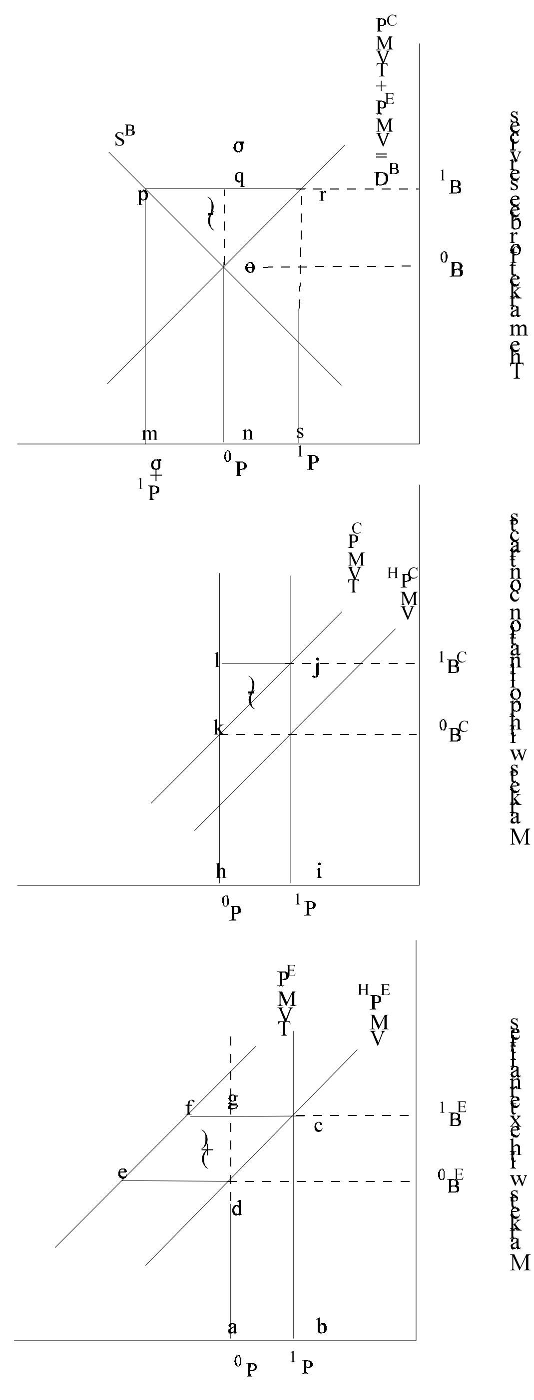


Figure 2 The Optimal Bee Stocking Rate on Oranges

Figure 3 The Effects of a Subsidy on Beekeeping



Appendix:

The Comparative Statics of the Fictional Organization of Industry

First, rewrite the equilibrium conditions in terms of the honey and fruit production functions:

$$P_H(f_H - bf_H') + P_F(f_F - bf_F') = w_A(A)$$
$$P_H f_H' + P_F f_F' = w_B(B),$$

where b=B/A, the per-acre stocking rate of bees, and f_H and f_F and their derivatives are understood to depend upon b.

The differentials of the system can be written as:

$$\begin{bmatrix} b^2\phi - Aw_A' & -b\phi \\ -b\phi & \phi - Aw_b' \end{bmatrix}\begin{bmatrix} dA \\ dB \end{bmatrix} = (-A)\begin{bmatrix} f_F - bf_F' & f_H - bf_H' \\ f_F' & f_H' \end{bmatrix}\begin{bmatrix} dP_F \\ dP_H \end{bmatrix},$$

where

$$\phi = \frac{\partial TVMP_B}{\partial b} = P_H f_H'' + P_F f_F'' < 0.$$

The solution for equilibrium changes in acres and bees is:

$$\begin{bmatrix} dA \\ dB \end{bmatrix} = \frac{1}{|D|}\begin{bmatrix} Aw_B'(f_F - bf_F') - \phi f & Aw_b'(f_H - bf_H') \\ Aw_A'f_F' - b\phi f_F & Aw_A'f_H' - b\phi f_H \end{bmatrix}\begin{bmatrix} dP_F \\ dP_H \end{bmatrix},$$

where

$$|D| = Aw_A'w_b' - \phi(b^2 w_B' + w_A') > 0.$$

The dependence of the wage for bees on the price of the fruit output can be determined by substituting the reduced form solution for dB/dP_F into $w_B(B)$:

$$\frac{\partial w_B}{\partial P_F} = w_B' \frac{dB}{dP_F} = w_B' \frac{Aw_A'f_F' - b\phi f_F}{Aw_A'w_B' - \phi(b^2 w_B' + w_A')}.$$

The comparative static derivative is positive if f_F', the marginal product of the stocking rate in fruit production, is positive. An easily interpretable special case of the above occurs when the supply of acres to fruit production is perfectly elastic:

$$\frac{\partial w_b}{P_F}\Big|_{w_A'=0} = \frac{f_F}{b}.$$

In this last situation, where a change in the price of fruit can cause no change in the price of land, the change in the bee wage is its marginal product in fruit production divided by the stocking rate.

Note that for equilibrium solutions involving positive employment of bees, $w_B = P_F f_F' + P_H f_H' > 0$. However, it may be the case that the marginal product of bees in one of the outputs, either f_H' or f_F', is negative.