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


The Washington Post

Energy and Environment

Maryland's honeybees are being massacred, and the weapon might be in your house

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

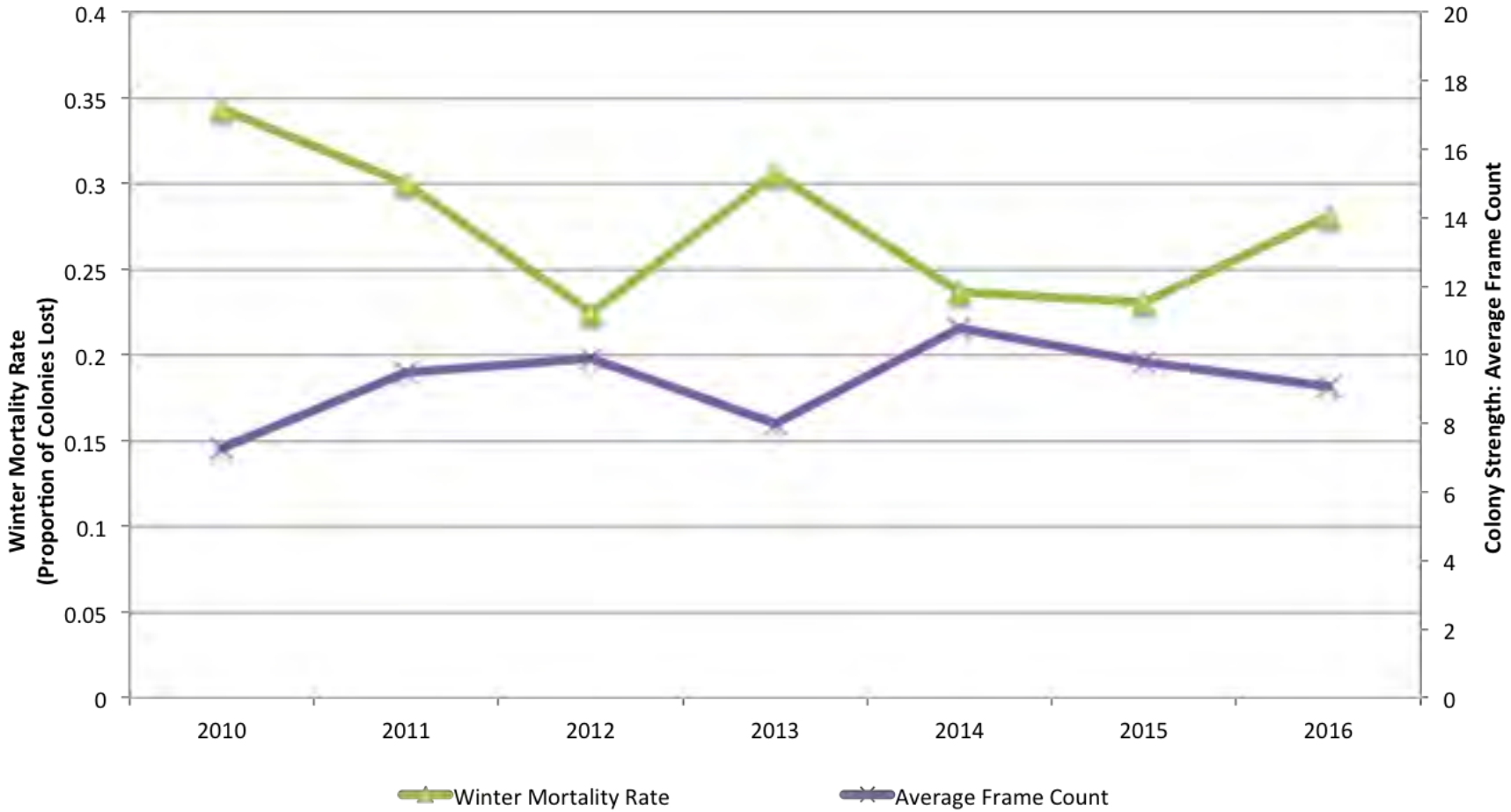
- CA almonds differ from other commercially-pollinated crops

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 ≈ 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:

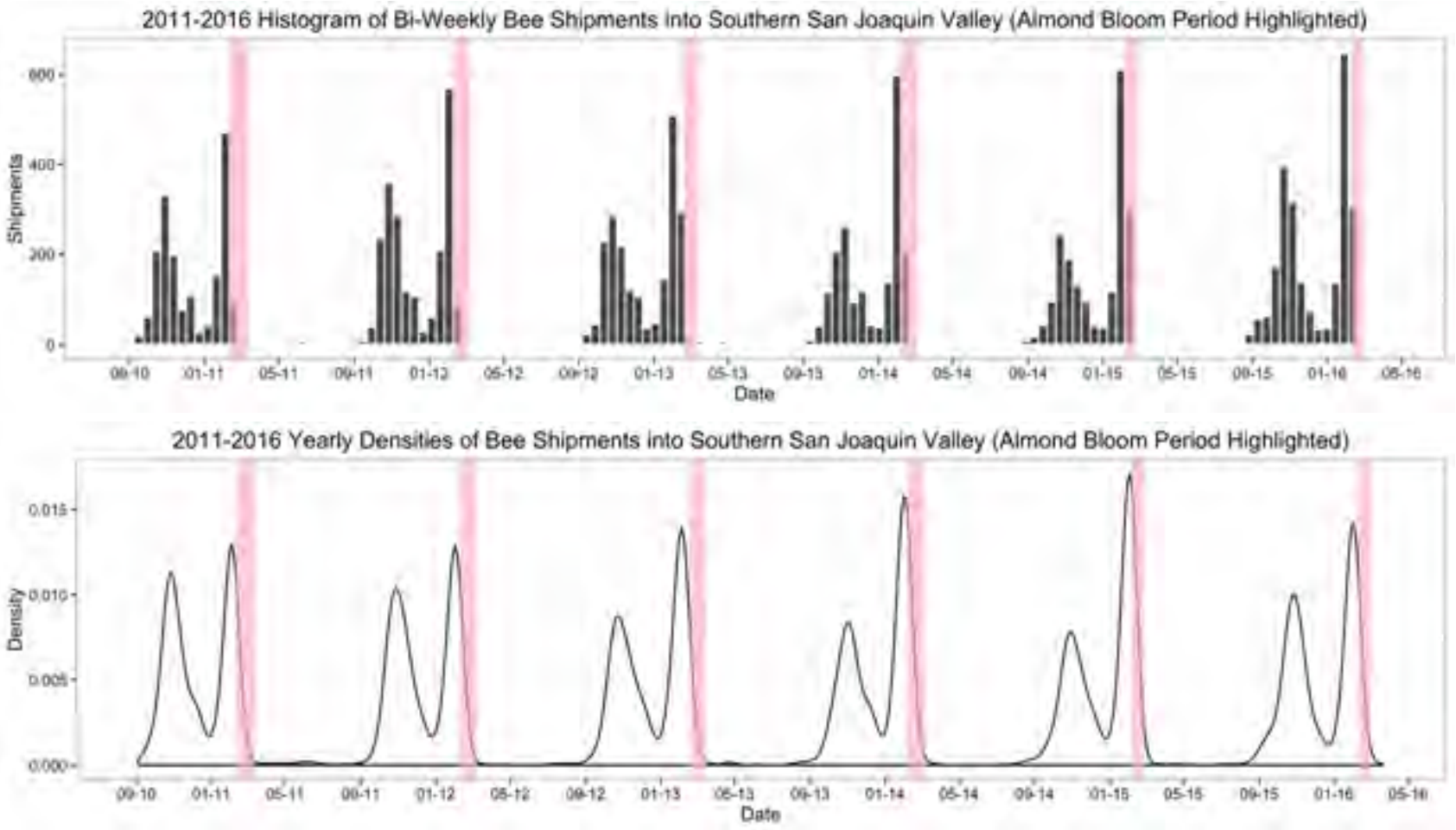
Almond Pollination Pricing Schedule

Benchmark Colony Strength: 8-frame average	Bonus/frame above benchmark	Penalty/frame below benchmark
$175	$10	$15

Beekeeper Per-Hive Payments

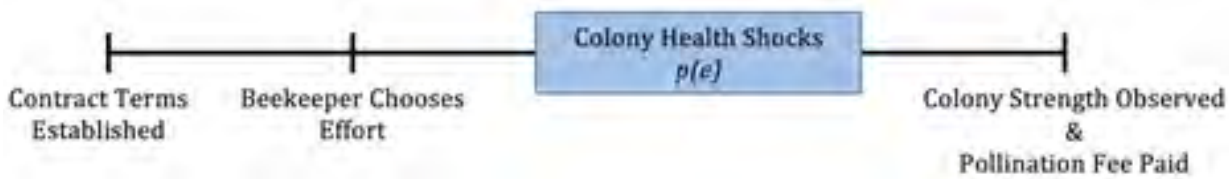
Beekeeper	Average Frame Count	Price/Hive
Beekeeper #1	9.5 frames	(1.5x10)+175=$190
Beekeeper #2	7 frames	175-(1x15)=$160

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}):

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

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

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

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:
  - $\frac{\partial e_{UB}}{\partial P \triangle y} > 0$: Profit-maximizing level of effort increases
  - $\frac{\partial t_H^*}{\partial P \triangle y} > 0$: Payment for high colony strength increases
  - $\frac{\partial t_L^*}{\partial P \triangle y} < 0$: Payment for low colony strength decreases

  ($\triangle y = y_H - y_L$: 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

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
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Interpretation of Results

- Many almond growers use contract provisions to address incentive problem in almond pollination
  - Vary in level of enforcement
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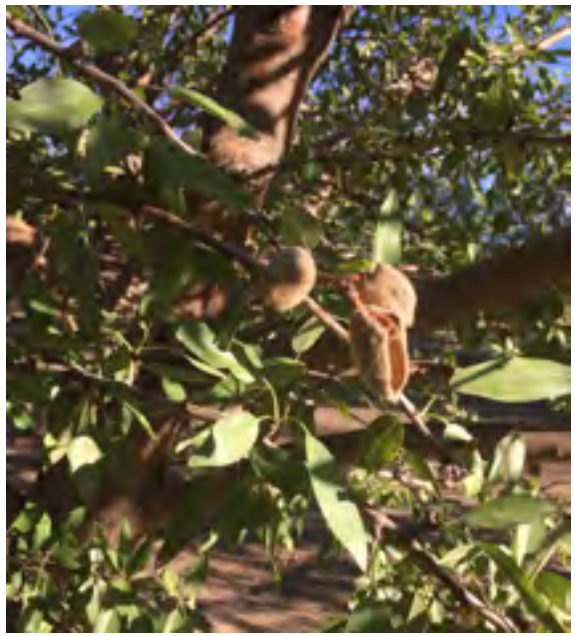
- Potential explanations for variation in contract preferences for future research:

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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