

**A Spatial Look at Negative Externalities in Agricultural Landscapes: Seedless  
Mandarins and Honey Bee Pollination in California.**

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*Selected Paper prepared for presentation at the American Agricultural Economics  
Association Annual Meeting, Orlando, FL, July 27-29, 2008.*

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## **Abstract**

When honey bees transport pollen across citrus orchards they can increase the number of seeds in varieties that remain seedless otherwise. An increase in seeds diminishes the market value of the fruit creating an externality between seedless growers and beekeepers. This paper investigates the efficiency of different policy resolution of this externality including a range of regulated spatial segregations of beekeeping and seedless farming with or without financial compensations.

We develop a spatial model of honey foraging behavior to quantify the efficiencies and redistributions of different policies that may be used to correct this market failure. Some of these policies have been implemented others are being currently discussed in policy debates in the California citrus belt.

This paper illustrates that quantifying biophysical processes that create externalities is a necessary step towards evaluating the economics efficiency of alternative solutions.

## **Introduction**

The canonical example of positive externalities is pollination of tree crops by honey bees as cited by Meade and others. As pointed out by Chueng and others generally, the benefits are internalized and the pollination market is well developed. However, pollination can create a negative externality that can become in some circumstances a significant issue. Pollination can reduce the quality and the market value of crops. This is the case with many seedless mandarin varieties. In absence of cross-pollination with other citrus, clementine and W. Murcott Afourer varieties are seedless and thus more highly valued by consumers. If both honey bees and other varieties of citrus (including tangelo, lemon, or other mandarins) are present in the vicinity of seedless orchards these mandarins become seedy and lose their quality premium. The externality

comes from the transport of pollen from other citrus orchards by bees into orchards intended to produce seedless fruits. This externality has become a major concern for both seedless mandarin growers and beekeepers operating in the citrus belt of Valencia in Spain and California in the United States. Heated policy debates are ongoing. California seedless citrus growers support a regulatory approach that would exclude bee hives from all locations within 2 miles of a seedless orchard, an option close to the one currently being used in Spain. Beekeepers, who would lose many valuable locations for their hives, oppose this policy. These beekeepers have been operating for decades before seedless citrus and hence claim they are protected under the Right to Farm Act. They also claim that flight patterns of bees are not controllable and have established rights to roam.

Externalities related to pollen transport are not new and a large literature exists on the problem of seed certification (Hokanson, Grumet, and Hancock (1997)). Much attention has been paid recently to pollen drift in genetically modified crop such as corn, but the issue has also been studied in the forestry industry or in sunflower seed production and certification. These externalities are generated from the uncontrolled dispersion of pollen and the vicinity of compatible crops with different genetic material. Wind is the most frequent vector of pollen dispersion for species with small pollen size. In such cases the only decisions that influence the presence and extent of the externality are planting decisions by neighboring farmers. In the case of seedless citrus, the magnitude of the externality is determined both by the vicinity of cross compatible varieties of citrus and by the distribution of honey bees in the crops. The fact that beekeepers indirectly control the vector of pollen is crucial in the determination of the efficiency of different externality resolutions.

In Spain, a segregation policy with compensation has been chosen where beekeepers are excluded from seedless growing areas and compensated for their loss. The objective of this paper is first to evaluate the policy option and rank them for the California Citrus Belt, and second to identify in which way the Spanish situation may differ. We rank the different policy options according to their benefits to the different groups of farmers as well as using an estimated social welfare gain that includes consumers of honey, citrus both seedless and seedy, and almonds which depend exclusively on honey bees for their pollination. The economic importance of almond production is strikingly different between Spain and California which may explain different optimal policies.

We first review the economics of the seedless externality issue in California before turning to a description of our modeling approach. Our model combines an ecological model of bee foraging behavior with an economic analysis of the costs and benefits of beekeeping and seedless production. We show that explicitly taking the spatial nature of the externality into account is crucial to evaluating policies. We then present our simulation results before concluding and making policy recommendations for the California citrus belt.

## **Background**

The California citrus belt is located in the southern San Joaquin Valley. It contained about 242,044 bearing acres in 2005 (USDA 2006). The break up in the main types is presented in table 1 along with the acreages of seedless varieties.

The current acreage of bearing seedless varieties is quite small relative to the total acreage of citrus but seedless orchards are rapidly expanding as the acreage of non-bearing acreage shows.

Among the varieties of Tangerines grown in California, the seedless varieties are the W.Murcott Afourer, the Fina Sodea/Clementine, the Clemenules, the Marisol, and a few other varieties of Clementines. The acreage for seedless shown in table 1 is the sum of the acreages for these varieties. Their fruits do not set seed unless pollen from compatible citrus is transported into the orchards. Compatible citrus varieties include some the seedless varieties themselves (see Kahn (2007) for an introduction to the biology of seedless citrus). Extension research recommends the use of other citrus such as navel oranges and Satsuma mandarins as buffer between compatible varieties (Chao (2004)). The current acreage of seedless citrus may allow the use of buffer rows to limit cross-pollination but as research on gene flows has shown that recommended buffers might be sufficient to avoid seedy fruits. In addition, as acreage of seedless expands buffer strategies may not be sufficient.

Planting decisions and policies that affect planting decisions such as zoning are possible tools for resolving the cross-pollination but we focus here instead on a possibly cheaper and more efficient set of policies that control pollen flow directly. Accordingly, we take acreage decisions as given and focus on the interaction between established seedless growers and beekeepers operating in their vicinity.

For that reason, our modeling focuses on the externality between seedless growers and beekeepers and leaves other citrus growers out of the picture. This simplification is reasonable given two facts. First, in the current policy debates the two main sides are the seedless growers and the beekeepers and seedy citrus growers are somewhat neutral, even though they do get some benefit from letting beekeepers operate on their farms. The second fact is that even if acreage of seedless orchards is increasing rapidly it still represents only a fraction of the citrus acreage with about 5% as presented in table 1. In this paper we take orchard maps as given and

only consider the decision of the number and locations of hives as a control variable. Our first step is to understand and propose solutions for the externality in the short run even though planting decisions both determine the size of the externality and depend on the outcome of the current negotiations. Indeed, if the rights to place hives in any location were given to beekeepers, the net return to seedless farming would decrease and seedless orchards might be relocated or disappear altogether.

### **Combining a Foraging Model and an Economic Model**

Honey bees (*Apis mellifera*) differ from solitary bees and other pollinators by their ability to gather information about forage resource and make collective foraging decision. The mechanisms of information sharing are well documented (Seeley (1994)). Hives send scouts to evaluate forage sources (pollen and nectar mainly) and allocate their foragers' efforts to the patches with highest returns. An extensive literature exists on the behavior of hives and bees and on the decision rules of individuals that generate the collective foraging patterns observed both in experimental and natural settings (e.g. Waddington et al. (1994), Biesmeijer J.C., Ermers (1999)). We use the decision rules from that literature and from the central foraging literature (Pyke (1984)) to develop a spatially explicit model of hive foraging in an agricultural landscape. Behavior of individual hives is however insufficient to derive foraging patterns at a landscape level when the density of bees is of the same order of magnitude as the forage density (de Vries and Biesmeijer (1994)). Indeed, the bee foraging literature says much about the decisions that one hive makes to choose on which patch to allocate effort, but less on how several hives interact. The consensus in the entomology literature and from entomologists' opinion is that when resources are not extremely scarce, bees do not enter in physical competition or exculsion and do not actively develop foraging territories. Instead, competition is mainly indirect through

depletion or mining of the forage. Accordingly, we develop a model of forage mining by hives in an agricultural landscape.

The initial data of the simulation model is a map of crops and hive locations. Each crop provides a certain density of forage that can be depleted by bees as they forage. In the citrus belt, we assume that all types of citrus provide the same amount of forage per acre, with no spatial heterogeneity. We also assume homogenous hives. Our default value for hives is of 50 000 bees with up to a third of foragers. We simplify the modeling of information gathering by assuming that our simple landscape all hives spend a fixed and identical proportion of their bees on scouting and transmit that information to all foragers with the result that bees have perfect information about the forage in each patch at every time.

The sequence of the simulation is as follows. Hives only dispose of a set flight time to collect the forage determined by temperature and humidity. This foraging period is split into rounds. At each round, each hive decides which patch to forage according to a cost minimizing rule and allocates the foragers present in the hive at that time accordingly. The cost of foraging a patch is a function of the distance from the hive to the patch and of the density of forage at that patch. As forage decreases on one patch, it becomes increasingly time consuming for a forager to collect one load of forage. After each round, the forage on the entire landscape is updated to reflect the loads collected by the different hives. Bees return to the hive after the number of rounds it takes them to collect their load, i.e. the cost of foraging. The simulation starts with a map of forage that is progressively mined until the flight time is up.

Our model has several limitations. First it assumes homogeneity of both hives and forage (within an orchard). It also does not allow to account for variability in biophysical parameters

that can affect the foraging range of bees, such as wind, roads etc... However, it captures important spatial features of published data since we calibrate it on such data (Gary, Witherell, and Lorenzen.(1976)). Further experiments will be required to validate or invalidate the predictions of our simulations.

Pollination and cross-pollination are the result of foraging. Every time a bee collects forage from a flower, it leaves some pollen that was incidentally gathered from previous visits to flowers or from contact with pollen stored in the hive. We estimate cross-pollination by assuming that when visiting a flower each bee leaves pollen from different citrus varieties according to the relative amount of pollen from each variety collected by the hive at that point in time. The output of the foraging model is a range of foraging for each hive. These ranges are used to generate a measure of cross-pollination. In the extreme case where all foraging ranges are within orchards with no overlap, no cross-pollination occurs since no pollen is transported to seedless varieties. In that situation, each hive only contains pollen from one variety. However, in some hives at least forage in different orchards generating cross-pollination.

This first foraging model provides a measure of the degree of cross-pollination using maps of orchard planting and hive locations. The second part of our modeling exercise is to find the economic costs and benefits associated with the initial maps and the cross-pollination outcomes. On the beekeepers side, we estimate a net revenue per hive which is generated from locating the hive in a citrus orchards. For citrus growers who do not grow seedless varieties, there is little benefit to having hives in their orchards, and accordingly, they usually charge a small fee or receive honey from the beekeepers. There is no strong evidence that bees improve citrus crops, as opposed to watermelons or cherry tomatoes for example where honey bees are not necessary for pollination but have been shown to increase fruit set and fruit quality.



Accordingly we assume that for beekeepers the revenues derived from using citrus orchards are to find a good location to maintain hives after the almond pollination season and to possibly produce citrus flavored honey that can be sold for a premium. Since it is difficult to estimate a value per hive for citrus orchard locations we carry an extensive sensitivity analysis on this parameter. On the seedless grower side, the loss due to the occurrence of cross-pollination is easier to estimate since market prices provide an estimate of the premium for seedless fruit. We assume that a few seed only suffice to lose the premium.

As noted earlier, this paper does not consider policies that affect planting decisions such as zoning and focuses on policies that affect hive locations and transport of pollen. The simplest way of making sure that no cross pollination occurs would be to remove all hives within the flight range of seedless orchards. Seedless growers support a policy that would establish the legal limit at 2 miles. We evaluate both a policy that ensures that seedless orchards are not within flight range of bees and a policy with a 2 mile radius of exclusion. Although the 2 mile radius seems a reasonable distance to reduce bee visitation, there is some evidence that flight ranges can exceed 5 miles, depending on the flight conditions, landscape characteristics and forage density. Comparing these two strict-exclusion policies allows first to evaluate the relevance of the 2 mile figure and second, to give an upper bound to the cost of solving the externality. Indeed, strict exclusion, a policy that would reduce seed set as much as possible does not take into account the opportunity cost of lost hive locations for beekeepers and does not allow for any trade off.

The second set of policies, is one where the trade offs are fully considered, either through an hypothetical market-based mechanisms between growers and beekeepers or through some taxation mechanism. We use an optimization algorithm to find the optimal limit of exclusion of

hives allowing for some level of seeds in mandarins. This is the standard economic concept of equating marginal cost to marginal benefits, where the costs are opportunity costs of losing hive locations for beekeepers and the benefits the increased market value of seedless fruits. This policy provides a picture of a spatial marginal cost-marginal benefit frontier. We also investigate the effects of non-zero transaction costs on this efficiency frontier.

The last policy considered is one where we take advantage of the partial exclusion of foraging range that hives show in experimental data (Gary, Witherell, and Lorenzen(1976)). When hives are placed inside seedless orchards, the forage inside the orchard is depleted, possibly before the arrival of bees from hives outside the orchards, which reduces the gains for these outside bees to forage and cross-pollinate. This solution is not an exclusion of bees but a segregation of bees, one group foraging a seedless variety only, another foraging outside the orchard only. To the extent that this segregation is possible, this solution neither limits the use of hive locations nor produces seedy fruits. We show how the efficiency of this policy depends on the foraging segregation predicted by our bee behavior model.

## **Results**

Table 2.

## **Conclusion**

The results and methods of this paper carry beyond the current debate between seedless citrus growers and beekeepers in California. First, beekeepers everywhere are concerned by the precedent that California's policy might set. Second, our contribution points at the lack of empirically sound pollination strategies from the economics literature. The seedless case represents merely a fraction of the externalities related to pollination in agricultural landscapes.

The Conservation Reserve Program has been recently modified to include the value of pollination for prioritization of conservation contracts. Sound pollination management strategies for both managed and wild pollinators will require contributions from entomologists, ecologists, and economists. Finally, our case study illustrates some of the gains obtained from coupling economic models with spatially explicit models of biophysical processes such as pollination.

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**Table 1: Citrus Acreage in 2005 in the California Citrus Belt.**

	Bearing	Non-Bearing	Total
<b>Grapefruit</b>	7,700	703	8,403
<b>Lemons</b>	42,930	3,287	46,217
<b>Limes</b>	365	30	395
<b>Oranges, Navel</b>	128,155	11,888	140,043
<b>Oranges Valencia</b>	48,761	402	49,163
<b>Pummelos</b>	1,929	113	2,042
<b>Tangerines</b>	12,204	11,834	24,038
<b>Total</b>	<b>242,044</b>	<b>28,257</b>	<b>270,301</b>
<b>Seedless</b>	<b>3,334</b>	<b>9,794</b>	<b>13,128</b>
<b>(percent of total)</b>	<b>(1.4%)</b>	<b>(34.7%)</b>	<b>(4.9%)</b>

Source: USDA (2006).

**Table 2: Surplus Changes Comparison for different policy alternatives.**

Policy scenarios	Cross-pollination intensity	Beekeeper surplus change	Seedless surplus change
<b>2 miles radius exculsion</b>			
<b>Seedless growers own rights</b>			
<b>Full exculsion with compensation (Spain)</b>			
<b>Beekeepers own rights</b>			
<b>Marginal cost/benefit policy</b>			
<b>Foraging range overlap control policy</b>			