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Are All Colonies Created Equal? The Role of Honey Bee Colony Strength in Almond Pollination Contracts

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Honey Bee Colony Health

- Since early 2000's U.S. beekeepers have experienced unpredictable spikes in winter mortality rates
 - Colony health stressors: varroa mites, poor nutrition, pesticides, Colony Collapse Disorder (CCD), many more
- Pollination services: Input for >\$18 billion of U.S. agricultural production

Economics of Pollination: Reciprocal Benefits

- Meade (1952): Hive placed near apple orchard
 - Apple grower receives pollination services (input to apples)
 - Beekeeper receives nectar (input to honey)
- Colonies exhibit increasing returns to scale in pollination services and honey production (*Sagili et al., 2011*)
 - Most commercially-pollinated crops
 - Grower and beekeeper benefit from hives with large bee populations

Grower View

Beekeeper View

California Almond Pollination

- CA almonds differ from other commercially-pollinated crops
- ① No market for almond honey
- ② Almond orchards bloom in mid-February (lasts ≈ 3 weeks)
 - Beekeepers just discover winter mortality rates
 - Colonies naturally at smallest size for winter dormancy
- ③ CA provides 82% of world almond production
 - 2016 Required $\approx 76\%$ of U.S. honey-producing colonies
 - All other spring blooming crops use 30% of almond pollination colonies

Almond Pollination Incentive Problem

- Almond pollination agreements are forward contracted
- Contracting parties have differing interests:
 - Almond grower desires many bees/hive (High colony strength)
 - More bees=more pollination
 - High colony strength costly for beekeeper
 - Food supplements, labor, pest treatments
- Almond grower's yield benefit depends on the beekeeper's actions to increase colony strength
- Exogenous colony health shocks=beekeeper's actions cannot be determined

Colony Health Shocks

Data Sources: *The Pollination Connection*; *Bee Informed Partnership Winter Loss Surveys*

Research Questions

- How **should** almond growers deal with incentive problem in almond pollination?
 - **Economic theory:** Almond growers should condition fee on delivered average colony strength (bees/hive)
 - Provides beekeeper with incentive
 - Approximates actual pollination services performed
- How **do** almond growers deal with incentive problem in almond pollination?
 - Surveyed growers at the Almond Board of California's 2015 Conference
 - 91% used contracts which specify minimum colony strength
- Findings suggest all colonies are not viewed as equal

Colony Strength in Almond Pollination

- Most prior literature assumes colonies homogenous in pollination services (*except Champetier et al., 2015*)
 - Why? **Very** costly to measure actual pollination services performed
 - i.e., number of blooms pollinated
- To estimate colony strength: Count the number of active frames in a hive
 - Active frame: $\geq 75\%$ covered in bees and brood
 - Almond growers may pay for colony strength inspections by a trained inspector
 - Cost: \$1.50-\$2.00/ inspected hive ($<1\%$ of *per-acre pollination costs*)
- Average colony strength $\approx$ pollination potential of colonies

Colony Strength Provisions in Contracts

- Used to adjust per-colony fees to better match the perceived value of pollination services in an orchard
- Most common: **minimum average active frame count**
 - Beekeepers (implicitly or explicitly) penalized if not met
 - Colony strength inspection: Not always performed
- Less common: **incentive contracts**
 - Colony strength inspection: Required
 - Example:

Almond Pollination Pricing Schedule		
Benchmark Colony Strength: 8-frame average	Bonus/frame above benchmark	Penalty/frame below benchmark
\$175	\$10	\$15
Beekeeper Per-Hive Payments		
Beekeeper	Average Frame Count	Price/Hive
Beekeeper #1	9.5 frames	$(1.5 \times 10) + 175 = \190
Beekeeper #2	7 frames	$175 - (1 \times 15) = \$160$

Honey Bee Shipments for Almond Pollination

Theoretical Model

- Principal-Agent Model
 - Almond grower: Risk Neutral Principal
 - Beekeeper: Risk Averse Agent
- Beekeeper's effort affects probability of high colony strength
 - High colony strength $\Rightarrow$ higher probability of large almond yield
 - Effort unobservable to almond grower

Profit Maximization

- Almond grower maximizes expected profits subject to beekeeper's participation and incentive compatibility constraints:

$$\max_{e, t_H, t_L} E[\pi] = p(e)(Py_H - t_H) + (1 - p(e))(Py_L - t_L) \quad s.t.$$

$$p(e)[1 - \exp(-At_H)] + (1 - p(e))[1 - \exp(-At_L)] - ce \geq 0 \quad (\lambda)$$

$$p'(e)[\exp(-At_L) - \exp(-At_H)] - c = 0 \quad (\mu)$$

- Profit-maximizing pollination fees and beekeeper effort (t_H^* , t_L^* and e_{UB}):

$$P\Delta y = (t_H^* - t_L^*) + \frac{\mu^* p''(e_{UB})c}{(p'(e_{UB}))^2}$$

$$t_H^* = -\frac{1}{A} \ln \left[(1 - ce_{UB}) - \frac{(1 - p(e_{UB}))c}{p'(e_{UB})} \right]$$

$$t_L^* = -\frac{1}{A} \ln \left[(1 - ce_{UB}) + \frac{p(e_{UB})c}{p'(e_{UB})} \right]$$

Profit-Maximizing Contract

- Profit-maximizing contract to address incentive problem:
 - Specify colony strength standard ($b \geq b_H^*$)
 - If met: Pay beekeeper high pollination fee (t_H^*)
 - If unmet: Pay beekeeper low pollination fee (t_L^*)
- High pollination fee gives beekeeper incentive to exert effort
- Trade-off between risk sharing and incentives
 - Effort observable: Risk-neutral grower bears all risk
 - Effort unobservable: Beekeeper bears price risk due to colony health shocks

Heterogeneity in Yield Benefits from Pollination

- Mapping of pollination to yield is uncertain (*Rucker et al., 2012*)
- Change in solution with respect to increase in expected yield benefits:
 - $\frac{\partial e_{UB}}{\partial P \Delta y} > 0$: Profit-maximizing level of effort increases
 - $\frac{\partial t_H^*}{\partial P \Delta y} > 0$: Payment for high colony strength increases
 - $\frac{\partial t_L^*}{\partial P \Delta y} < 0$: Payment for low colony strength decreases

($\Delta y = y_H - y_L$: Difference in expected yields from high and low colony strength outcomes)

- Suggests: Growers with highest expected yield benefits subject beekeepers to most price risk

Almond Board of CA Pollination Contract Survey

- Surveyed growers at the December 2015 Almond Conference
- Questions:
 - 2015 contract provisions
 - Other pollination variables
 - Operation characteristics

1. What form of pollination agreement did you use during the 2015 pollination season?

Select one answer:

A. Verbal Contract
B. Oral Agreement/Contract
C. Both written and oral contracts depending on size of pollinating orchard
D. None of the above

2. In the 2015 pollination season, how many beekeepers did you rent hives from directly?

Select one answer:

A. 1
B. 2
C. 3
D. 4
E. 5
F. 6
G. 7
H. 8 or more

I. I am unsure through the respondent pollination broker
J. I am unsure of exacting pollination needs

Methods

- **Objective:** Determine types of pollination agreements used in 2015
 - Explore role of uncertainty in colony strength in shaping contract preferences
- Cluster analysis
 - Groups responses into similar pollination contract types
 - Used in contracting literature (*Bessy and Brousseau, 1998; Boger, 2001; Kaplan and Stromberg, 2003*)
 - Identifies 5 clusters (pollination contract types)

Contract Provision Variables

Variable	Specification	Mean (N=74)
Per-Colony Fee	\$/Colony (Continuous)	\$170.72
Min Avg Frame Count	0-10 (Integer)	7 frames
Form	Written or Both=1,	57%
	Oral=0	43%
Financial Incentive	Bonus Provision=1,	21%
	No Bonus Provision=0	79%
Inspection	Every=1,	27%
	If Low or Never=0	73%

Results

Contract types consistent with theoretical contract

Per-Frame Bonus Contract (21% of growers)

- Per-frame bonus provision: 100%
- Minimum colony strength requirement: 100%
- Inspection every year: 80%

Strictly Enforced Contract (10% of growers)

- Minimum colony strength requirement: 100%
- Inspection every year: 100%
- Highest average fee: \$186/colony

Results

Contract types not consistent with theoretical contract

Standard Written Contract (29% of growers)

- Minimum colony strength requirement: 100%
- Inspection never: 82%
- Written agreement usage: 100%

Standard Oral Agreement (29% of growers)

- Minimum colony strength requirement: 100%
- Inspection never: 77%
- Oral agreement usage: 100%

Informal Agreement (11% of growers)

- Minimum colony strength requirement: 0%
- Inspection never: 100%
- Lowest average fee: \$165/colony

Interpretation of Results

- Many almond growers use contract provisions to address incentive problem in almond pollination
 - Vary in level of enforcement
 - Some never monitor colony strength

Interpretation of Results

- Many almond growers use contract provisions to address incentive problem in almond pollination
 - Vary in level of enforcement
 - Some never monitor colony strength
- Potential explanations for variation in contract preferences for future research:
 - 1 Orchard characteristics (Expectations of yield benefits)
 - Higher yield benefits=more concern about colony strength
 - 2 Repeated transactions
 - Over half respondents worked with a beekeeper/pollination broker for ≥ 7 years
 - 3 Hive transport logistics
 - 4 Large fixed costs of third-party inspection

Conclusion

- Are all colonies created equal?
 - No
- Colony health issues cause uncertainty in beekeeper's almond pollination income due to:
 - Number of colonies available post-winter
 - Per-colony pollination fees for surviving colonies
 - Higher costs of increasing colony strength
- Almond pollination $\approx \frac{1}{3}$ of total beekeeping revenues
 - Health issues prior to almond pollination may threaten a beekeeping operation's future income
- Need to further explore colony health implications in other crop pollination and honey production

Thank you!

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