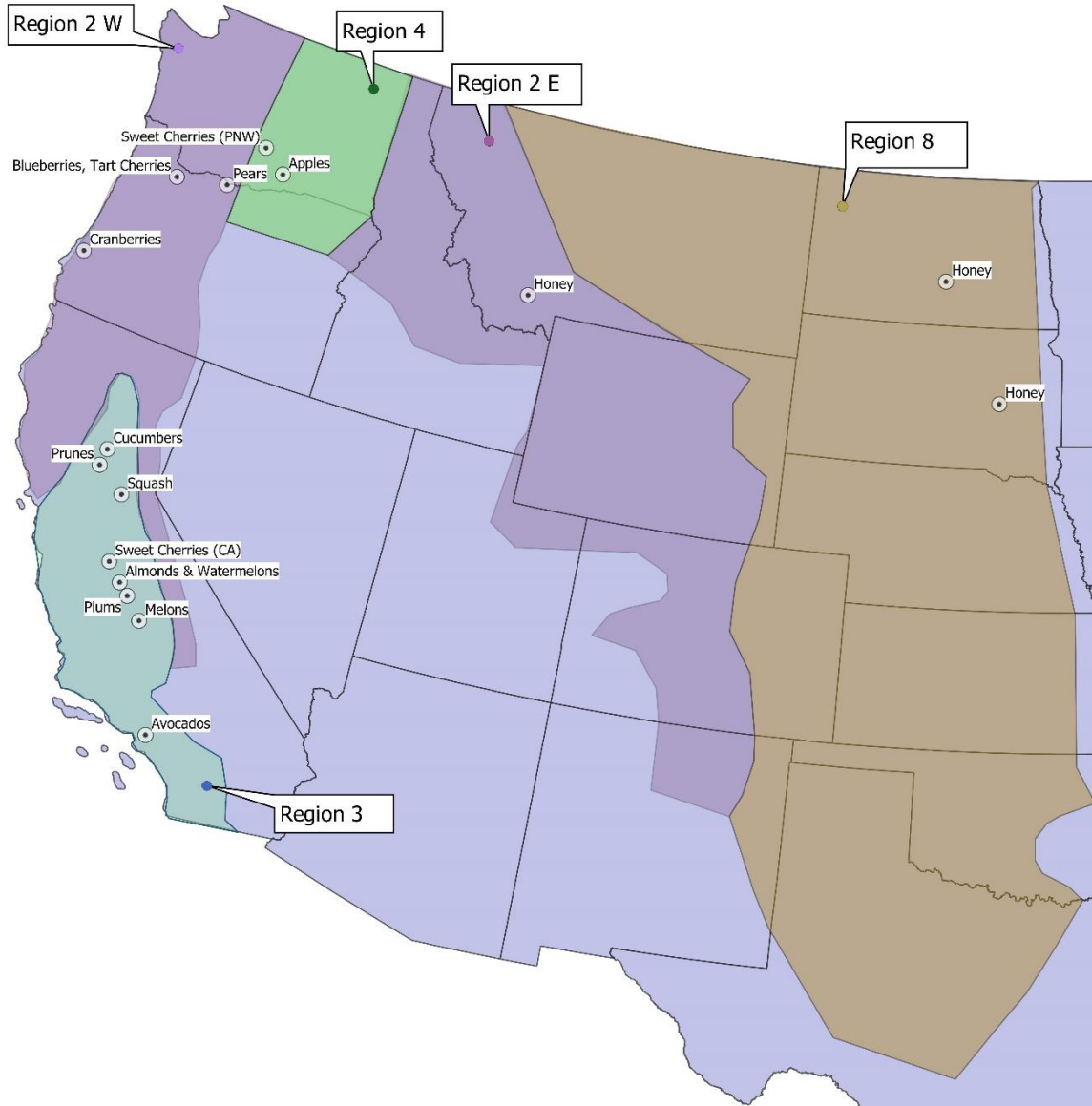
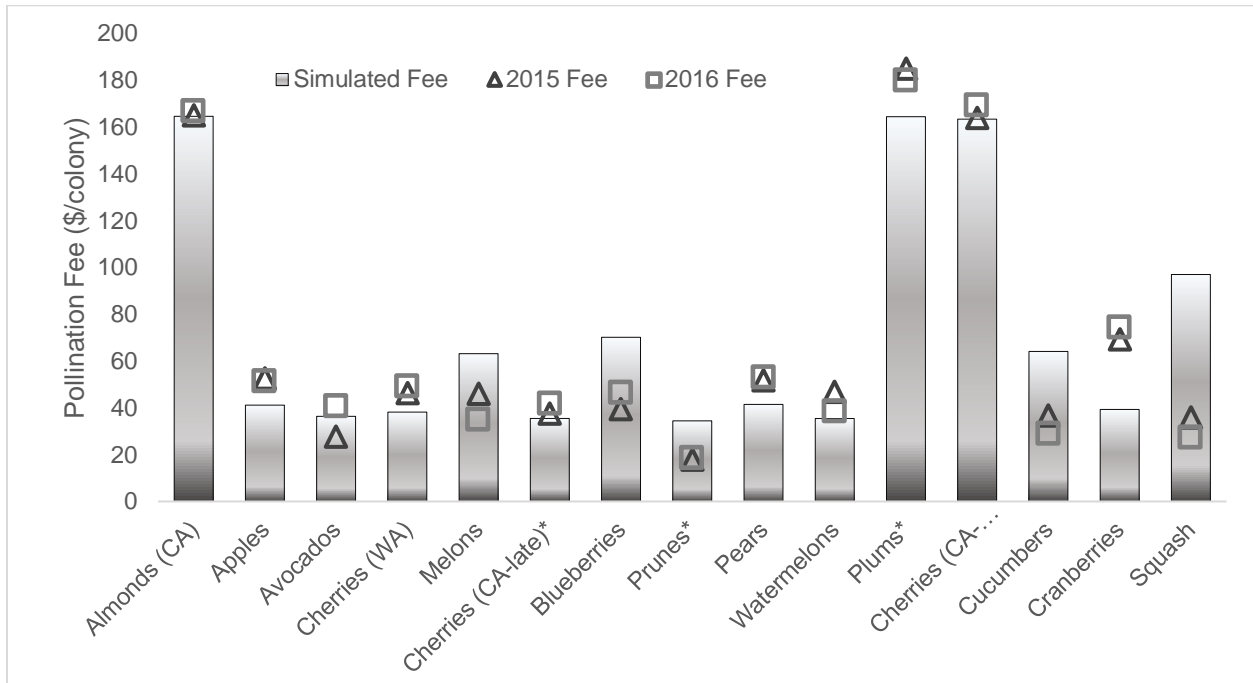


**Appendix to  
Fei et al. “Honey Bees, Almonds, and Colony Mortality: An Economic Simulation of  
the U.S. Pollination Market”**



**Figure A.1: Crop pollination and honey- production locations in the western U.S., as well as and bee forage regions.** Crop and honey locations are production-weighted centroids based on production of each crop or major honey production region (USDA National Agricultural Statistics Service). Bee forage regions are drawn to closely replicate the map in Nickeson and Esaias (2015).



**Figure A.2: Observed pollination fees compared to simulated fees for 14 crops.** Crops are arrayed from left to right based on pollination demand in 2016. All fees are drawn from USDA-NASS (2017a) except those indicated with a \*, which identifies sub-crops only reported in aggregate by USDA. Data on those fees are drawn from CSBA (2017).

**Table A1: Model indices, variables, and parameters**

Parameter	Description
	<b>Objective Function</b>
$W$	Welfare (objective that is maximized)
	<b>Indices</b>
$k=1, \dots, K$	Time periods during year
$i$	Initial location index, where the colony is located in a time period prior to shipment
$j$	Ending location index, where the colony is located at the end of the period
	<b>Variables</b>
$A_{k,i}$	Number of colonies initially in location $i$ at the beginning of period $k$
$B_{k,j}$	Number of colonies available to pollinate and produce honey in location $j$ during period $k$
$T_{k,i,j}$	Number of colonies shipped from location $i$ to location $j$ during period $k$
$N_{k,j}$	Number of colonies added through splits ending in location $j$ in period $k$
$S$	Quantity of honey sold in total during the year
$P^H$	Price of honey
$C_k^M$	Total feeding and splitting cost incurred in period $k$
$H^S$	Direct honey consumers' surplus: area under the honey demand curve less extraction costs
	<b>Parameters</b>
$\gamma_{k,j}$	Cost of feeding and maintaining a colony in location $j$ during period $k$
$\beta_{k,j}$	Number of colonies demanded for pollination at place $j$ during time $k$
$H_{k,j}$	Honey production per colony in location $j$ during period $k$
$D_{i,j}$	Cost of shipping from location $i$ to location $j$
$L_{i,j}$	Fraction of the colony population lost when it is moved from location $i$ to location $j$ .
$V_{k,j}$	Base level for the percentage change in colony population in location $j$ at time period $k$
$\varepsilon$	Price elasticity of demand for honey: $\% \Delta \text{Quantity} / \% \Delta \text{Price}$
$\eta$	Honey demand function multiplicative parameter
$\lambda$	Cost of extracting and processing a pound of honey for sale
$\rho$	Cost of initiating a colony
$\sigma$	Cost of splitting one colony into two.
$\alpha$	bee forage scarcity parameter
$\delta_R$	Bee forage scarcity discount rate $\delta_R = 1 - \alpha \left( \frac{\sum_{j \in R} B_{k,j} - \sum_{j \in R} \bar{B}_{k,j}}{\sum_{j \in R} \bar{B}_{k,j}} \right)$

**Table A1: Calibrated V Matrix. Matrix of colony population change parameters for each region and period.** If value is less than one, then colony size declines during the period; if the value is greater than one, then beekeepers have the option to split their colonies, leading to growth. Rates during pollination are boxed and bolded; all other values are for adjacent areas (see Figure A.1) which can be used for bee forage and honey production. Almonds and watermelons share a location, as do blueberries and Washington cherries.

	Almond	Apple	Avocado	Blueberry	Cranberry	Cherry (CA)	Cucumbe r	Melons	Pear	Plum	Prune	Squash	Cherry (WA)	Honey Regions
Feb2	1.03	1.00	1.06	1.00	1.01	1.06	1.06	1.06	1.00	1.05	1.06	1.06	1.00	1.01
Mar1	1.06	1.02	1.06	1.01	1.02	1.02	1.02	1.07	1.01	1.00	1.07	1.07	1.02	1.02
Mar2	1.05	1.00	1.06	1.00	1.01	1.00	1.05	1.00	1.00	1.02	1.02	1.05	1.00	1.03
Apr1	1.06	1.01	1.06	1.02	1.03	1.00	1.06	1.06	1.03	1.06	1.09	1.03	1.00	1.04
Apr2	1.03	1.03	1.05	1.10	1.08	1.07	1.05	1.03	1.01	1.08	1.09	1.08	1.03	1.08
May1	1.02	1.00	1.04	1.08	1.06	1.07	1.07	1.06	1.01	1.07	1.07	1.07	1.03	1.06
May2	1.00	1.02	1.01	1.07	1.00	1.03	1.06	1.01	1.01	1.00	1.06	1.05	1.03	1.01
Jun1	1.03	1.03	1.03	1.10	1.00	1.03	1.08	1.05	1.03	1.03	1.08	1.08	1.03	1.03
Jun2	1.01	1.03	1.01	1.03	1.00	1.01	1.10	1.10	1.03	1.01	1.07	1.10	1.03	1.03
Jul1	1.00	1.00	1.00	1.01	1.00	1.00	1.08	1.06	1.01	1.00	1.00	1.08	1.01	1.00
Jul2	1.00	1.00	1.00	1.00	1.00	1.00	1.08	1.06	1.00	1.00	1.00	1.08	1.00	1.04
Aug1	1.01	1.00	1.00	1.00	1.00	1.00	1.08	1.00	1.01	1.00	1.00	1.03	1.00	1.10
Aug2	1.00	1.01	1.01	1.03	1.02	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.01	1.08
Sep1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.08	1.00	1.01
Sep2	1.08	1.05	1.03	1.10	1.08	1.06	1.00	1.05	1.07	1.05	1.02	1.07	1.05	1.07
Oct1	1.04	1.00	1.00	1.00	1.02	1.04	1.00	1.05	1.05	1.05	1.04	1.00	1.05	1.01
Oct2	0.99	0.99	0.99	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98
Nov1	0.99	0.94	0.99	1.00	1.00	0.99	0.98	0.99	0.99	0.99	0.98	0.98	0.99	0.98
Nov2	0.97	0.97	0.97	0.97	0.96	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Dec1	0.99	0.99	0.99	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Dec2	0.91	0.90	0.91	0.90	0.91	0.91	0.91	0.91	0.90	0.91	0.91	0.91	0.90	0.90
Jan1	0.91	0.90	0.90	0.90	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.90
Jan2	0.90	0.90	0.91	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Feb1	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90

**Table A2: Decomposition of the marginal cost of almond pollination for different levels of winter mortality.** Honey prices are presented in the final row.

<b>Winter Mortality Rates</b>					
% change relative to 2016	<b>-20%</b>	<b>-10%</b>	<b>0%</b>	<b>10%</b>	<b>20%</b>
<b>Marginal Cost of an additional colony for almond pollination (\$/colony)</b>					
Shipping	-22.9	-27.8	-27.8	21.8	-49.9
Splitting	15.5	18.8	24.9	66.1	46.9
Feeding	116.8	123.5	133.8	143.5	154.8
Other pollination costs	33.8	33.8	33.8	33.8	54.9
Honey extraction	1.2	0.0	0.0	19.1	0.0
<b>Gross marginal costs</b>	<b>144.4</b>	<b>148.3</b>	<b>164.7</b>	<b>284.3</b>	<b>206.7</b>
Increase in honey surplus	6.6	0.0	0.0	105.9	0.0
<b>Net marginal decline in welfare = Pollination fee</b>	<b>137.8</b>	<b>148.3</b>	<b>164.7</b>	<b>178.4</b>	<b>206.7</b>
Honey price/lb.	1.79	1.79	1.80	1.81	1.79