DISSERTATION

ESTIMATING THE ECONOMIC IMPACTS OF BIRD AND RODENT DAMAGE TO SELECTED CALIFORNIA CROPS

Submitted by

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ABSTRACT

ESTIMATING THE ECONOMIC IMPACTS OF BIRD AND RODENT DAMAGE TO SELECTED CALIFORNIA CROPS

This research estimates the direct financial costs and the changes in economic welfare associated with bird and rodent damage to 15 different crop markets in eight agricultural regions in California. Three different models are used to quantify this impact: a meta-analysis to aggregate and analysis a large database of 206 damage estimates from 43 studies related to 15 crops across 6 (of 8) regions of California, a direct financial cost model to identify changes in profits and costs from an individual producer's perspective, and a combination of an equilibrium displacement model (EDM) and an economic surplus model to estimate changes to producer and consumer surpluses. Using a range of damage estimates calculated from the meta-analysis, results from the direct financial analysis indicate that birds and rodents have a direct financial impact in reducing income from lower production and increasing production costs and was calculated as a range from $1,153 m to $1,726 m. Results from the EDM and economic surplus model are the estimated gain in consumer surplus resulting from an absence of bird and rodent damage and a reduction is between $689.6 m and $$1,148.5 m and the estimated gain in producer surplus is between $396.0 m and $658.8 m. Understanding the aggregate impact of damage caused by birds and rodents to multiple economically important crops in California agriculture is crucial. The results of this study indicate that

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bird and rodent have caused negative impacts on California producers and consumers. Through the inclusion of a more complete damage data set, the impact of this damage on profits and consumer and producer surpluses was estimated with greater accuracy and yielded predictive and interpretive value to the profession.

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CHAPTER 1: INTRODUCTION

1.1 Background

In 2008, the value of California's agricultural production was $36.2 billion. This exceeded the value of any other state's agricultural production by nearly $12 billion. California accounts for 14% of national revenue from crops and produces nearly half of U.S.-grown fruits, nuts, and vegetables. Additionally, California is the sole domestic producer of many agricultural products such as artichokes and almonds and is the leading producer of many others. Agriculture is a critical sector of California's economy. There are approximately 81,500 farms and ranches in the state which cover 25.4 million acres employing approximately 372,600 people in 2008 (CDFA 2009).

Agricultural pests in California impose costs on its producers. These producers face a loss of crops, reductions in crop yield, and loss of crop quality relative to the potential yield and quality that would be possible without pests. This potential decrease in yield and quality necessitates the input requirement of pest control (Jones et al., 2005; Sexton et al., 2007). In the cases where pest damage is significant and impacts multiple producers, the loss in yield can have broad economic significance. If the majority of producers are affected, changes in crop prices and quantities will impact consumers and producers as a whole (Jones et al., 2005). Pests in California agriculture include: vertebrates, such as coyotes, rodents, rabbits, birds, and feral hogs; invertebrates, such as

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the avocado thrip and the Mediterranean fruit fly; plants; fungi; and bacteria, such as *Xylella fastidiosa* (which causes Pierce's Disease in wine grapes).

Much of the published literature describing the negative effects pests have on California agriculture has been focused on insects, plants, and diseases (see Kogan, 1998; Hoddle, 2003; Seward et al., 2004). Literature focusing on vertebrate damage has been largely restricted in scope. The works tend to focus on large pest species such as coyotes, foxes, and feral swine (see Mitchell et al., 2004; Jay et al, 2007). There is limited published work on damage to agriculture caused by small vertebrates such as birds and rodents (see Salmon et al. 1986; Hueth et al., 1998; Cummings et al. 1998; Marsh, 1998; Whisson et al., 2000).

Despite the limited published work, the damage caused by vertebrates is substantial. National estimates of total vertebrate pest damage to field crops and fruit/nut crops were $619 million and $146 million respectively in 2001 (NASS, 2002). Clark (1976) estimated in 1974 that vertebrates created $12.75 million in damage to all California crops. Marsh (1998) estimated that California ground squirrel alone caused between $8 and $12 million in damage to California crops. This damage has caused market-wide price impacts and alters the size and distribution of economic surpluses, often with decreasing consumer surplus in affected markets.

Previous research on the economic impacts of bird and rodent damage to California agriculture has two shortcomings. First, in restricting its focus to estimating direct economic cost of bird and rodent damage to producers, previous research largely ignored the industry-wide supply, demand, and price effects caused by both the presence and control of damaging species. Second, previous analyses generally focused only on a single crop, pest, county, region, or control measure, rather than focusing on an aggregated multi-crop, multi-pest, or multi-regional analysis. The estimates provided in this research will show the more comprehensive economic welfare effects of bird and rodent damage to California.

The importance of California agriculture implies that negative impacts (e.g., bird and rodent damage or drought) to agricultural production can have a major effect not only on the state’s economy, but also the consumers throughout the U.S. and around the world. Understanding the aggregate impact of damage caused by birds and rodents to multiple economically important crops in California agriculture is crucial for many reasons.

The information provided by this study can be used by California state government to ensure pest control is available to mitigate the negative impact cause by pest species. The ability to control vertebrate pests and protect endangered species is limited by the number of effective control materials registered for agricultural field use. Many of these control options are no longer registered with or have been restricted by the Environmental Protection Agency (EPA). Additionally, many pesticides have additional restrictions required by the California Department of Pesticide Regulation (CDPR). In California and other states, users of restricted materials must have certain training, but in California, the purchase or use of most restricted materials in agriculture requires an additional permit from the County Agricultural Commissioner. California is the only state with such a pesticide permitting system (CDPR, 2010).

Prior to 1990, field use of toxicants included rodenticides (e.g., Compound 1080, strychnine, zinc phosphide, diphacinone, chlorophacinone) used for broadcast baiting in bait stations, avicides (e.g., 4-aminopyridine also known as Avitrol, 3-chloro-p-toluidine hydrochloride also known as Starlicide), and fumigants used in rodent burrows (e.g., aluminum phosphide, methyl bromide, and gas cartridges). Broadcast baiting or bait used in bait stations was a relatively inexpensive way to treat rodent (e.g., ground squirrel, meadow vole, gopher, and rat) infestations (Whisson et al., 2000). In recent decades, Compound 1080, strychnine, zinc phosphide and chlorophacinone have been severely restricted or are no longer registered for agricultural purposes. In response, the use of the three fumigants and of the avicides has increased (CALPIP, 2010). In past decades, fumigants were thought of as suitable only for spot treatment because of their cost. The regulation of rodenticides is an issue because control by means other than toxic baits (e.g., such as shooting or trapping) are generally less effective on a large scale (VPC Task Force, 1988).

Restricting the use of these pesticides stems from concerns about human health, secondary effects on predators, and the impact on threatened and endangered species (CDPR, 2010; Anderson, 1995). While the reasons for regulation are important concerns, regulation without a discussion about the impacts on agricultural producers and consumers is incomplete. The inclusion of a discussion about the effects of bird and rodent damage to producer and consumer welfare in California would provide a more complete picture and allow additional benefits and costs of removing or restricting a pesticide to be evaluated leading to improved policy.

Understanding the impact of damage caused by birds and rodents is beneficial to agricultural producers because there is increased information and transparency of the costs and benefits of production. With the information provided by this study, producers can efficiently implement management strategies and techniques to mitigate the negative impact. Through this, the negative effects of damage on the greater economy can be minimized.

The agricultural sector is a fundamental segment of the California economy not only because it contributes substantially to general economic activity and employment in the state, but also because it provides inputs to almost all other sectors in the economy (e.g., manufacturing, retail trade, and accommodation and food service). Positive and negative economic impacts to this sector ripple through the general economy, affecting many other sectors, and multiplying the impact. Any negative impact on production and producer revenue will also negatively impact the agricultural and closely related sectors which comprised more than 13% of total state employment in 2002 (NASS, 2002). Arguably, negative and positive impacts to agriculture are felt strongest in rural areas because 18.5% of rural employment in agriculture and closely related sectors (ERS, 2007). Agricultural production plays an important role in the health of the California economy and the information from this study can be used in an input-output analysis to determine the regional multiplier effects of damage in future research.

Consumers are also impacted by bird and rodent damage. The share of disposable income spent on food in the United States is about 9.726% (Seale et al., 2003). Although this budget share is low compared to other countries, any change in price of agriculture will impact the amount of agricultural products purchased by consumers. The consequences of increased food prices include changing consumption patterns and malnutrition especially for low income families (Knutson, 1999).

A final reason to understand the effects of bird and rodent damage to California agriculture is to shed light on the potential impacts on agricultural trade. Exports are

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important to California's agricultural producers and statewide economy. To give perspective about the importance of agriculture exports in California, the state ranked 1st in the nation in 2008 with agricultural exports estimated at $13.6 billion (FAS, 2009). Historically, commodities such as wheat and rice accounted for most of U.S. agricultural exports. However, this changed in the 1990s when U.S. exports of high-value products such as meat, nuts, fruits and vegetables showed growth, while exports of commodities tended to fluctuate in response to prices (ERS, 2009). This is of particular relevancy to crops grown in California because the state leads the nation in the production of many of the nut, fruit, and vegetable products. In addition to supplying the nation, California exports more than $3 billion in tree nuts, $3 billion in fruits and preparations and $2 billion in vegetables and preparations (FAS, 2009).

Agriculture productivity in the U.S. is growing faster than domestic demand which causes U.S. agricultural producer to rely on export markets to sustain prices and revenue (ERS, 2009). The USDA estimates that anywhere from 26 to 30 percent of agricultural producer cash receipts in any one year comes from exports. Crops, such as almonds (64% of crop exported), benefit dramatically from sales in overseas markets (FAS, 2010). Agricultural exports not only help boost farm prices and income, but they also support jobs both on and off the farm in food processing, storage, and transportation. The results from this study can be used to help identify changing trade patterns.

1.2 Outline of research question

This research estimates the direct financial costs and the changes in economic welfare associated with bird and rodent damage to 15 different crop markets in eight

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agricultural regions in California. Three different models are used to quantify this impact: a direct financial cost model, an equilibrium displacement model (EDM) and an economic surplus model.

The direct financial cost model is used to estimate the direct economic cost associated with bird and rodent damage for each modeled crop in each region. These costs are estimated by identifying the change in profits corresponding to bird and rodent damage and/or pest control costs. This is because profit for an individual producer is the difference between total revenue and costs. This model assumes total revenue remains unchanged thus any changes in cost are directly reflected as changes in profit. Although the direct financial cost model does not take into account industry wide impacts on price, these results are useful in decision making by the individual producer and results could be used in input-output modeling.

The EDM will estimate how price and quantity changes in the presence and absence of damage. In other words, current agricultural output with bird and rodent damage and control costs is compared to a hypothetical estimated output in the absence of damage and control costs. Finally, the estimated changes in price (from the EDM) will be used in an economic surplus model to estimate the changes in the size and distribution of economic welfare between consumers and producers. This estimation is important because the results of this study can be used by California state government to ensure pest control is available to mitigate the negative impact cause by the pest species, by agricultural producers to make better decisions about the costs and benefits of production, to understand the effects of changing prices on consumers' budgets, and to explore the effects on international agricultural trade. These models were parameterized on a regional level to account for growing differences between heterogeneous regions. Figure 1.1 is a flow chart outlining the relationship of these models[1].

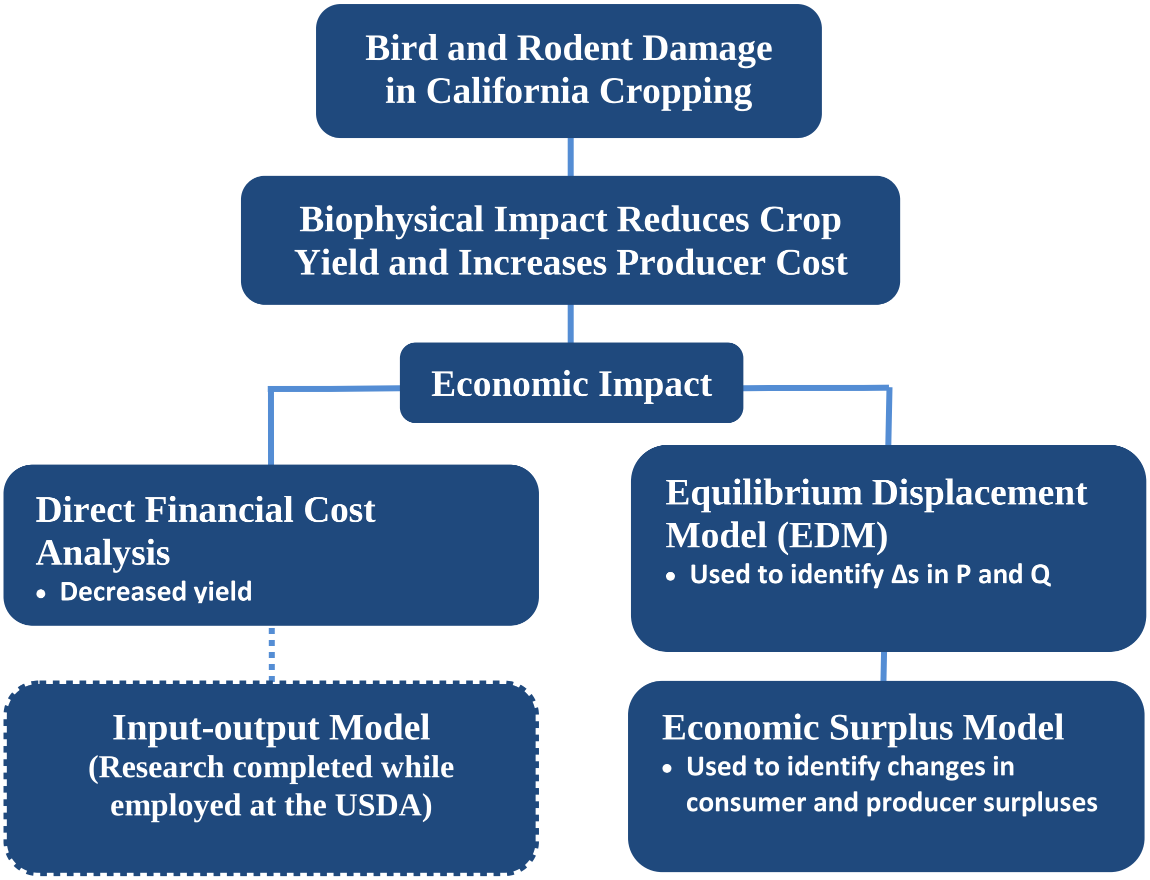

Figure 1.1: Flow chart representation of proposed research.

The input-output analysis shown in the flow chart is not included as part of this dissertation but was completed in my work at the United States Department of Agriculture, Animal and Plant Health Inspection Services, Wildlife Services, National Wildlife Research Center. This input-output analysis, titled "The economic impact of bird and rodent damage to California crops", was submitted to the California Department of Agriculture's Vertebrate Pest Control Research Advisory Council in 2009.

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[1] This project is funded through a grant from the California Department of Agriculture's Vertebrate Pest Control Research Advisory Council, CDFA contract #07-0377.

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1.3 Outline of dissertation

The estimates provided in this research will show the economic welfare effects of bird and rodent damage to California. It is organized into six chapters. Chapter one is an introduction. Chapter two reviews two bodies of literature estimating the change in economic surplus due to agricultural pests: (1) literature which uses direct financial cost methods, and (2) literature which details the use of an EDM and an economic surplus model. Chapter three establishes the theoretical foundations in this study to estimate the direct economic cost and the changes to economic welfare associated with bird and rodent damage. The direct financial cost method was used to estimate the costs associated with damage at the individual producer level, and the combined EDM and economic surplus models were used to estimate industry-wide changes in price and quantity resulting from damage. Chapter four develops and describes the use of the data in the empirical study. It includes alternate estimation of the key parameters; including producer control costs, price and quantity data, supply and demand elasticities, and a meta-analysis of bird and rodent damage. Chapter five provides a summary of results and includes a discussion.

1.4 Results and Implications

In this dissertation, I reviewed previous analyses related to crop damage caused by pest species and the economic theory used to analyze this crop damage. I then developed a model based on the theory. I gathered data, analyzed my data, and then completed my analysis.

The dissertation is intended to have contribution in two areas. The first one is the aggregation and analysis of an amount of damage data previously unanalyzed. A large database of damage estimates across California is analyzed. With respect to my damage data, I use a meta-analysis to combine and describe the characteristics of the data. The analysis of such a large amount of data is a unique contribution to the study of the economic impacts of crop damage in California. The meta-analysis explored the trends in pest damage over time, the differences in damage between regions and/or crop groups, and the lack of difference in damage estimates between field studies and interviews or surveys. Results of the meta-analysis indicated a decreasing level of damage over the years. Although this annual change is small, it is significant.

The second contribution is an estimate of the welfare impacts of bird and rodent damage, again with the impact on consumer and producer surplus that was never analyzed before. Results indicate that the negative impacts of damage can be substantial. Through the inclusion of a more complete damage data set, the impact of this damage on consumer and producer surplus was estimated with greater accuracy and the study yields a predictive and interpretive value to the profession.

CHAPTER 2: LITERATURE REVIEW

National estimates of total vertebrate pest damage to field crops and fruit/nut crops in 2001 were $619 million and $146 million respectively (NASS, 2002). In California, Clark (1976) estimated in 1974 that vertebrates caused $12.75 million in damage to all crops. More recently, Marsh (1998) estimated that the California ground squirrel alone caused between $8 and $12 million in damage to crops in California. These estimates indicate that damage can be substantial and can cause widespread economic consequences due to changing prices and quantities of crop produced that would potentially alter the size and distribution of economic surpluses.

The goal of this chapter is to critically review previous published literature related to the theory of the estimation of the welfare effects of bird and rodent damage to California crops. Literature detailing estimation of direct financial costs, changes in price and quantity, and changes in economic welfare caused by pest damage and pest control in agricultural markets will be reviewed.

There are two main techniques used to measure the economic impacts of bird and rodent damage to agriculture, a direct financial cost analysis and a combined equilibrium displacement model (EDM) and economic surplus analysis. The direct financial cost analysis estimates the costs and/or benefits of damage or pest control from the perspective of an individual producer. Authors of these studies often aggregate their findings to an industry level. The combined EDM and economic surplus analysis is a

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method to identify changes in economic surplus using in a partial equilibrium framework for a single market, or several markets which have horizontal or vertical integration. Although only one of these techniques has been used to model the economic impacts bird and rodent damage in California (direct financial cost analysis), both are applicable.

The first section of this chapter outlines how birds and rodents can impact crop production. The second part examines how direct financial cost analysis can be a measure of economic costs at the individual producer level, reviews several important studies, and provides a critique of this type of methodology. The third section introduces EDM techniques used to estimate the change in price and quantity in affected agricultural markets due to small[2] exogenous shocks modeled in a partial equilibrium framework. The model will be introduced, critical assumptions will be explored, and the strengths and weakness of the model will be discussed. EDM results are often used in conjunction with an economic surplus analysis to estimate the value of changes in economic welfare. Thus, the fourth section introduces the economic surplus analysis. The general theory and assumptions of the economic surplus analysis will be identified. The fifth section is a review of four important studies which use EDM and economic surplus modeling to estimate changes in economic welfare due to pest diseases, insects, or weeds. The final section is a conclusion.

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[2] EDM results from large shifts (>10% of price or quantity) cannot be reasonably relied upon because of the assumption of linear demand and supply curves (Piggott, 1992).

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2.1 Conceptualization of Bird and Rodents in Crop Production Systems

The traditional foundation of agriculture and applied economics has been on production economics (Doll and Orazem, 1984; Beattie and Taylor, 1985). Agricultural and applied economists analyze how resources (land, labor, capital, etc.) are transformed into agricultural goods and services (production) that benefit society through consumption. Birds and rodents interact with the agricultural production processes in a multitude of ways. For example, bird and rodent damage lowers the productivity of agricultural lands and the inputs applied to them which lower the benefits society gains through the production and consumption process. Additionally, pest control measures used to reduce the impacts of damage is a resource that producers must use efficiently in conjunction with other resources (Sexton et al., 2007).

Following the structure presented in McInerney (1996) relating to the economics of animal disease, I will discuss the consequences of bird and rodents in crops. The negative and positive economic impacts of bird and rodents in agriculture are diverse (figure 2.1).

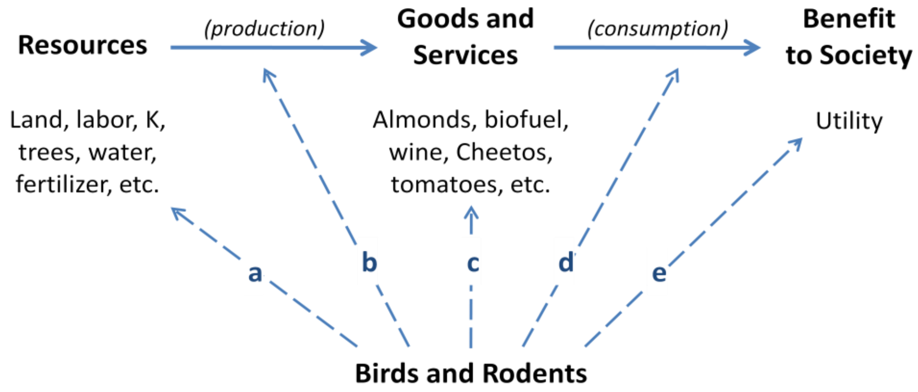

Figure 2.1: Birds and rodents in the agricultural production system.

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Negative impacts are most widely recognized in the production sector of crop farming and arise because birds and rodents:

a. destroy basic resources (e.g. rodents girdling almond trees kills the affected trees);
b. lower the efficiency of the production process and the productivity of resources used (e.g. tunnels dug by ground squirrels divert water, or to prevent rodent contamination the drying platforms for raisin grapes are raised off the vineyard floor or the drying process is moved indoors); and
c. reduce the realized physical output of the production process or its unit value (e.g. lower grape yield or quality due to house finch damage).

A broader view of the production system recognizes that birds and rodents can also:

d. lower the suitability of crop products for processing, or generate additional costs in the distribution chain (e.g. pesticide residues on fresh products requiring additional cleaning, rodent infestations in distribution warehouses contaminate stored products); and
e. affect society's well-being directly (e.g. rodent fecal contamination in leafy greens reduces utility).

Finally there is an array of more diffuse negative economic impacts. An additional negative impact could be the reductions in consumption of a particular crop, such as spinach or tomatoes, because of the existence or threat of the transmission of a zoonotic disease. Because of these diverse impacts, the negative impacts of birds and rodents can be substantial.

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In addition to causing negative impacts, birds and rodents in agriculture can cause positive impacts to producers and society as a whole. For example, birds and rodents consume insect pests providing benefits to agricultural producers. Additionally, crops provide an abundant and accessible source for nourishment for migratory birds and/or threatened and endangered species.

Estimating all the costs of birds and rodents in crops as detailed in figure 2.1 has not been completed in California; instead, much of the work has been limited to estimating the impact of reduced individual producer revenue through reduced final output. Biologists and vertebrate pest scientists have initiated studies to provide an economic, or more appropriately termed, financial, estimate of the costs of damage and/or the benefits and costs of pest control expenditures. These studies estimate the cost of bird and rodent damage (see Whisson et al., 2000; York et al., 2000; Cummings et al., 2005; Delwiche et al., 2007; Berge et al., 2007) through multiplying the quantity of decreased crop yield and the current market price for that crop to obtain the “cost” of the damage for a single crop, pest or region. On the contrary, estimation of market changes in price, quantity, and consumer and producer surpluses due to damage has not been completed for California. Arguably, widespread bird and rodent damage has market-wide implications. Estimating the impact of birds and rodents on agriculture using an EDM and an economic surplus analysis will add to this literature.

2.2 Direct financial cost studies

The only economic studies related to bird and rodent damage in California are direct financial cost studies. In general, the applied use of direct financial cost studies are

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extensive, spanning nearly all areas of agricultural research. This literature covers impacts from pest species (birds, insects, rodents, large vertebrates, disease, and weeds), invasive species, changes in technology, genetic enhancement of crops, regulatory changes, and others. Three recent examples of studies specifically relating to pest species include Jones et al. (2005), Cummings et al. (2005), and Berge et al. (2007).

Direct financial cost studies related to pests in agriculture identify the cost of pest damage as the reduction in revenue an individual producer receives due to decreased crop yield. Often this cost is added to the producer's expenditures on pest control measures. These costs are estimated at the "average" producer level and then aggregated up to encompass all producers.

In this section, I will discuss two direct financial cost studies specific to bird and rodent damage to California (Cummings et al., 2005 and Berge et al., 2007) and one study by an Australian author related to weeds in grain crops (Jones et al., 2005). Although Jones et al. is not related to birds and/or rodents, I highlight this study because the author describes direct financial cost modeling methodically and in detail. I will start with Jones et al. to introduce the theory and then move to the other two studies as additional examples.

2.2.1 Jones et al. (2005)

Jones et al. (2005) estimated the annual financial cost of weeds in Australian annual winter crops as a function of the weed free yield, area of infestation, the presence of yield lost due to weed infestation, and the cost of weed control. The authors identified the total financial cost of pest weed species as the summation of the total value of revenue loss due to the decrease in yield and aggregate weed control expenditures. Twelve agroecological zones, 15 weed species and 7 types of crops were analyzed. The first four equations (eqs. 2.1 – 2.4) describe the calculation of the loss in revenue due to yield loss using current control methods. When damage occurs, producers use pest control measures to limit the amount of yield loss. This means that even with control measures, producers often still experience some remaining yield loss. Control measures often reduce but not completely eliminate damage. Current control measures for weeds include the use of herbicides and special cultivation techniques. The fifth equation (2.5) represents total expenditures on current control methods. The authors calculate the total financial cost of weed damage in Australian winter crops as the summation of the lost revenue due to lower yield and the control costs (summation of equations 2.3 – 2.5).

Growers of each crop were surveyed across each agroecological zone to identify yield loss due to weeds and weed control expenditures. For each crop, weed, and zone the yield loss caused by all 15 weed species (with each weed species having three possible densities) is represented by:

$$, \qquad (2.1)$$

where YL is the yield loss, A is the area of weed infestation, Y_0 is the weed-free yield for each crop in each zone, and D is the yield-loss coefficient. The yield loss coefficient is the percentage loss of yield caused by a particular density of weed. D is a proportional variable and is bounded by zero and one. Y_0D represents the loss in yield to a crop caused by a particular weed density. An increasing value of D represents greater yield

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damage due to higher weed densities. AY_0D is the total loss in yield for all areas of crop acreage affected by a particular density of weed. The subscripts are, $i = 1, \ldots, 7$ individual crops, $j = 1, \ldots, 15$ weed species, $k = 1, \ldots, 3$ weed densities, and $z = 1, \ldots, 12$ agroecological zones. This means for each of the 12 zones, the yield loss for a potential of 7 crops impacted by 3 densities of 15 individual weed species can be estimated. This allows the yield loss estimate (YL) to account for differences in crop planting and variations in weed distributions and densities across zones. A maximum of 1,260 disaggregated yield loss estimates can be calculated for Australia.

In each of the 12 zones (z), there are 7 crops (i) and each crop can be affected by a maximum of 3 densities (k) of 15 different weed species (j). The loss in revenue due to all possible densities of a weed species for each crop in each zone is calculated as:

, (2.2)

where RL is the revenue loss and P is the crop price. Multiplying the price of each crop in each zone by the yield loss caused by a particular weed to a crop in a zone represents the financial loss due to that weed infestation for each modeled crop, zone, and weed species. It is then possible to obtain the loss in revenue for each zone for each crop and weed and the total value of the revenue losses from weeds over all zones. The total value of revenue loss (TVL) is represented by:

, (2.3)

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where TVL is the sum of the revenue losses for each crop (TVL_i) and weed species (and density) (TVL_j) in all 12 zones. The calculated total value of revenue loss (TVL) is the total financial value of the yield loss directly resulting from lower crop yields due to weed damage.

In addition to yield loss due weed damage, the authors also estimated the price penalty. The price penalty is a decreased price (P) when the grain sold by the producer to the marketer is contaminated by weeds necessitating additional cleaning. The price penalty is a decreased price paid to the producer which results in additional revenue loss due to weed infestation. In each zone the total penalty from grain contamination is represented by:

(2.4)

where PP is the total price penalty, NF is the number of farms in each zone affected, pc is the proportion of farms penalized for weed contamination in crops, C is the average tonnage for each crop contaminated, PR is the average price reduction, and GC is the average grain-cleaning costs per farm for each crop. This is the additional loss in revenue for farms with contamination. The total financial loss due to decreased yield would be the sum of the TVL and PP (*eq. 2.3* + *eq. 2.4*).

The authors also identified weed control expenditures. The costs for each zone were determined as

, (2.5)

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where *HC* is the cost of herbicides (used to kill weeds), *NF* is the number of farms treated with herbicides, and *Pe*, *Po* and *Tr* are the average farm pre-emergent herbicide, post-emergent herbicide, and treatment costs.

The authors summed equations 2.3 through 2.5 to obtain their estimate of total costs of weed damage to winter crops in Australia. The authors estimated that the total weed control expenditure cost was 77.3 million (AU$) with the greatest expenditure in the southern and western regions. Their results indicate that the total direct financial cost associated with residual weed and grain contamination costs was 405.1million (AU$) with the majority of the costs arising from residual weeds in the field after control (AU$379.8 million).

The authors integrated the costs of decreased yield, the penalty if grain is contaminated with weeds, and the costs to control weeds across several crops and agricultural regions. There are multiple modeling techniques that are applicable to my research. For example, California has many different agricultural areas which grow a variety of crops. Additionally, price penalties exist in California when a producer's crop is downgraded at the packing house because of bird and rodent caused damage or decrease quality. In some cases, entire fields of crop are not purchased because of pesticide residue or bird or rodent fecal contamination.

I will not provide specific details of the equations used in the following two studies because their methodology is very similar to Jones et al. Instead, I will focus on describing the main points of each study and how the study contributes to theoretical aspects of my dissertation.

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2.2.2 *Cummings et al. (2005)*

A second paper I will highlight relates to bird damage to rice in 5 states. Cummings et al. (2005) estimated the annual financial cost of bird damage to rice as the summation of the aggregate value of lost yield, the lost government price support payments, and the expenditures on bird control in 2001 for Arkansas, California, Louisiana, Missouri, and Texas. Like Jones et al., the authors used a survey to obtain damage and control cost data. The authors surveyed individual rice producers in each state regarding damage to rice caused by blackbirds and expenditures on bird control. In this study, the total financial cost associated with damage was calculated as the aggregated value of lost yield (pounds of rice damaged multiplied by market price) plus the value of lost government payments (because the USDA price supports were based on actual yield) plus the producer's expenditure on blackbird management in dollars per acre. Unlike Jones et al., this study aggregates the modeled crop (rice) into one category for each modeled state.

The authors estimated that the production loss for the rice industry in Louisiana, Texas, Arkansas, California, and Missouri in 2001 was 235 million pounds of rice valued at $13.4 million. This would have represented approximately 1% of the total rice production for that year. The results indicate that the estimated cost for prevention of rice damage for the rice industry in Louisiana, Texas, Arkansas, California and Missouri in 2001 was $3.2 million. Also, inclusion of the USDA price support loss for the rice industry in these same states in 2001 is equivalent to $4.9 million. This is because USDA price supports are based on actual out of field yield which is affected when blackbird cause damage.

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One addition in modeling that Cummings et al. provide is the inclusion of lost government support payments because the producer markets fewer crops. Reduced producer revenue resulting from fewer government payments is applicable to crops that are associated with support programs (e.g., rice, corn, or soybean) but many crops are not eligible for government payments (e.g., grapes or almonds). For this study, the majority of the crops analyzed do not benefit from government payments.

2.2.3 Berge et al. (2007)

Berge et al. (2007) estimated the annual benefits and costs associated with the use of sonic broadcasters (which potentially deter birds) to limit bird damage in vineyards in the Carneros American Viticultural Area of California. Unlike Jones et al. and Cummings et al., this study estimated the benefits of control as the decrease in yield loss. The authors then compared this benefit to the cost of control which was estimated as the actual expenditure associated with bird control to identify if sonic broadcasters used to deter birds was cost efficient. Unlike Jones et al., and Cummings et al., the authors conducted field studies (as compared to interviews) on treated (with sonic broadcasters) and control (without sonic broadcasters but other pest control measures may have been used) study sites to identify the marginal decrease in damage resulting from the additional use of the new control measure. The decrease in damage was identified as the benefit of the control measure. The value of the benefits were measured on a per acre basis as the percentage decrease in damage (increase in yield) multiplied by the producer price for the particular variety of grapes. The cost of control for one acre using broadcasters was the sum of the component and construction costs for the broadcasters.

This methodological approach is somewhat different from either of the two previous studies. This study was interesting because the authors conduct a simple benefit-cost analysis of the use of a new pest control measure instead of calculating the total financial cost associated with bird and rodent damage. Berge et al. compares the difference between the higher and lower level of crop yield in the presence and absence of the sonic broadcaster (pest control). This is different because the previous two studies compare the hypothetical higher pest-free yield to the current yield. This additional method is applicable because, ideally, data would be complete enough (i.e., in the presence of damage with and without control measures and the absence of damage) to know the potential level of damage in all three potential scenarios. Data related to projecting the potential maximum level of damage caused by birds and rodents in the absence of pest control is nearly impossible to obtain because of the expense involved with these types of studies. Data related to the hypothetical yield in the absence of bird and rodent damage is more obtainable due to testing completed to identify crop viability and maximum crop production in various regions. Data related to the current level of crop yield with bird and rodent damage and pest control measures is fairly abundant. There are many studies that measure, either through interviews or field studies, the current level of yield loss and pest control expenditures.

Damage data were measured over two consecutive seasons. The first year was to evaluate the effect of treatments without broadcast calls and the second year was to determine the effect of broadcast calls. Results indicated that broadcast distress calls added to conventional methods significantly reduced damage compared with

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conventional control (5.7% vs. 13.0%). The authors noted that netting yielded the least damage (2.3%).

For my study, I do not have data identifying the maximum level of pest damage, so I have to compare the hypothetical level of crop yield in the absence of damage to the current level of damage using pest control measures similar to Jones et al. and Cummings et al.

2.2.4 Strengths and weaknesses of direct financial cost studies

Direct financial cost studies are useful for several reasons. This type of model is easy to understand, and it can be used in both ex ante and ex post evaluations (Daku, 2002). Since these studies generally measure only direct costs associated with damage, the results can be used as in an input-output (I-O) model to estimate indirect and induced impacts of damage (see Shwiff et al., 2009). Indirect and induced impacts are secondary impacts to the regional economy that arise from direct costs. For example, a direct cost is the loss in producer revenue caused by bird and rodent damage. The direct impacts are important to the economy as producers' expenditures support other industries, causing additional impacts. Producers purchase inputs such as seed, fertilizer, and harvesting equipment, and spend their income at local shops and restaurants, thereby generating revenue for suppliers, shop and restaurant owners. Inter-industry effects that occur as producers purchase necessary inputs are referred to as indirect economic impacts. For example, increased demand stimulates production from the industries supplying the producers, which in turn, increases the suppliers' demand for inputs into their own production processes. The direct and indirect impacts to the agricultural and other sectors

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result in a third kind of effect on the regional economy: induced economic impacts. Induced impacts occur as farm laborers, administrative support staff and managers spend their earned income and business profits within the regional economy, creating demands on the economy through daily personal consumption of goods and services from other sectors. Indirect and induced impacts are often referred to as secondary economic impacts. Any increase or decrease in growers' revenue and expenditures can be expected to cause increases or decreases in the region's secondary economic impacts. The magnitude of the secondary impacts depends in large part upon whether the growers' inputs are purchased from within the region and if the growers' employees spend their wages within the region.

I-O modeling can be used to estimate these additional impacts. An I-O model is a mathematical representation of a regional (city, county, state, etc.) economy that contains the linkages among economic sectors (e.g., agricultural, manufacturing and industrial). I-O modeling is an accepted methodology for estimating the secondary impacts in an economy based on the most current economic and demographic data available (BEA, 2008). The relationships among economic sectors in the I-O model, as well as the positive and negative attributes of this type of model, have been discussed extensively in the economic literature (Blair, 1995; Bon, 2000; Lahr and Dietzenbacher, 2001; Loomis and Helfand, 2001; McCann, 2001). Although I do not conduct an I-O analysis to complete this dissertation, several studies have used I-O models to estimate the total impact (direct, indirect and induced) of California agriculture to the state and/or county economies (Carter and Goldman, 1997; Hueth et al., 1998; Sumner et al., 2004; Shwiff et al., 2006), and Shwiff et al. (2009) used this model to specifically analyze the total impact of bird and rodent damage to California crops.

The direct financial costs studies reviewed can also be used in a more general benefit-cost analysis. The comparison of the effectiveness of various control options may be useful to agricultural producers (similar to the study completed by Berge et al.). To accomplish this, the loss in yield caused by pests without control measures would first be identified. Then, the efficacy of different control measures could be identified. Finally, the benefits of reduced yield damage could be compared to the costs of control.

These direct financial cost studies attempt to measure the economic impacts of bird and rodent damage. The problem is that damage, when conceptualized as an economic problem, is much more complicated and nuanced than just the aggregated price of damaged nuts, girdled trees, or contaminated lettuce. McInerney (1996) identified several basic critiques of direct financial cost studies used as measurers of economic cost. First, these financial costs are often not the cost of bird and rodents in crops, but are generally limited to the direct impact of damage (crop loss at the farm level) experienced in the production process. Second, quantities of crops damages are aggregated to state or national levels without regard to the integration of supply and demand elasticities and the impacts on market prices. This is the critique that a forest is not just the summation of the trees. Third, the presence of damage often means that producers incur additional costs on pest control and pest prevention to minimize production losses. These expenditures can be substantial and impact producers’ choices of resource use, arguably causing changes in marginal productivity of inputs. The availability of pest control measures changes the firm’s production function. Additionally, this type of analysis

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ignores potential price and quantity effects due to the changing pest damage or pest control options or entry and exit of firms that would arise in competitive industries. If an individual grower or small group of growers were the only growers in an industry to suffer damage, then summing the damage and pest control costs would give an accurate representation of economic costs. On the other hand, if damage occurs to many or most of the growers (as is generally the case), there will be changes in the quantity of crop produced and changes in the price of that crop in a given season as long as the price elasticity of demand is greater than zero. When there are price and quantity changes in a competitive industry, there will be impacts on the consumers and producers of the product in terms of changing consumer and producer surplus. By limiting economic research to direct financial cost studies, the importance of bird and rodent damage is obscured by financial measures.

2.3 Estimating Changes in Market Price and Quantity in the Presence of Damage using Equilibrium Displacement Models (EDM)

To partially address some of the above criticisms of direct financial cost studies, some authors estimate the economic impacts due to pest damage to agriculture through use of equilibrium displacement models. An EDM is a more sophisticated way to assess the economic impacts of pest damage or the benefits and costs of pest control measures. This modeling technique has been one of the most frequently used in agricultural economics. It applies a comparative static analysis to structural models of commodity markets to linearly approximate changes in prices and quantities due to exogenous shifts of the supply or demand curves resulting from changes in technology, expenditures,

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damage, income, government intervention, or other exogenous shocks in a partial equilibrium framework. Large shocks cannot be modeled because the estimated changes in price and quantity are unreliable because of the special assumption of linear supply and demand curves. In general, exogenous shocks are modeled as vertically parallel shifts in supply or demand curves. EDM is very versatile and can be used in multimarket analysis, international trade impacts, and simultaneous supply and demand shocks. Often researchers combine the results from the EDM with an economic surplus model to estimate changes in producer and consumer surpluses.

EDM differs from traditional comparative statics. For example, comparative statics uses calculus to indicate the direction of change in equilibrium price and quantity as the result of a change in exogenous variables allowing for general equilibrium effects to occur as long as the functional form of demand and supply can be obtained. Instead, with EDM, there is an application of comparative static analyses to general function models with a goal to focus on finite changes in exogenous variables and changes in exogenous and endogenous variables measured as elasticities (Piggott, 1992).

EDM originated with Muth in 1964 and has been used extensively to model exogenous demand and/or supply shocks in various agricultural markets. The use of EDM to model demand shocks is often completed to determine the effects of generic advertising or promotion (see Piggott et al. 1995, Wohlegenant, 1993b, 1995; Alston et al., 1995a; Kinnucan et al., 1997) or changes in government policy (see Acquaye et al., 2005). Modeled supply shocks include the effect of research and technology on agriculture (see Wohlegenant, 1993a; Alston et al., 1995b; Perrin,1997; Krishna and

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Qaim, 2008) or the effects of pests and pest control (see Choi et al., 2003; Hoddle et al., 2003; Jones et al., 2005; Alamo et al., 2007 detailed later in this chapter).

In sum, the general features of EDMs are: (1) a market situation is characterized by a set of general supply and demand functions in which no particular functional forms are assumed, (2) a change in the value of an exogenous variable causes a supply and/or a demand shock causing the affected curve to shift, and (3) the impacts of the shock are approximated by functions that are assumed linear, allowing the use of elasticities to estimate changes in market price and quantity (Piggott, 1992).

Although I have not found a study detailing the use of an EDM to estimate the impacts of bird and/or rodent damage, I will discuss later in this section four studies that use equilibrium displacement modeling to estimate changes in market price and quantity (and consumer and producer surpluses) when pest weed, insect or disease damage are present (Choi et al., 2003; Hoddle et al., 2003; Jones et al., 2005; Alamo et al., 2007).

2.3.1 Characteristics of Equilibrium Displacement Models

The goal of Muth's 1964 study was to provide an analysis to derive the elasticity of an industry supply schedule as well as the coefficients of other variables appeared in the supply schedule and other factor demand schedules. Muth focused on deriving the industry factor demand schedules and in obtaining the supply schedule for the industry applied to land economics. Although Muth applied this model to the field of urban land economics, it is applicable to virtually all competitive markets, agricultural or otherwise. The major use for EDM is to estimate changes in equilibrium prices and quantities due to

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very small exogenous shocks to supply and/or demand or small changes in technology in agricultural markets.

In his original model, Muth assumes that the firms in the modeled industry are competitive price takers in both product and factor markets and produce a single, homogenous product. The industry output is *Q* and it depends only upon the inputs of the two productive factors *A* and *B* and certain parameters describing the existing state of technology. The production function is assumed to be homogenous to degree one. These firms have identical production functions and the two factors are unspecialized to any firm but may be specialized to the industry. The price paid to each productive factor is equal to the value of its marginal product. Finally, there are no external (or spillover) technological effects.

Under these assumptions, all firms have identical production functions. Depending on the limitations of the capacity for factors of production or technological conditions, growth in the industry may come from expansion of current firms' output or the entry of new firms.

From Muth, the standard set of structural equations in an EDM is:

$$Q = f(p, \text{with all exogenous variables, such as income, given}), \tag{2.6}$$

$$Q = Q(A, B), \tag{2.7}$$

$$p_A = pQ_A, \tag{2.8}$$

$$p_B = pQ_B, \tag{2.9}$$

$$A = g(p_A), \tag{2.10}$$

$$B = h(p_B). \tag{2.11}$$

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where Q is industry output, A and B are the two factors used by industry, p is the price per unit for the final product, and p_A and p_B are factor prices. Equation 2.6 is the demand schedule for the industry's output. Equation 2.7 can be considered the industry production function and it shows that industry output depends only on the amount of the two factors. Equations 2.8 and 2.9 express that each factor is paid the value of its marginal product with Q_A and Q_B being the marginal product of inputs A and B. Equation 2.10 and 2.11 are the industry factor supply schedules.

A displacement from the original equilibrium can occur when any of the above equations (2.6 – 2.11) shifts due to the effects of a changing exogenous variable. Possible modeled shifts include an increase in demand due to higher incomes, a decrease in supply due to yield loss caused by pests, an increase in input prices, or a change in technology changing the relative marginal productivities of factor inputs. All structural equations are converted into linear logarithmic transformations and shifts of demand and supply curves are evaluated in the direction of the price axis (as opposed to the quantity axis). With this model, shifts of demand, supply, or prices of inputs can be modeled.

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Changes in Supply

A shift in supply can be modeled (figure 2.2).

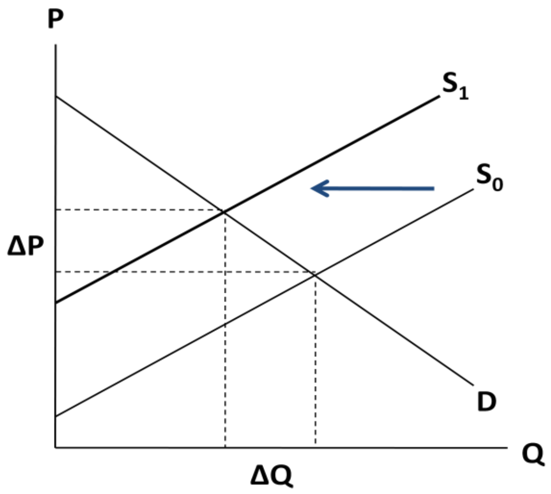

Figure 2.2: A decrease in supply is an upward shift to the left of the supply curve.

Along a given linear demand schedule (equation 2.6), the relative change in *Q* (which is equal to the logarithmic differential of *Q* or *dlnQ*) resulting from a decrease (or increase) in supply, is equal to the elasticity of the industry demand schedule (η) multiplied by the relative change in price (*dlnp*) (i.e., $dlnQ = \eta dlnp$). Therefore, Equation 2.6 can be transformed into its logarithmic differential format as:

$$\alpha = -dlnQ + dlnp, \tag{2.6'}$$

where α is the relative change in price for any given change in quantity on the demand schedule. This allows the use of elasticities to estimate the proportionate changes in *P* and *Q* due to a supply shock.

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Changes in Input Supplies

Similarly, a shift in the supplies of inputs can be modeled. Using the same logic as in the previous paragraph shifts in the supply factors (equations 2.10 and 2.11) can be rewritten as:

— , (2.10’)

— , (2.11’)

where β and γ stand for shifts in the supply of factors A and B, and e_A and e_B are the elasticities of these factor supply. A negative shift parameter is an increase in the supply of the factor because the shifts are measured in the direction of the price axis.

As long as the production technology equation (eq. 2.7) is unchanging and homogenous of degree 1, then:

or, — —

or, . (2.12)

The coefficient of *dlnA* and *dlnB* in 2.12 are:

– — , (2.13)

– — , (2.14)

where $Q_A = MP_A$ and $Q_B = MP_B$ are the marginal products of these factors for all firms, $p_A = pQ_A$ and $p_B = pQ_B$, k_A and k_B are shares of factor payments in the industry. A firm

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will hire factors until the value of the marginal product of each factor is equal to the price of that factor. If expansion in Q comes from increases in output along horizontal segments of their average cost curves from existing firms (an increase in demand without firm entry) or from firms entering the industry at a minimum cost average firm output (an increase in demand with firm entry), then the incremental change in the output of a firm is the marginal product of each factor multiplied by the change in the amount used of each factor summed over both factors.

Changes in Technology

Shifts in equations 2.7 through 2.9 result from technological changes in the production process. Muth separates technological changes into a neutral technological change and a “*B*-saving” change. A neutral technological change is one that increases the marginal physical products of both factors proportionally. This type of technological change simply renumbers the isoquants of a firm’s production function. A *B*-saving technological change is one which increases the marginal physical product of *A* (likely capital) relative to that of *B*, but which leaves total output unchanged for the inputs of the two factors which were used prior to the change. A To illustrate, since equation 2.7 is homogenous to degree one, it can be written as:

$$Q = AQ_A + BQ_B, \tag{2.15}$$

And, holding inputs *A* and *B* constant:

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$$dlnQ = k_A dlnQ_A + k_B dlnQ_B. \tag{2.16}$$

If there is a neutral technological change where the marginal physical products of both factors increase by the same relative amount (δ), then:

$$dlnQ = (k_A + k_B)\delta = \delta. \tag{2.17}$$

Which means that the change in output resulting from the technology is equal to the scalar (δ) since $k_A + k_B = 1$. The input mix would not change because A and B are used in the same proportion as before. The only change is that *A's* and *B's* productivities have increased by the same relative amount leading to output gain, regardless of the relative proportions used in production prior to the technological change.

On the other hand, if there is a B-saving technological change which increases A's marginal physical product by an amount in relative terms, then:

$$dlnQ = k_A \quad + k_B dlnQ_B = 0,$$

or,

$$— \tag{2.18}$$

This means that the technological change only increased one factor's productivity. This leads to the $MP_A > MP_B$. If there are no changes in factor prices, for optimization the firm would increase the use of A and decrease the use of B to maintain $P_B/Q_B = P_A/Q_A$. Equation 2.18 represents the change in Q_B when there is B-saving technology. The

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change in Q_B is equal to the ratio of the values of the marginal products multiplied by the amount of the technological change.

Equation 2.7 can be written in the differential form:

$$dlnQ - k_A dlnA - k_B dlnB = \delta \qquad (2.7')$$

To transform equations 2.8 and 2.9, given the level of technology, for example, the relative change in p_A is equal to the relative change in the price of the output plus the relative change in the marginal physical product of *A*. The relative change in the marginal physical product of A is:

—— —— . (2.19)

where Q_{AA} is the change in the marginal productivity of *A* when *A* changes ($\delta Q_A/\delta A$) and Q_{AB} is the change in the marginal productivity of *A* when more *B* is available ($\delta Q_A/\delta B$). The change in the marginal physical product of *A* ($dlnQ_A$) is the summation of these changes. Since each firm operates with its production function homogenous of degree one in *A* and *B*,

– and ——, (2.20)

where σ is the elasticity of factor substitution. Substitute 2.20 into 2.19, equation 2.19 becomes:

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$$—— \qquad —— \qquad — \qquad — \qquad . \qquad (2.21)$$

Adding in the shift in 2.8 which results from a change in technology,

$$— \qquad — \qquad , \qquad (2.8’)$$

And the same for equation 2.9:

$$— \qquad — \qquad — \; . \qquad (2.9’)$$

The system of equations 2.7’ through 2.11’ can be solved for all the endogenous variables, obtaining reduced form equations for each of them in terms of the shifts in the functions and parameters η (elasticity of the industry demand), σ (the elasticity of factor substitution of a firm’s production function), e_A *and* e_B,(elasticities of factor supply), and k_A and k_B (proportions of factor payments).

This model is simple yet very powerful. The log-linear transformation of the structural equations allows the use of elasticities to estimate the proportionate changes in P and Q due to an exogenous shocks such as shocks to supply (i.e. pest damage), demand (i.e. increase in generic advertising), changes in the quantity of a factor of production (i.e. pest control expenditures), or changes in technology. The effect of these shocks on the factors (i.e. capital enhancing technology) can be modeled. The most applicable portion of this model to my research is the use of an EDM to identify of the change in price due

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to an exogenous supply shock. Damage by birds and rodents is a supply shock which decreases crop yield causing an increase in price. The estimated changes in price and quantity can be used to estimate welfare impacts to producers and consumers.

2.4 Estimating the Welfare Effects using an Economic Surplus Analysis

A common approach for analyzing the welfare effects of pest damage is to use an economic surplus analysis in a partial equilibrium framework preferred to econometric analyses especially when there are data limitations. The majority of pest damage data are based on interviews with producers, pest control advisors, agricultural commissioners, industry experts or, at best, one-year field studies. The completion of multi-year studies to collect data relating to damage or the effects of pest control covering a wide variety of crops, pest pressures, and environmental factors are necessary for a solid econometric analysis. Unfortunately, these types of studies are often not completed due to the very high costs associated with conducting these studies.

A general approach to estimating welfare changes in a partial equilibrium framework was discussed extensively by Harberger (1971). Harberger offered three postulates to establish the legitimacy in using consumer and/or producer surplus for applied welfare economics. These postulate are that: (1) the competitive demand price for a given unit measures the value of that unit to the demander, (2) the competitive supply price for a given unit measured the value of that unit to the supplier, and (3) that when evaluating the net benefits or costs of a given action, the costs and benefits accruing to each member of the relevant group should be added without regard to the individual(s) to whom they accrue. Net changes in consumer welfare can be measured using

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Marshallian consumer surplus. The area beneath the supply curve is a measure of total costs, so changes in the net welfare of producers can be measured using producer surplus which is the area under the price line and above the supply curve.

In figure 2.3, the linear supply curve for a crop without any pest damage is S_0S_0' and the linear demand curve is represented as *DD'*. The original price is P_0 and the quantity demanded and supplied is Q_0. Using the above postulates, the total consumer surplus from consumption of the crop is equal to the triangular area DbP_0 (the area under the demand curve subtracting the cost of the consumption). The total producer surplus is equal to the triangular area P_0bS_0 (total revenue less total costs of production). Total surplus is equal to the sum of consumer and producer surpluses (area DbS_0). Changes in consumer, producer, and total economic surplus are measured as changes in these areas.

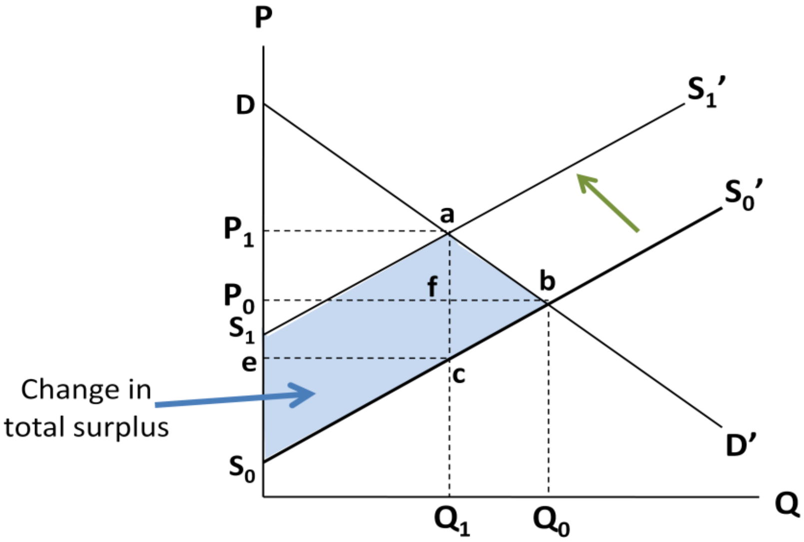

Figure 2.3: Measuring producer, consumer, and total surpluses. When there is a decrease in supply, total surplus falls.

Pest damage results in the supply curve shifting leftward to S_1S_1' because less crop is marketed given available inputs (figure 2.3) leading to a new equilibrium price and quantity of P_1 and Q_1. The change in total surplus associated with this decrease in supply is equal to the area beneath the demand curve and between the two supply curves (ΔTS = area S_1abS_0). This area is the sum of two parts: (1) the loss in surplus associated with decreased production and consumption represented by the triangular area *abc* which is the decrease in the total value of consumption (area Q_0baQ_1) less the cost of that production (area Q_0bcQ_1), and (2) the cost increase on the remaining quantity represented by the area between the two supply curves to the left of Q_1 (area S_1acS_0). Alternatively, the change in total surplus can be measured as the sum of the changes in consumer (ΔCS = area DbP_0 – area DaP_1 = area P_1abP_0) and producer surpluses (ΔPS = area P_0bS_0 – area P_1aS_1). Given the special assumption of a linear supply and demand curves and a parallel shift in S where the vertical distance between the two curves is constant, area P_1aS_1 = area ecS_0. This implies that the ΔPS = area P_0bS_0 – area ecS_0, and the net loss to producers can be measured as the loss due to the decreased increment of production (area *fbc*) plus the loss of benefit of the remaining production quantity (area P_0fce). Identified this way, this change in total surplus is the sum of the change in producer surplus (P_0bce) and consumer surplus (P_1abP_0).

Consumers necessarily lose because they consume fewer goods at a higher price. The net welfare effect on producers may be positive or negative depending on the supply and demand elasticities. This is because of two effects working in opposite directions. As producers sell fewer crops, they will sell them at higher prices, and total revenue decreases (increases) if demand is elastic (inelastic).

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2.4.1 Using results from an EDM to estimate changes in producer, consumer, and total surpluses

Equilibrium displacement models are useful in estimating changes in producer, consumer, and total surpluses because the EDM identifies the estimated change in equilibrium prices and quantities resulting from an exogenous shock. These changes in *P* and *Q* can then be used in an economic surplus analysis to estimate the resulting changes in economic welfare caused by the shock. The following section details the link between EDMs and the measurement of consumer and producer surplus.

Alston et al. (1995b) demonstrated techniques to estimate changes in economic welfare using an EDM and economic surplus analysis. Although the focus of Alston et al.'s work was to estimate changes in the economic effects of research-induced technological changes, the techniques presented are applicable to economic effects of bird and rodent damage.

In the basic combined EDM and economic surplus analysis used to estimate changes in consumer, producer, and total surpluses f or a single market in a closed economy, four simplifying assumptions are made. First, supply and demand curves are assumed to be linear and shift in a parallel manner. Second, a static (single-period) model is used and dynamic issues are ignored. Third, competitive market clearing is imposed. Fourth, Harberger's (1971) three postulated are assumed so standard surplus measures can be used to estimate changes in economic welfare.

With these assumptions, the changes in welfare associated with, for example, a decrease in supply, are shown in the following (figure 2.3). *DD'* is the demand for a homogenous product, $S_0 S_0'$ represents the supply of the product in the initial equilibrium.

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The initial equilibrium price and quantity are P_0 and Q_0. A supply shift caused by an exogenous shock such as a decrease in crop yield due to bird and rodent damage or an increase in input costs, causes supply to shift to S_1 S_1'. After the supply shift, equilibrium price increases to P_1 and equilibrium quantity decreases to Q_1. In this model, all curves and producer and consumer surplus measures are defined as flows per unit time, typically annually.

Alston et al. (1995b) provides the algebraic interpretation of the changes in surpluses as follows:

$$\Delta CS = P_0Q_0Z(1 + 0.5Z\eta) \tag{2.22}$$

$$\Delta PS = P_0Q_0(K-Z)(1 + 0.5Z\eta) \tag{2.23}$$

$$\Delta TS = \Delta CS + \Delta PS = P_0Q_0K(1 + 0.5Z\eta) \tag{2.24}$$

where the change in price, relative to its initial (P_0) value, due to the supply shift is:

$$\frac{}{} \tag{2.25}$$

and where K is the vertical shift of the supply function expressed as a proportion of the initial price (which is equivalent to $a – c$ or $P_1 – e$ in figure 2.4), η is the absolute value of the elasticity of demand, and ε is the elasticity of supply.

The use of an EDM makes the estimation of changes in consumer and producer surpluses easier. This is because the EDM identifies the estimated change in equilibrium prices resulting from the modeled exogenous shock. To parameterize the EDM model,

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P_0, Q_0, η, ε are identified. The EDM predicts, based on these parameters, the change in P and Q. The new P is then compared to P_0 to derive K. Once K is identified, the changes in consumer and producer surpluses can be estimated. Thus, the results of the EDM provide K and a seamless transition between EDM and economic surplus analysis.

For my study, the initial California crop prices and quantities are readily available (see Appendix C). The three more difficult variables to parameterize include the supply shock (percent decrease in quantity due to bird and rodent damage and control costs) and the price elasticities of supply and demand. I will argue in chapter 4 that my data is complete enough to parameterize this model. I have completed an extensive literature review as well as spoke with agricultural experts to identify the value of the supply shock for each modeled crop (see Appendices A and B). Elasticities have also been empirically estimated for most of the crops modeled. Agriculture is extensively studied in economics and elasticities are a common topic to study. Additionally, I am continuing to search for additional elasticity estimates in government databases and literature.

2.4.2 Assessing the Critical Variables and Assumptions of Equilibrium Displacement Models and Economic Surplus Analysis

In order to use these economic analyses, critical variables have to be estimated and assumptions are made which can alter the outcome of the analyses. Key variables and assumptions include the estimated values of price elasticities of supply and demand, the functional form of supply and demand and the nature of the shift in supply (Alston et al,. 1995b).

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The estimates of the elasticities of supply and demand are important because of their influence on absolute size of the changes in producer and consumer surpluses. The measures of producer and consumer surpluses are areas and the size of each area is impacted by the estimated values of price elasticity of supply and demand. For a given decrease in supply, the more elastic demand is, the larger the deadweight loss triangle (abc > a'bc' in Figure 2.4). Similarly, for a given decrease in supply, the more elastic the supply curve is, the greater the deadweight loss (abc > a'bc' in Figure 2.5).

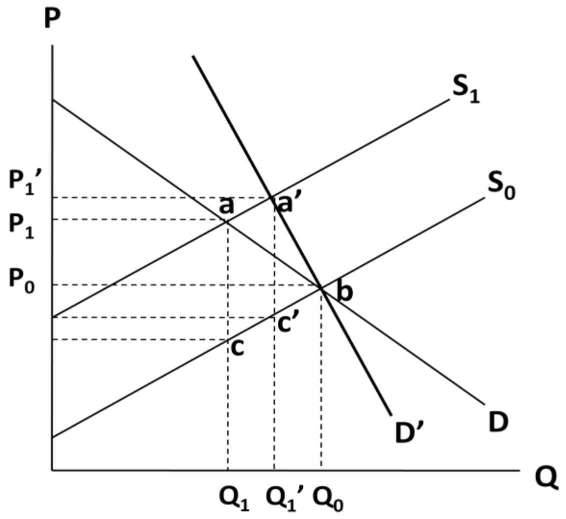

Figure 2.4: Measuring deadweight loss with different demand elasticities. Curve D is relatively more elastic than curve D'. With the same decrease in supply, greater deadweight loss exists with curve D (area abc > area a'b'c').

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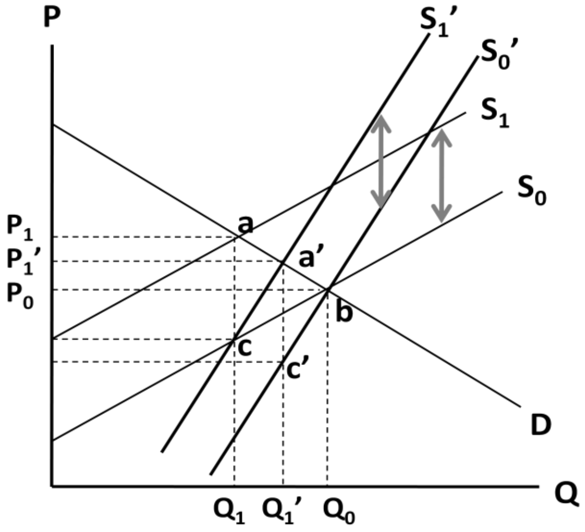

Figure 2.5: Measuring deadweight loss with different supply elasticities. Curves S_0 and S_1 are relatively more elastic than curves S_0' and S_1'. With the same decrease in supply, greater deadweight loss exists with curves S_0 and S_1 (area abc > area a'b'c').

Again, following Alston et al., mathematically, for a shift from S_0S_0' to S_1S_1' (i.e. a 100K percent shift up in S), the area of the rectangle is equal to

$$KP_1Q_1, \tag{2.26}$$

and the area of the triangle is equal to

$$\frac{1}{2} K^2P_1Q_1\text{——}. \tag{2.27}$$

This means the area of the triangle is equal to $\frac{1}{2} K\varepsilon\eta/(\varepsilon+\eta)$ percent of the rectangle. When the supply and demand elasticities are unit elastic or inelastic (i.e., equal to one or less), the triangle is equal to 25K percent (or less) of the rectangle.

Elasticity estimates influence the distributional effect of changes in consumer and producer surplus. A decrease in supply unambiguously causes a decrease in consumer surplus, the more elastic demand is, the greater the loss to consumers. Additionally, the more inelastic demand is relative to supply, the greater the possibility that producers may gain. The figures above (figures 2.4 and 2.5) illustrate the effect on consumer and producer surplus when there are variable supply and demand elasticities.

2.4.3 Strengths and Weaknesses of Equilibrium Displacement Modeling

Piggot (1992) advocated the use of EDMs and suggested that this type of modeling, which applies comparative static analysis to general function models, has several strengths. Its main strength is that it allows qualitative assessments to be made of the impact on endogenous variables of small changes in exogenous variables. Additionally, this technique is useful in revealing how cross-commodity relationships (substitutes or complements in consumption or factor usage in production) or horizontal integration (such as cooperatives) influence the outcomes from changes in exogenous variables.

EDM is also a powerful analytical procedure in that the modeling technique allows quantitative assessment of the effects on endogenous variables caused by relatively small changes (<10%) in exogenous variables (with the assumption of linear supply and demand curves) in which resources or time limits the possibility of econometric modeling. Parameter values in an EDM (i.e. elasticities and exogenous shocks) are often based on previous econometric work, economic theory, intuition, or a combination of those three. Parameters for variables that have not been econometrically estimated are generally presented in the model as a range (i.e. = 0.2, 0.4, 0.6) and/or a sensitivity analysis is conducted. This type of modeling is relevant in the case of

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developing countries where the data for econometric modeling may be either unavailable or not believed. This is also applicable to the analysis of bird and rodent damage. Obtaining accurate field estimates of yield loss or pest control efficacy over time is extremely expensive. Estimates based on grower surveys are less expensive but these surveys have other associated biases.

A final strength of EDM is that changes in two or more exogenous variables can be modeled at once. This is applicable to analyses of the effectiveness of pest control measures. When evaluating expenditures on pest control measures there are two exogenous variables changing; first is an increase in grower costs due to increased factor costs (pest control expenditures), and second, an increase in yield due to the effects of pest control.

The main weakness of EDM is that it uses a linear approximation to estimate the impacts of finite exogenous shocks. Supporters suggest that little would be lost if the functional form was assumed to be linear. Piggott (1992) argues that EDM provides a first-order approximation of the shock irrespective of the true underlying functional form. Another criticism is that since this is a type of comparative static analysis, the path of adjustment is ignored. A potential solution is through repeated applications of the modeling using different lengths of run. Modeling the differing elasticities present in the short run compared to the long run could shed light on the paths of adjustment.

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2.5 Applications of Equilibrium Displacement Modeling and Economic Surplus Modeling on the Impacts of Disease, Weed, or Insect Pests in Agriculture

Although both EDM and economic welfare theory are well established and many studies exist that use both these models, only a few studies use these models to examine the impacts of pests (e.g., disease, insects, weeds, birds and rodents) or pest control in agriculture. All four studies use EDM and economic surplus analysis to estimate changes in economic surplus due to pests or pest control. Each of these studies follows the model developed by Muth (1964) for a shift in supply, none models a shift in demand (like the focus of much of Alston's work) and none derives factor demand schedules. The following four studies highlight important theoretical and methodological aspects of EDM and an economic surplus model relating to pest damage and pest control. In this section, the theoretical models and strengths and weaknesses of each study will be discussed. First, Choi et al. (2003) examined the economic consequences of the introduction of rice blast disease (an exotic pest) to California. Second, Alamo et al. (2007) explored the economic impact and trade implications of the introduction of black sigatoka (a disease that affects banana and plantain trees) into Puerto Rico. Third, Hoddle et al. (2003) studied the impact of insect damage on Hass avocados in California. Fourth, Jones et al. (2005) analyzed the impact of weeds on Australian winter crops.

2.5.1 Choi et al., 2003

Choi et al. measured the annual effects of the introduction of an exotic disease, (rice blast) on rice price, quantity, producer revenue and changes in economic welfare to producers and consumers in California. Rice blast is a fungus that reduces yield per acre

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and lowers milling yield of paddy rice. An EDM was used to estimate the changes in price, quantity, acreage, and producer revenue caused by blast in the presence and absence of control measures compared to a disease free equilibrium. Changes in producer and consumer surpluses were then estimated.

The following log-linear EDM was used:

$$dlnY = \delta \tag{2.28}$$

$$dlnL = \varepsilon(dlnP - dlnC + dlnY) \tag{2.29}$$

$$dlnS = \varepsilon dlnP - \varepsilon dlnC + \delta(1 + \varepsilon) \tag{2.30}$$

$$dlnD = - \eta dlnP \tag{2.31}$$

$$dlnS = dlnD \tag{2.32}$$

The change in yield per acre (*Y*) is represented by equation 2.28, where δ denotes the percentage of change in the milled rice-adjusted paddy yield per acre. Equation 2.29 represented planted area (*L*) as a function of price (*P*) and production costs (*C*), where ε is the price elasticity of area planted. I think that equation 2.29 is incorrectly specified because the inclusion of *dlnY* double counts the effects of blast damage. The effects of blast damage are reflected in both *dlnP* and *dlnC* as decreases in rice price and costs, respectively. The authors use the same ε in equation 2.29 to modify *dlnP* and *dlnC*. I think this is inappropriate because an increase in price should have the same effect on producer decision making as an increase in costs. When both price decreases and cost increases happen simultaneously, as in the case of blast infection and control, there is an additive impact on quantity of acres grown of rice. By summing the proportional changes in price and costs, the authors capture this additive effect. The authors note that

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the elasticity of area with respect to marginal cost per acre is the negative value of ε under constant returns to scale.

The total change in supply (*dlnS*) represents an additive effect. The total change in supply is represented by equation 2.30 and it is the sum of the percent changes in acreage and yield. In other words, it is the summation of the loss in acreage plus the loss in yield in the remaining acres in production. Equation 2.31 represents the market demand (*D*) as a function of price (P), where η is the absolute value of price elasticity of demand. The market clearing condition is equation 2.32.

The authors model interaction between acreage and yield. This is good because acreage is expected to change when yield changes. If the marginal revenue gained from an additional acre is greater than the marginal costs of production, that acre will be produced. When there is a rice blast infection, yield decreases and costs increase which leads to an increase in the marginal cost of producing an acre. It is reasonable that some acres would be taken out of production.

The authors completed two simulations. The first simulation is solved for the exogenous shock of the presence of blast acts in equation 2.28. The second simulation is solved for the situation when blast control is undertaken. The solved equilibrium system gives formulas for changes in price, acreage, equilibrium quantity, and revenue as follows:

$$\rule{2em}{0.4pt} \tag{2.33}$$

$$\rule{2em}{0.4pt} \tag{2.34}$$

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$$\overline{} \qquad (2.35)$$

$$\overline{} \qquad (2.36)$$

where *dnlP* is the percentage change in price, *dnlL* is the percentage change in acreage planted, *dnlQ* is the percentage change in equilibrium quantity, and *dln(PQ)* is the percentage change in total producer revenue. The authors then approximated the changes in producer and consumer surpluses following Alston and Larson (1993) which is similar to Alston et al. (1995b) except the changes in producer and consumer surpluses are calculated as the ratio to the industry revenue as:

$$\Delta PS = (1 + dlnP)(1 + dlnQ)(K - Z)(1 + 0.5Z\eta) \text{ and} \qquad (2.37)$$

$$\Delta CS = (1 + dlnP)(1 + dlnQ)Z(1 + 0.5Z\eta) \qquad (2.38)$$

where

$$\overline{}\ , \text{ and} \qquad (2.39)$$

$$. \qquad (2.40)$$

Three sets of variables had to be parameterized; damage caused by blast, control costs and efficacy, and elasticities. The damage variable (δ) was the summation of change in yield due to direct yield reduction and the decreased milling quality due to the blast. Rice blast affects some regions and types of rice more than others. For example, some acreage has experienced 30-40% loss while others have had only traces of the disease. Therefore the authors used aggregate, industry-wide estimates of 5%, 10%, and

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15% decrease in yield based on information provided by the California Rice Association, other "agricultural specialists," and a field study of blast infected and control study plots.

The control efficacy parameter was the summation of the increase in control costs and the decrease in yield loss. Control cost and control efficacy parameters were obtained from industry estimates of fungicide application costs and biological data resulting from a field study estimates on fungicide efficacy. Again, the authors used a range of cost and control efficacy parameters (e.g., a 5% increase in costs caused an 80% reduction in yield loss and a 10% increase in costs caused a 90% reduction in yield loss).

Price elasticity of supply data came from several published studies and was estimated as a range of between 0.5 and 1.0. The authors assumed that the price elasticity of rice yield is relatively low over the ranges considered. The authors note that the overall national and international demand for rice is inelastic (around -0.2), but they assert the demand curve facing California rice producers is much more elastic than this. Thus, price elasticity of demand data was a range that was based on national and international estimates of elasticity (2.0, 4.0, or 6.0). This was done to reflect the "small nature" of California share in the domestic (about 20%; IRRI, 2010), and international markets (less than 1% ; CDFA, 2009) as well as the impact of Japan's very inelastic demand due to the WTO's strict import quotas (Sumner and Lee, 2000). This makes sense because price elasticity of demand will be greater if there are many close substitutes available (Varian, 1999). This is the case for California rice as evidenced by the relatively low share of domestic and international production produced by California rice producers. This means that those who consume rice have many other producers

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(both domestic and international) to choose from leading to a more elastic demand for California rice.

Based on these estimated parameters and initial prices and quantities, the effect that rice blast causes compared to the initial equilibrium without blast is that price increased 1.2-10%, acreage decreased 1.0-10.7%, quantity decreased 6.0-25.7%, and industry revenue decreased 3.0-21.4%. Additionally, the ratio of producer and consumer surpluses to the total industry revenue fell. Producer surplus fell 5.7-17.4% and consumer surplus fell 0.5-7.9% depending on values of estimated parameters.

There are several strengths in this paper. For example, the authors were comprehensive in estimating yield loss as the sum of direct loss yield per acre and the loss of milling quantity. Yield loss per acre estimates were obtained from the California Rice Association and other agricultural specialists. Reduction in milling quantity was obtained through a previously published field study. A second strength is that the authors used a range in the damage, control, and elasticity parameters. Utilizing a range for these parameters acknowledges the uncertainty in each of these variables. Ranges show how sensitive each parameter is to the model as a whole. A final strength is that the authors integrated changes in acreage into the model. This allows for increases in quantity to come from increases in acreage as well as decreases in damage. Although the authors did not estimate how government payments impacted the economic variables, the structure of government payments for rice is that they are not affected directly by market price or quantity of rice produced in California (Sumner and Lee, 2000). This means that government payments are unaffected by blast.

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One weakness is that the authors do not compare the gains or losses in producer surplus to producers affected versus those not affected by the disease. Arguably, since blast only affects 50% of the acreage planted at the time of the study, those producers without blast will enjoy gains in producer surplus resulting from higher rice prices. Another weakness is that elasticity estimates of demand for California rice were unavailable so the authors estimated a range of elasticities based on national and international estimates. The authors correctly assumed that demand for California rice would be much more elastic as compared to rice in general. This is due to the relatively small quantity of rice produced in California as a percentage of the whole rice market in the world. To address this issue of a lack of empirical estimated, the authors should have based their parameter on elasticity estimated from rice grown in nearby counties, states, or countries with similar growing practices to identify this parameter.

2.5.2 Alamo et al., 2007

This study estimates the potential impacts of the introduction of black sigatoka (a disease affecting plantains and bananas) into Puerto Rico. This study is structurally nearly identical to that of Choi et al. but two key differences exist. First, the authors compare the disease free state to a diseased state with control (figure 2.9). Second, international trade is modeled in the presence of disease and disease control (figure 2.10).

The authors use an EDM (following Choi et al., 2003) and an economic surplus model (following Alston et al., 1995b) to estimate changes in price, quantity, and consumer, producer, and total surpluses in two scenarios. Both scenarios assume that there is an introduction of the disease to a disease-free island, control measures were

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taken, and the government subsidized the control efforts. The difference between the two scenarios is that one assumes autarky conditions, and the other considers free trade conditions.

In an autarky situation, all plantains and bananas were supplied domestically and imports were strictly prohibited except when there are hurricanes that destroy the domestic crop. The disease was recently introduced to the island, presumably spread through the presence of disease on people or windborne spread. The government of Puerto Rico provides support to combat the disease through local quarantines and chemical and cultural treatments.

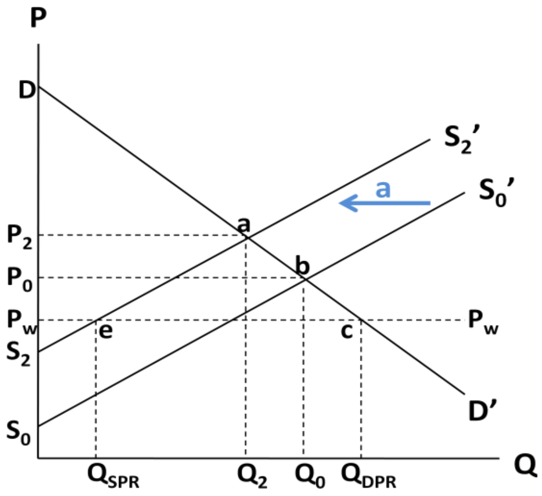

Figure 2.6: Supply effects of black sigatoka infestation and disease control costs where (a) represents the subsidized production cost increase due to expenditures on disease control and the loss in yield and fruit weight due to residual disease damage.

Graphically, the disease free autarky equilibrium would be at point *b* (figure 2.6). Consumer surplus would equal DbP_0 and producer surplus would equal P_0bS_0. If disease was introduced in an autarky situation, the equilibrium would be at point *a*. Consumer surplus would equal DaP_2 and producer surplus would equal P_2aS_2. If disease was

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introduced in a gree trade situation with world price less than autarky price ($P_W < P_0$), the quantity Puerto Rican consumers would demand is Q_{DPR}, the quantity Puerto Rican growers would produce would be Q_{SPR}, and imports would equal $Q_{DPR} – Q_{SPR}$. Consumer surplus would equal DcP_w and producer surplus would equal P_weS_2. The authors first evaluate the change from *b* to *a* and then the change from *a* to *c*.

The structural equations are as follows:

$$dlnY = \delta \tag{2.41}$$

$$dlnA = \varepsilon dlnP - \varepsilon dlnC \tag{2.42}$$

$$dlnS = \varepsilon dlnP - \varepsilon dlnC + \delta \tag{2.43}$$

$$dlnD = - \eta dlnP \tag{2.44}$$

$$dlnS = dlnD. \tag{2.45}$$

The change in yield per acre (*Y*) is represented by equation 2.41, where δ denotes the percentage of change in the banana or plantain yield per acre. Equation 2.42 denotes planted area (*A*) as a function of price (*P*) and production costs (*C*), where *ε* is the price elasticity of area planted. Equation 2.43 is the total change in supply resulting from decreased acreage and decreased yield on remaining acreage. Equation 2.44 represents the market demand (*D*) as a function of price (*P*), where *η* is the absolute value of price elasticity of demand. The market clearing condition is equation 2.45.

One key difference between Alamo et al. and Choi et al. (2003) is that acreage in Alamo et al. (2007) (“land” in Choi et al.) is only a function of $\varepsilon dlnP$ and $\varepsilon dlnC$. This difference is reflected in comparing equations 2.28-2.32 to 2.41-2.45. Choi includes δ in

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the estimation of the change in land due to pest damage. I think that Alamo et al. is more correct to exclude δ in this estimation. Excluding δ avoids the issue of double counting the impacts that cause the decrease in acreage. The decrease in quantity that arises from acres that go out of production is the entire production (yield) of those acres. By adding an extra δ, the decrease in quantity caused by a decrease in yield due to pest damage is included in the decrease in acreage. You cannot count the decreased production from the acres that go out of production and the decreased yield from those acres as decreases in the total production quantities.

The reduced equations are as follows:

(2.46)

(2.47)

(2.48)

(2.49)

Important variables were parameterized using a variety of data sources and techniques. Data related to damage (percent change in yield and acreage) used in this study were based on the result of a 2005 survey of banana and plantain growers conducted by the University of Puerto Rico Extension Services and interviews with industry experts and agricultural extension agents. Initial crop price, yield and acreage data were based on the three year average (2001-2003) values. Since there was no free trade at the time of the study, world price was estimated based on grower (farmgate) prices inclusive of transportation, insurance and inspection costs and normal profits from a nearby country (Ecuador). The elasticity parameters (ε and η) were based on typical estimates of elasticity for these crops with some modifications based on the Puerto Rican producer and consumer characteristics. The authors found one study that estimated the acreage elasticity for bananas, but the study was dated. The chosen acreage supply elasticities (0.25 for plantains and 1.0 for bananas) reflect the inelastic nature of the supply response of both crops. The authors note that most arable lands are currently under production so the possibility of increasing production of either crop is limited. The authors did not find any study that estimated the price elasticity of demand parameter for either crop. Therefore, they interviewed consumers and used general knowledge about the consumption of the two crops to estimate the parameter ranges. Both ranges were estimates to be inelastic, but plantains more so. This is due to the limited availability of substitute for plantains. Only imperfect substitutes, such as cassava and potato, are available.

Results for the scenario where the disease was introduced, import prohibitions are maintained and government assistance is available to treat the plants, the average production costs were estimated to increase by 11% for plantain and 8.6% for banana cultivation. Yields were estimated to have decreased by 6.25% and 10% respectively. Producer surplus increased by \$0.48 million and consumer surplus fell by \$2.14 million. However, in the scenario where the import ban was removed, producer surplus fell by \$2.28 million and consumer surplus increased by \$0.81 million. These results indicate that the impact of a black sigatoka infection would cause a decrease in net welfare

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whether or not there is a ban on imports. However, when there is a ban on imports, consumers lose and producers gain and the opposite is the case when there is free trade.

The benefit from this study is that the authors explored how economic surpluses change when the country goes from a disease-free to a diseased state with and without international trade.

Although the authors did not evaluate external effects of pesticide use, the authors discussed the importance of the potential negative externalities associated with fungicide residue and runoff. They also discussed some of the steps the government takes to mitigate these external costs. This applies to my project because some of the control measures in California to prevent bird and rodent damage include rodenticides and avicides. A problem associated with the use of these chemical pesticides is that there is a chance that non-targets will be poisoned or secondary poisoning will occur. United States Federal and California State governments are increasing regulations to monitor and prevent the probability and extent of these external effects and corresponding costs.

The authors analyze two commodities (plantains and bananas) but they do not analyze horizontal linkages. This is appropriate from a consumer's perspective because these goods are not substitutes for one another. Plantains are commonly used as a starch similar to potatoes and bananas are eaten as a fruit. But, from the producers' perspective, plantains and bananas are substitutes in production. This is most likely irrelevant because black sigatoka affects both crops.

The international trade aspect is applicable to my study. The international trade modeled in this study was interesting. At the time of the study, international trade was

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only allowed when domestic production was interrupted by hurricanes. In California, the majority, if not all crops are traded with other regions, states, and even internationally.

One of the interesting conclusions from this study is that the authors note that although the modeled scenarios reflect relatively small overall changes in cost to society, the distribution of benefits and costs of the damage and control differs considerably between consumers and producer. When free trade is prohibited, producers would gain relative to consumers because of the upward pressure on market prices. On the other hand when there is free trade, producers' welfare decreases and consumers' welfare increases when black sigatoka is established. Despite the redistribution differentials on welfare, the net economic effect is negative because the free trade price is not significantly less than the preinfestation price; the losses to producers outweigh the benefits to consumers.

2.5.3 Hoddle et al., 2003

Hoddle et al. (2003) used an EDM and an economic welfare analysis to estimate the impact of increased production costs incurred to combat insect damage to avocados in Southern California with emphasis on the cross relationship between two different varieties of avocados. The establishment of an exotic insect, avocado thrips, caused economic losses to producers from the damage to the avocado fruit causing the fruit to be unsold or the quality downgraded, or when producers apply pesticides in an attempt to reduce the damage of the thrips to non-damaging densities. The exogenous shock modeled was the costs associated with thrip control for impacted domestic producers for Hass and other avocados. The authors estimate the effects of the increase in production costs resulting from expenditures on pest control only. The authors estimated the change in producer surplus for infested and uninfested Hass and other avocado producers when substitute avocados are available through international trade.

The following log-linear EDM was used:

$$dlnD_h = \eta_{hh}dlnP_h + \eta_{ho}dlnP_o \tag{2.50}$$

$$dlnD_o = \eta_{oo}dlnP_h + \eta_{oh}dlnP_h \tag{2.51}$$

$$dlnS_h = \lambda_{hic}dlnT_{hic} + \lambda_{huc}dlnT_{huc} + \lambda_{hm}dlnM_h \tag{2.52}$$

$$dlnT_{hic} = \varepsilon_{hc}dlnP_h - \varepsilon_{hc}dlnC_h \tag{2.53}$$

$$dlnT_{huc} = \varepsilon_{hc}dlnP_h \tag{2.54}$$

$$dlnM_h = \varepsilon_{hm}dlnP_h \tag{2.55}$$

$$dlnS_o = \lambda_{oic}dlnT_{oic} + \lambda_{ouc}dlnT_{ouc} + \lambda_{orus}dlnS_{orus} \tag{2.56}$$

$$dlnT_{oic} = \varepsilon_{oc}dlnP_o - \varepsilon_{oc}dlnC_o \tag{2.57}$$

$$dlnT_{ouc} = \varepsilon_{oc}dlnP_o \tag{2.58}$$

$$dlnT_{orus} = \gamma_{orus}dlnS_{orus} + \gamma_{oe}dlnE_o \tag{2.59}$$

$$dlnT_{orus} = \varepsilon_{orus}dlnP_o \tag{2.60}$$

$$dlnE_o = \varepsilon_{oe}dlnP_o \tag{2.61}$$

$$dlnD_h = dlnS_h \tag{2.62}$$

$$dlnD_o = dlnS_o \tag{2.63}$$

Demand is separated into demand for Hass avocados, (D_h) and other varieties, (D_o). Quantity demanded for each variety is a function of the prices of both Hass avocados (P_h) and other varieties, (P_o) (equations 2.50 and 2.51). Z_{hh} is the Hass own-price elasticity of

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demand, Z_{ho} is the Hass cross-price elasticity of demand, Z_{oo} is the other varieties own-price elasticity of demand, Z_{oh} is the other varieties cross-price elasticity of demand.

Equations 2.52 through 2.61 describe the supply side of the EDM being separated into supply for Hass avocados (S_h) and other avocado varieties (S_o). The total supply of Hass (S_h) is equal to California production by producers infested with thrips (T_{hic}), California production by producers uninfested with thrips (T_{huc}), plus imports (M_h). P is a function of the price producers receive for their output (P_h), and the costs of production, (C_h). California production by uninfested producers is only a function of the price producers receive for their output (P_h). Because costs do not change for producers who do not experience a thrips infestation, the cost term is not included. Import quantity (M_h) is a function of the USA market price for Hass (P_h).

The total supply of other avocado varieties (S_o) is equal to total production of other varieties from California by infested producers ($\mathrm{T}_{\mathrm{oic}}$), by uninfested producers in California (T_{ouc}), and supply from the rest of the USA (S_{orus}). California production by infested producers (T_{oic}) is a function of the market price (P_o) and costs of production (C_o). California production by uninfested producers (T_{ouc}) is a function only of the market price. Florida and Hawaii export other varieties of avocados so supply by this region to the USA is equal to total production (T_{orus}) less exports (E_o). Total production and exports of other varieties are a function of USA market prices of other varieties. Other, non-Hass, varieties of avocados are not imported into the USA

The coefficient ε_{hc} is the elasticity of supply for Hass avocados from California, $\mathrm{\varepsilon}_{\mathrm{hm}}$ is the elasticity of import trade for Hass avocados, ε_{oc} is the elasticity of supply for other varieties from California, ε_{orus} is the elasticity of supply for other varieties of

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avocados produced by Florida and Hawaii, ε_{oe} is the elasticity of supply for exports, λ_{hic} is the share of Hass avocados from California in the USA market produced by producers who experience a thrips infestation, λ_{huc} is the share of Hass avocados produced by California producers whose groves remain uninfested, λ_{hm} is the share of imported Hass in the USA market, λ_{oic} is the share of other non-Hass avocado varieties from California in the USA market produced by producers who have a thrips infestation, λ_{ouc} is the share of other non-Hass avocado varieties from California produced by producers whose groves remain uninfested, λ_{orus} is the share of other non-Hass varieties from Florida and Hawaii in the USA market, γ_{ous} is the share of production from Florida and Hawaii that is marketed in the USA, and γ_{oe} is the share of production from Florida and Hawaii that is exported to other countries.

The final two equations (3.62 and 3.63) are the market equilibrium conditions stating that the quantity demanded of Hass (D_h) must equal the quantity supplied of Hass (S_h) and the quantity demanded of other varieties (D_o) must equal the quantity supplied (S_o).

The structural model include two markets (Hass and other avocados) and five production areas (California infested, California uninfested, rest of United States, import, and export). Both Hass and other avocados are produced in California and can be classified as infested or uninfested.

The authors then completed a welfare analysis following Alston (1995b) as:

$$\Delta TS = ((NP_{jt} - OP_{pj}) - (OP_j dlnC_j))(OT_{ij} + NT_{jit}) \qquad (2.64)$$

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where *NP* is the new price of avocado fruit, *OP* the original (pre-infestation) price of avocado fruit, *NT* the new production level of avocado fruit, *OT* the original production level of avocado fruit, *dlnC* is the percentage increase in industry costs due to the establishment of the thrips, *j* is equal to Hass or other varieties, *i* is equal to infested or uninfested production region, and *t* is equal to the short- or long-run time period. For uninfested producers, $dlnC_j$ is equal to zero. This calculation is based on a parallel shift up of the supply curve around the initial equilibrium point.

Control costs were constructed from pre- and post-infestation production budgets developed by the California Avocado Commission. Production budgets identify average producer costs to produce and an average orchard of avocados. The difference in fungicide and pesticide costs gives an indication of how much production costs increased due to thirp infestation. Imports, exports, and supply shares (m, x, λ, *and* γ) were calculated based on 3-year average production for both Hass and other avocados for domestic (California), domestic (other regions), and import and export markets. Acreage susceptible to damage was based on scientific observation and surveys of avocado growers in Southern California (susceptible acreage was less than 10 miles from the California coast). Number of damaged and undamaged acreage was then calculated from industry records detailing current geographical location of avocado acreage. Own price and cross price elasticities of demand, and supply elasticity were obtained from literature.

There are several strengths in this analysis. First, this study compared the welfare impacts on infested and uninfested producers. This is different because previous studies aggregate all domestic producers into one homogenous group, thus gains or losses in producer surplus are spread equally among the producers. This is important distinction

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because if pest damage lowers market output thereby raising market prices, then infested and uninfested producers are impacted differently. Infested producers must increase their costs of production to combat the pest damage but uninfested producers have no change in the costs of production. This leads to uninfested producers gaining from higher market prices.

A second major strength is that the authors allow for substitution in consumption between related goods (Hass and other avocados) either produced domestically or internationally. This model incorporated substitution effects of Hass and other varieties. The authors only look at substitution in consumption (between Hass and other varieties). This is accomplished through the integration of cross price elasticities of demand. When substitutes are available, the market impacts caused by pest damage for the infested crop will be amplified.

A third strength is that the authors estimated the short run versus long run effects through varying supply elasticity estimates where the short run elasticities are less elastic and the long run elasticities are more elastic. This makes sense because in the long run producers have more flexibility in adapting to infestations or production can cease. The authors assert that long run changes in market quantities generally occur through reductions in productive acreage. Losses to producers in the long run are expected to be higher. In general, if there is acreage where the total revenue was less than the fixed costs of production, the acreage would be taken out of production. Otherwise (if TR > FC), the acreage would still be cultivated and marketed with downgraded quality. The authors allow substitution in consumption but not in production. Avocado trees take many years (>3) to mature so the increase in quantity due to the establishment of new

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acreage takes a long time. The authors integrate short and long run price elasticities of supply. This indicates that the authors considered firm entry and exit and that substitution in production can occur.

Finally, the authors use separate regions and assume that the damage and control costs are different for each region. This is applicable to my study because it can be expected that each of the 8 California agricultural regions experiences different level of damage and control costs based on type of crop, natural resource characteristics, etc. found within each region. This is a simple, yet effective analysis.

Results of this study indicate that net welfare losses would exist if there was an introduction of avocado thrips. In the short run, infested producers would lose $8.65 million, and uninfested producers would gain $1.04 million. The negative impacts are less strong in the long run resulting in a loss of $5.22 million for infested producers and a gain of $0.77 million for uninfested producers. In both the short and long runs, exports of avocados fall, imports rise and the market price increases.

Multiple weaknesses exist in this analysis. First, the authors only estimated the loss in welfare due to an increase in pest control costs and ignored the welfare impacts of reduced yield or quality or the benefits of pest control to reduce yield loss. Estimation of the control costs is good, but control does not restore yield to the pest-free level. Second, the authors do not integrate a full international trade analysis. World prices are not taken into account. Instead, the authors assume that imported avocados are sold at the domestic Hass (or other) avocado price. Avocados are traded throughout the world, with Mexico and California being a large group of competitive producers. The authors should have obtained world prices.

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The most significant shortcoming of this paper is that the authors claimed to measure the change in producer surplus, but instead they measured the change in *total surplus* for infested and uninfested producers, thus are not accurate measures of changes in producer surplus as the authors claim. The authors conclude that when looking only at uninfested producers, "producer surplus" increases. In reality, if *total surplus* is increasing, then the gain in producer surplus outweighs the loss in consumer surplus that results from higher market prices. Another conclusion from the study is that "producer surplus" decreases when looking at infested producers only. This means if *total surplus* decreases, either both producer and consumer surplus decrease or the decrease in one surplus outweighs the increase in the other surplus.

2.5.4 Jones et al., 2005

The final study I will discuss is Jones et al. (2005). I will not detail the model used because it is very similar to the three previous studies, but I highlight this study because of how the authors integrate a regional analysis (similar to Hoddle et al., 2003). Jones et al. estimated the annual economic cost of weeds in seven winter crops across three regions in Australia using an EDM and an economic surplus model. The EDM used was the computer based research evaluation model DREAM © (Dynamic Research Evaluation for Management) described by Alston et al. (1995b). This model is often used to analyze a market with horizontal integration or for a multi-market analysis. Jones et al. follow Alston et al. (1995b) in estimating the changes in producer, consumer, and total surpluses for each region.

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Data for pre- and post-emergent pesticide costs, area and density of residual weeds, weed-free yield, estimates for proportion of contaminated grain, and seed cleaning costs due to contamination were gathered from a survey of grain growers in the study region. Their data gathered was sufficient to disaggregate into three homogenous production regions. Each region had different cost conditions. The authors compared a hypothetical weed-free equilibrium to the current situation where there is weed contamination and weed control costs.

The DREAM© research evaluation model is a regional disaggregated model in which technology adoption in one region generates price effects that spillover into other regions and the international commodity market. This means that if damage or control efficacy or cost changes in one region, the price impacts are felt throughout all regions because consumers can substitute consumption from all regions.

Results of this study show that the economic welfare loss caused by weeds in the Australian annual winter cropping systems is 1,278.9 million (AU$). In this scenario, both consumers [273.2 million (AU$)] and producers [1,005.7 million (AU$)] experience a decrease in surplus. The authors conclude that weeds are a significant problem and economic gains could be realized through new weed control technologies or management strategies focused on reducing the amount and extend of weeds in the winter crops.

This study is a good application of EDM and an economic welfare analysis when a type of agricultural pests (weeds) impacts several regions differently. The most important addition this analysis provides is that a regional perspective was used for the EDM and economic welfare analysis. Different regions in a state or country have

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different production environments which create different cost conditions. Disaggregation allows different cost conditions to be modeled.

2.6 Conclusion

Bird and rodent damage can have broad consequences on a large majority of the crops grown in California. Because of the breadth of damage, analyzing the economic impacts on multiple crops is the only way to understand the true impacts of this damage. Estimating all the costs of birds and rodents in crops has not been completed in California; instead, much of the work has been limited to estimating the impact of reduced individual producer revenue through reduced final output by way of direct financial cost studies. There are several benefits of direct financial cost studies, but with the shortcomings of these studies, e.g., potential market level price changes or entry and exit of firms are not accounted for, another type of modeling may be more appropriate. Although this model is appropriate for an individual price taking firm in a competitive market in the short run, it ignores important interactions between firms, within the market, and does not address long run firm entry and exit (Alston et al., 1995b).

The use of equilibrium displacement models addresses some of the shortcomings of direct financial cost models. This model is used to estimate changes in price and quantity in agricultural markets due to very small exogenous shocks in a partial equilibrium framework. These changes in price and quantity can then be used to estimate changes in producer and consumer surpluses. This modeling technique has been one of the most frequently used in agricultural economics. There are many benefits to this type of modeling, including the model's practicality. Several weaknesses do exist (e.g., elasticities must be parameterized correctly and the assumption of linear supply and demand must be modified).

Although both EDM and economic welfare theory are well established and many studies exist that use both these models, only a few studies use these models to examine the impacts of pests or pest control in agriculture. Several authors have used EMD models to estimate the impact of pest damage to agriculture. Each of the studies highlighted follows the model developed by Muth (1964) for a shift in supply.

Each of the reviewed studies offer a methodological contribution to my research. For example, one interesting and applicable modification made in several of these studies (Choi et al., and Alamo et al.) is the integration of an elasticity of area planted parameter. This parameter takes into account the varying time needed to expand agricultural production with each type of crop in different regions. Although Hoddle et al. was rife with errors, one good aspect was the integration of cross price elasticities among closely related goods. This provided a more nuanced estimation of the changes in total surplus because consumers were able to substitute between different varieties of avocados. The most important benefit of the study by Jones et al. was the use of a regional perspective. Different regions in a state or country have different production environments which create different cost conditions. Disaggregation allows different cost conditions and damage to be modeled.

For my study, I will use the basic model as described by Choi et al. (2003) and Alamo et al., (2007) to estimate the change in consumer and producer surpluses cause by the presence of bird and rodent damage using current control measures as compared to the absence of damage (and control costs) for 10 crops. Damage data does not exist in

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the absence of control measures so the analysis will be limited to estimating the difference between the presence and absence of damage only. I will integrate cross price elasticities based on available data for related crops (similar to Hoddle et al., 2003). Finally, I will integrate a regional perspective (following Jones et al., 2005) to complete the analysis for each of the 8 agricultural regions in California. This type of modeling is relatively straight forward, but the difficulty lies in obtaining accurate estimates for each variable. I have completed an extensive literature review of published and unpublished data and personally interviewed agricultural experts, growers, extension specialists, state agricultural specialists, and university faculty to obtain damage and control cost estimates.

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CHAPTER 3:

DIRECT FINANCIAL COST ESTIMATES OF BIRD AND RODENT DAMAGE AND ESTIMATING CHANGES IN ECONOMIC SURPLUSES DUE OT BIRD AND RODENT DAMAGE USING AN EQUILIBRIUM DISPLACEMENT MODEL AND AN ECONOMIC SURPLUS ANALYSIS

The goal of this chapter is twofold: first to develop a model to estimate the direct financial costs of bird and rodent damage to California agriculture, second, to develop an equilibrium displacement model (EDM) and an economic surplus analysis to estimate market changes in price, quantities, producer revenue, and producer and consumer surpluses.

Simple direct financial cost analysis is an important way to evaluate pest damage and the resulting estimates are useful as an economic decision-making tool for individual producers. The negative aspect of this analysis is that it ignores potential price and quantity effects due to the changing pest damage or pest control options or potential entry and exit of firms that would arise in competitive industries. If an individual grower or small group of growers were the only growers in an industry to suffer damage, then summing the damage and pest control costs would give an accurate representation of economic costs. On the other hand, if damage occurs to many or most of the growers (as is generally the case), there will be changes in the quantity and the price of that crop in a

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given season as long as the price elasticity of demand is not zero. Consequently, there will be impacts on the consumers and producers of the product in terms of consumer and producer surpluses. Therefore, I will also use an EDM and an economic surplus analysis to explore the impacts bird and rodent damage on economic welfare. EDMs are used to estimate changes in price and quantity in agricultural markets due to very small exogenous shocks. These changes in price and quantity can then be used to estimate changes in producer and consumer surpluses, using an economic surplus analysis.

One of the key assumptions of these economic models is that the markets modeled are perfectly competitive. This is a strong assumption that needs to be addressed thoroughly, therefore I will first discuss how, at the producer level, each crop modeled can be assumed to be in a perfectly competitive market. Second, I will describe the model to estimate the direct financial cost of bird and rodent damage. Third, I will develop the EDM and economic surplus models to estimate changes in key economic variables due to bird and rodent damage.

3.1 The Assumption of Perfect Competition

In this section, I will discuss how the market for the crops analyzed in this study can be approximated as perfectly competitive at the producer level. Although some evidence supports limited price making capabilities in selected California agricultural markets, this section will demonstrate that as an initial benchmark it is appropriate to treat all producers as perfect competitors. First, a chart introduces the concept of the movement of agricultural products from producers to consumers which lead into a discussion of the characteristics of a perfectly competitive market with price-taking

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behavior. Next, two types of agricultural institutions will be introduced, marketing programs and cooperative bargaining associations, and the potential impact of these institutions in theory and in practice will be discussed. Finally, an overview of how economic literature treats agriculture markets in California will be presented.

3.1.1 The Supply Chain for Food

There are multiple transactions that take place as food is transferred from the farm to the consumer (figure 3.1).

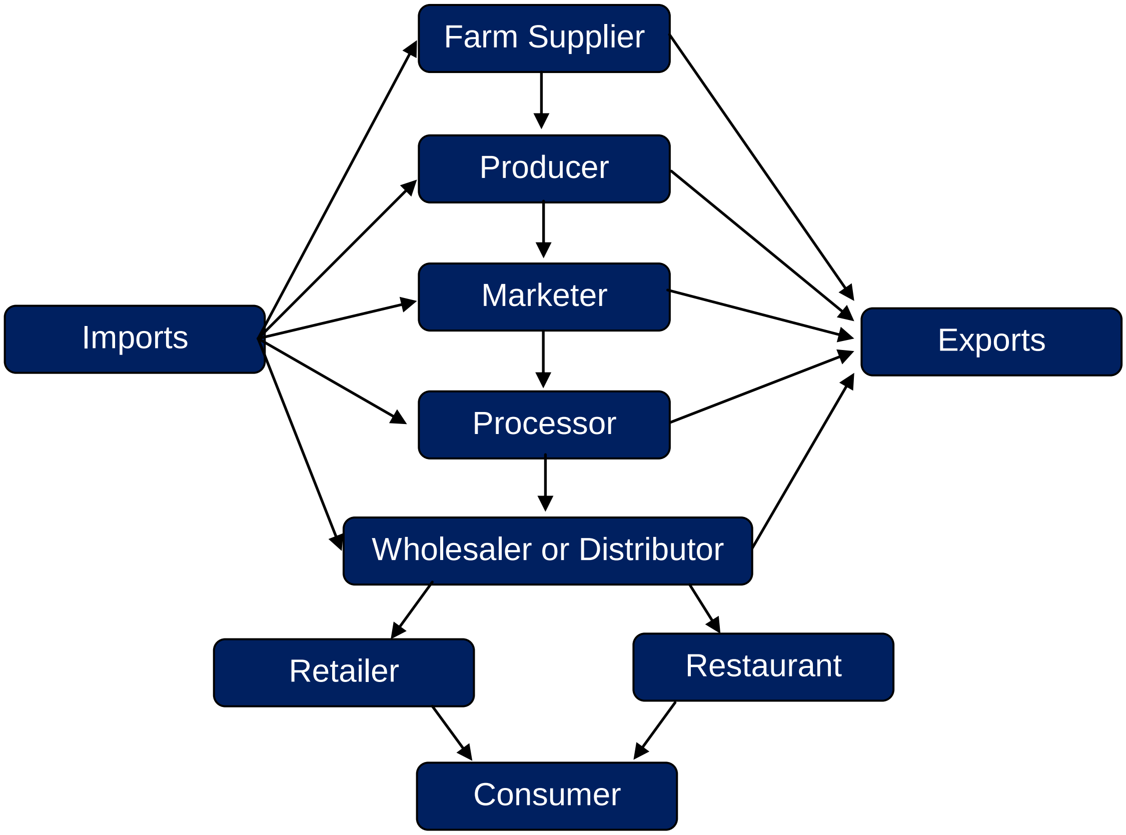

Figure 3.1: The supply chain for food.

In general, food travels through the supply chain from farm suppliers providing inputs to producers, to producers selling their crop to marketers, processors, and

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distributors who sell to retailers and restaurants who then ultimately sell the product to consumers. Each of these segments can be treated as a separate market with unique assumptions about market structure, pricing schemes, and institutional practices. Referring to this supply chain, this dissertation focuses solely on the impact of pest damage on grower prices, not on the preceding impacts to supplier price or the subsequent impacts on processor, distributor, or consumer prices.

3.1.2 The Assumption of Perfect Competition at the Producer Level

At the producer level, the market for agricultural products can be identified as an example of a perfectly competitive market. A perfectly competitive market is one in which: (1) there are a large number of firms, (2) producing a homogenous product, (3) many buyers, (4) no barriers to entry, and (5) information is perfect. These characteristics combined generate price-taking behavior from the producer because the producer believes that individual production of crop will have no effect on prevailing market prices (Jehle and Reny, 2001).

Many of the crop markets in California have all of the perfectly competitive market characteristics. There are a large number of agricultural producers in California. There are approximately 81,000 farms utilizing more than 25 million acres of land for agricultural production in the State (Table 3.1). For example, most of the nation’s almonds are grown in California on a total of 5,821 farms and grow almonds on 649.892 acres in 43 counties. Farms are also mall in California. Although concentration of farms is increasing over time in all areas of the United States, the average size of a farm in California is 25% smaller than the national average (313 acres compared to 418 acres)

(NASS, 2007). This large number of smaller farms diminishes the possibility of one producer having market power.

Table 3.1: Number and size of farms in California

Number of Farms	**81,033**
Farms by size, *1 to 9 acres*	25,278
Farms by size, *10 to 49 acres*	28,080
Farms by size, *50 to 179 acres*	12,939
Farms by size, *180 to 499 acres*	7,014
Farms by size, *500 to 999 acres*	3,267
Farms by size, *1,000 to 1,999 acres*	2,194
Farms by size, *2,000 acres or more*	2,261

Source: NASS Census of Agriculture, 2007

California farmers produce homogenous output. The assumption of a homogeneous product is appropriate because, in practice, agricultural buyers, marketers and consumers consider the majority of agricultural products to be homogenous. A carrot from one farm is the same as a carrot from a neighboring farm. But, it can be argued that all crops are not homogenous potentially leading to price differences. For example, if different varieties of tomatoes are grown in the same region where some varieties are for the fresh market and some are for the processing markets, it is reasonable to expect that these would be considered heterogeneous goods receiving different market prices. It would be inappropriate to aggregate these two types of tomatoes together. On the other hand, multiple varieties of almonds are grown, some of which are considered superior over others. But in the case of almonds, disaggregation doesn't matter as much because the grower price differences between varieties are not as significant as the difference in prices for fresh vs. processing tomatoes. Additionally, some crops may be grown in a certain region or are grown organically which could lead to price differences. Therefore,

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this study will use the most disaggregated price data possible (e.g., by county or region and fresh or processing market) which will generate outcomes closest to the assumption of homogenous product.

There are many buyers of California's agricultural output. California producers sell to thousands of processors, export their output to hundreds of countries, and sell direct to millions of consumers. Additionally, there are low barriers to entry in California agriculture.

The assumption that information is perfect and prices are known by all market participants is reasonable. Prices at the producer level are well known, published, and projected annually. For the crops analyzed in this study the first price received by the grower will be used as the price parameter. It would be difficult to analyze final consumer demand for agricultural products because many final consumer products are an aggregate of multiple inputs. This is illustrated easily with processed foods. Ready-to-eat guacamole contains avocados, onions, lemon, tomato, spices, etc. It is difficult to know the disaggregated effects on the individual crops when consumer demand for guacamole changes. Additionally, the direct estimates of retail quantities for disaggregated food commodities are frequently unavailable (Wohlgenant, 1989).

Although there are exceptions to each of these assumptions that could be applied to producers anywhere, these five characteristics combined lead to price taking behavior from the vast majority of producers in California.

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3.1.3 Potential Market Power

Within the food supply chain, it is possible that market power can exist at any step, from the farm supplier to the consumer. This is an important issue because when there is market power market participants have some influence on market price and an alternative model to perfect competition is required. Two potential institutional sources of producer market power exist in California agricultural markets: federal and state marketing programs and grower cooperatives.

3.1.3.1 Federal and California State Marketing Programs

Federal marketing programs were authorized in the Agricultural Adjustment Acts of 1933 and 1935, and were revised in 1937 in the Agricultural Marketing Agreement Act. California enacted a similar law in 1937, the California Marketing Act. While each federal or state program operates slightly differently, the goal is to develop more efficient and equitable marketing, and to aid producers in maintaining their purchasing power. Federal marketing programs tend to focus on quality regulations and sometimes on volume control, whereas state marketing programs tend to focus on marketing and promotion (Carman and Alston, 2005). Marketing orders may be specific to a single crop (e.g., California Fresh Carrot Advisory Board) or cover multiple crops within a region or state (e.g., Buy California Marketing Agreement) (CDFA, 2009). All marketing programs are legally binding and mandate compliance for all producers specified by the marketing program (Crespi and Chacón-Casante, 2004).

Authorized activities for marketing programs affecting California commodities include: quality standards and inspection, research, advertising and promotion, and quantity controls. In California, all of the crops I will analyze in this study except for broccoli and alfalfa have an associated federal and/or state marketing program (Table 3.2) (Carman and Alston, 2005). Currently, all federal marketing orders for modeled crops have active quality standards and inspection programs, three are involved with research, one advertizes and promotes the crop, and one (almond) has active quantity controls. Three state marketing orders, commissions, or marketing agreements have active quality standards and inspection programs; 13 are involved with research; 11 advertize and promote the commodity, and one has an active quantity control (pistachios) (Carman and Alston, 2005).

Quantity control programs can weaken the assumption of perfect competition because producers can legally restrict market supply. The goal of quantity control is to act as a legally enforceable cartel to selectively restrict the quantity supplied of an agricultural product to raise prices and producer revenue. For example, quantity control methods have been used to divert product to markets with the most elastic demand while restricting shipments in markets with inelastic demand (Carman and Alston, 2005). Additionally, crop reserves are used to limit supply for a particular use or year and to manage supply across years (Alston, 1995a). Historically, federal marketing programs took a more active role in quantity controls than today. Although the federal marketing orders for almonds, dates, California desert grapes, prunes, raisins, and walnuts have used active quantity control programs in the past, only one is currently active (almonds). State marketing orders have not used quantity controls since the 1970s (CDFA, 1985), but one state marketing agreement (pistachios) is authorized to use quantity controls.

Table 3.2: Modeled crops which have active Federal and/or State Marketing Programs

	Federal Marketing Program				**State Marketing Program(s)***			
	Quality Standards and Inspection	*Research*	*Advertising and Promotion*	*Quantity Controls*	*Quality Standards and Inspection*	*Research*	*Advertising and Promotion*	*Quantity Controls*
Almond	**x**	**x**		**x**				
Artichoke							**x**	
Carrots						**x**	**x**	
Cherries						**x**	**x**	
Citrus						**x**		
Grapes, table						**x**	**x**	
Grapes, wine[#]						**x**	**x**	
Lettuce						**x**		
Melons**					**x**	**x**	**x**	
Peaches[ŧ]	**x**	**x**	**x**					
Pistachios	**x**					**x**	**x**	**x**
Rice						**x**	**x**	
Rice, wild						**x**	**x**	
Strawberry[^]					**x**	**x**	**x**	
Tomato[^]					**x**	**x**	**x**	
Walnut	**x**	**x**					**x**	

Source: Carman and Alston (2005)
*includes State Market Orders, Commodity Commissions, and Marketing Agreements
**includes cantaloupes
[ŧ] fresh and/or cling
[^] processing and/or fresh
[#] Lodi-Woodbridge Winegrape Commission in San Joaquin County

Economic researchers have found that quantity control programs created through federal or state marketing programs do impact market power, but not to the extent expected by theory. There is some empirical evidence that short run prices have been enhanced through the use of quantity control tools (e.g., crop reserves and product diversion) (Carman and Alston, 2005). Crespi and Chacón-Casante (2004) analyzed almonds to test the conventional wisdom that the firms participating in marketing orders act as profit-maximizing cartels. The marketing order for almonds allows the Almond Board of California (ABC) to hold reserves to be marketed in later years to be diverted to other markets, potentially leading to cartel behavior. The authors analyzed the behavior of the ABC, which decides the level of allocated and unallocated reserves, to see if they use reserves to maximize joint industry profits or to smooth price fluctuations. The authors found that the market power exerted by the Almond Board of California is significantly less than would be expected from a profit-maximizing cartel in both domestic and international markets. An important part of their analysis, which applies to this dissertation, is that the individual farmers and handlers were treated as price takers and are assumed to act competitively. The authors found this assumption to be reasonable because of the homogeneity of almonds and the fact that there are hundreds of almond handlers.

Today, most marketing programs have focused their efforts on advertising and promotion. Under perfect competition in a homogenous goods market, no individual firm would have the profit incentive to advertize its product. The majority of these marketing programs compel all producers under the order to participate in generic advertising through contributing funds through a “check-off”, which is a fee at the first point of sale, often levied when the producer sells the crop to a handler or packer. The funds raised through a check-off are used to promote the crop in general and not for a producer or brand specifically. Generic advertising is defined as the cooperative effort of producers of a nearly homogenous product to disseminate information about the product to increase demand for the product (Crespi and Sexton, 2005). Some cooperatives, packer, or handlers participate in additional advertising to promote their brand in particular, but the dollars spent on brand-specific promotion cannot be raised through a federal or state marketing program. Although the legality of demand-enhancing check-off programs has been challenged, these programs persist (Crespi and Marette, 2009).

Other advertising and promotion programs funded or provided by the federal government exist. For example, the Market Access Promotion program (MAP) uses funds from the USDA’s Commodity Credit Corporation (CCC) to help U.S. producers finance promotional activities for their agricultural products in foreign markets. Activities financed include consumer promotions, market research, technical assistance, and trade servicing (FAS, 2008). Many groups, including federal and state marketing programs and agricultural cooperatives, are participants and receive funds. For example, in California, the Strawberry Commission and Tree Fruit Agreement (both marketing programs), and Blue Diamond Growers (a cooperative) received funds in 2008 (FAS, 2008). Like other advertising and promotional programs, the goal of the MAP program is to increase consumer demand.

Generic advertising and promotion programs, like those authorized by marketing programs or the MAP program, do not diminish the competitiveness of the participating agricultural producers. In fact, Crespi and Marette (2009) found that the existence of the check-off program for almonds can act as a procompetitive factor that diminishes a dominant firm's attempts at excluding competition. This is applicable to almond market or the cranberry market where there is a dominant firm (Blue Diamond and Ocean Spray, respectively). The goal of these programs is to increase demand for the affected crops and commodities.

Hundreds of studies exist which examine the effectiveness of generic advertising and promotion programs, nearly all assuming competitive markets (Crespi and Marette, 2009). In general, it has been shown that generic advertising has generated a statistically significant positive effect on domestic consumption of many products such as prunes, avocados, and almonds (Alston et al., 1998; Carman and Craft, 2005; Crespi and Sexton, 2005). Although these programs do uniformly increase per unit costs for individual producers (represented by a decrease in supply), the increase in net revenues resulting from marketing programs (benefits as measured by gain in producer surplus) has also been shown to be large enough to offset program costs (costs as measured by loss in producer surplus) (see Alston et al., 1998; Crespi and Sexton, 2005).

3.1.3.2 Cooperative Bargaining Associations

Producer market power can exist when producers band together and form a cooperative bargaining association (often called cooperatives) to generate market power, to obtain economies of scale, or to combat the power of large oligopolistic buyers. A cooperative acts as a single firm in the market representing the producers who are members. Cooperative bargaining associations provide a variety of services to members. The four main roles of cooperative bargaining in agricultural markets are: (1) acting as a trade association by sponsoring promotional activities, participating in lobbying efforts, and collecting data, (2) providing legal counsel to participating producers, (3) ensuring contract reliability between producers and intermediaries, and (4) participating in price enhancement (Hueth and Marcoul, 2003). Hueth et al. (2003) argued that the most important service is to conduct price and contract negotiations with market intermediaries such as packers, handlers, or buyers.

Membership in cooperative bargaining associations is voluntary. In California, cooperative bargaining organizations have existed for peach, raisin (Sun-Maid), apricot, olive, pear, prune, walnut (Diamond), and wine grapes. The number of cooperatives has diminished over time (Table 3.3).

Table 3.3: Participation in California Cooperatives, 1993 – 2007

Year	Number	Membership
1993	*200*	*65,490*
1994	*197*	–
1995	*190*	*59,550*
1996	*184*	–
1997	*185*	*56,720*
1998	*186*	–
1999	*183*	*53,600*
2000	*178*	–
2001	*171*	*49,550*
2002	*164*	–
2003	*162*	*44,200*
2004	*154*	–
2005	*150*	*41,220*
2006	*143*	*39,270*
2007	*136*	*39,710*

Source: USDA, http://www.rurdev.usda.gov/rbs/coops/data.htm (tables 26, 27)

Three types of cooperatives exist in California; (1) vertically integrated cooperatives have integrated their production from growing, processing, and marketing; (2) information-sharing cooperatives operate to expand and strengthen communication between producers; and (3) bargaining cooperatives enable producers to bargain collectively for pricing with processors (Carman et al., 2003). The strengthened price and bargaining capabilities were made possible by the Capper-Volstead Act. This act was passed by Congress in 1922 to provide cooperatives with partial immunity from the antitrust laws, allowing agricultural producers to set prices together, as long as they do not excessively enhance market prices (Carman et al., 2003; Hardesty, 2005).

3.1.4 Modeling Agriculture as Perfectly Competitive in Economic Literature

When looking at market power arising from marketing orders, two crops with active quantity control programs (almonds and pistachios) have the greatest potential to have market power. But, in the limited economic literature that has analyzed the impact on price taking behavior caused by these marketing orders, the majority of authors treat these two markets in California as perfectly competitive. For example, Crespi and Sexton (2005) evaluated the effectiveness of California almond promotion and modeled almonds as a perfectly competitive market and Kinnucan and Christian (1997) measured returns to nonprice export promotion applied to a perfectly competitive almond market.

Although market power sometimes exists with agricultural producers, the assumption that each firm is a price taker can be applicable to individual producers in California. At the very least, the assumption of perfect competition is useful as a benchmark. Assumptions will be made to approximate the perfectly competitive framework for this study. For example, to achieve the closest approximation, the most specific crop data available at the county level and the first price received data will be used.

3.2 Estimating Direct Economic Costs of Bird and Rodent Damage using a Direct Financial Cost Analysis

The value of yield loss and pest control expenditures associated with current management practices can be derived and can be used to determine the direct financial costs to producers, thus providing an important reference point for identifying the impacts of birds and rodents to agriculture. To measure the cost of direct bird and rodent damage in California crops, yield losses are defined as yield reductions due to direct taking of the final product of crops by birds and rodents and control expenditures are the costs associated with biological or other control measures. Thus, birds and rodents have a direct financial impact in reducing income from lower production and/or increasing production costs.

Following Jones et al. (2005) I will estimate the annual financial cost of bird and rodent damage in California agriculture as a function of the damage free yield, acres damages, the percent of yield lost due to birds and rodents, and the cost of control. The total cost of pest bird and rodent species is the summation of the total value of revenue loss and aggregate bird and rodent control expenditures for 15 crops in 8 agricultural zones.

For each crop and zone the yield loss is calculated as:

(3.1)

where *YL* is the yield loss, *A* is the number of bird and rodent damaged acres, Y_0 is the pest-free yield for each crop in each zone, and *D* is the yield-loss coefficient. The yield loss coefficient is the percentage loss of yield caused by a particular bird and rodent pest pressure. *D* is a proportional variable and is bounded by zero and one. An increasing value of *D* represents greater yield damage due to increased bird and rodent damage. Y_0D represents the loss in yield to a crop caused by a particular level bird and rodent damage. Y_0DA is the total loss in yield for all areas of crop acreage affected by a particular level of bird and rodent damage. The subscripts are, $i = 1, \ldots, 15$ individual crops and $j = 1, \ldots, 8$ agricultural regions. This means for each of the 8 regions, the yield loss for 15 crops impacted by bird and rodent damage can be estimated. This allows the yield loss estimate (*YL*) to account for differences in crop planting and variations in bird and rodent damage levels across regions. A maximum of 120 disaggregated yield loss estimates can be calculated for California.

The loss in revenue due to birds and rodents for each crop is calculated as:

, (3.2)

where *RL* is the revenue loss and *P* is the crop price. Multiplying the price of each crop in each region by the yield loss caused by a particular level of bird and rodent damage in each region represents the financial loss due to that level of bird and rodent damage for each modeled crop and region. It is then possible to obtain the loss in revenue for each region for each crop and the total value of the revenue losses from bird and rodent damage across all regions. The total value of revenue loss (*TVL*) is represented by:

, (3.3)

where *TVL* represents the total value of revenue loss as the sum of the revenue losses for each crop in each of the 8 regions. The calculated total value of revenue loss (*TVL*) is the total financial value of the crop lost with control measures.

Pest control expenditures are determined as:

(3.4)

where *CE* is the cost of pest control measures, *A* is the number of acres treated with pest control, and *C* is the average per acre control expenditures.

The total financial cost (TFC) of bird and rodent damage to selected crops in California is the summation of equations 3.6 and 3.7:

$TFC =$ (3.5)

This model is valuable because it shows how individual producers would react to bird and rodent damage if market impacts were not considered. This analysis is useful to understand the magnitude of the pest bird and rodent control expenditures. This type of analysis can be used in conjunction with an input-output analysis to estimate the total impacts (direct, indirect, and induced impacts) to the economy.

The data I have collected is sufficient to estimate this first model. Data I have gathered include: estimated damage for each modeled crop by county, region, or state; regional control costs; county prices and acreage for each crop; estimated proportion of acreage damaged by crop by county, region, or state; and average crop yield by county.

3.3 Equilibrium Displacement Model and Economic Surplus Analysis

The goal of this section is to develop an EDM and an economic surplus analysis to estimate small shifts in the supply curve, representing differing levels of damage and control which cause short run changes to price and quantities in a perfectly competitive industry. Current crop loss and pest control expenditures will be measured in terms of the economic surplus change that results from the supply shifts for each crop when there is an absence of damage or control costs, or when there is damage but no control expenditures. The implicit assumption is that bird and rodent damage constrain crop production and cause an inward supply shift (to the left) for the affected crops (Figure 3.2, shift *a*). The use of pest control reduces yield loss leading to a shift of the supply curve outward (to the right), but at the same time, costs increase which would temper this shift (figure 3.2, shift *b*). While substantial pest damage could result in increased crop prices to consumers, widespread pest control use may consequently result in decreased prices in the competitive California crop markets.

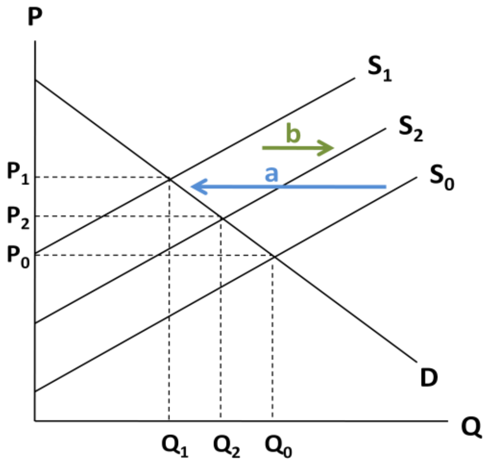

Figure 3.2: Supply effects of bird and rodent damage (shift a) and control (shift b).

In applying the EDM to evaluating the impact of birds and rodents to selected California crops, the assumption of a uniform parallel industry-wide supply shift is not likely due to diversity in production regions similar to Hoddle et al. (2003) and Jones et al. (2005). To recognize this issue, this analysis will be completed as an 8-region analysis (each region has multiple counties) corresponding to the California Agricultural Statistics Districts (Figure 3.3).

Figure 3.3: Map of California's Agricultural Statistics Regions

Although welfare changes can be measured at the aggregate, industry level, a simpler approach is to estimate the changes in consumer and producer surplus in each of the 8 individual regions and then add the surpluses together. This approach is attractive when there are a large number of individual counties as is the case with this analysis.

This benchmark model will be used to compare prices, quantities, total revenue, and economic surpluses between a hypothetical damage-free equilibrium and the current situation where there is bird and rodent damage and control expenditures (figure 3.4). The complexity of the model depends partially on the robustness of the available data.

Additional models could include assessing changes in economic surpluses to damaged and undamaged producers or estimating the change in surpluses between the current situation with pest damage and control measures and the situation without control measures. Also, if damage data is trusted and multiple cross-elasticities have been estimated, then this model could be a multi-market EDM taking into account the horizontal relationships between crops.

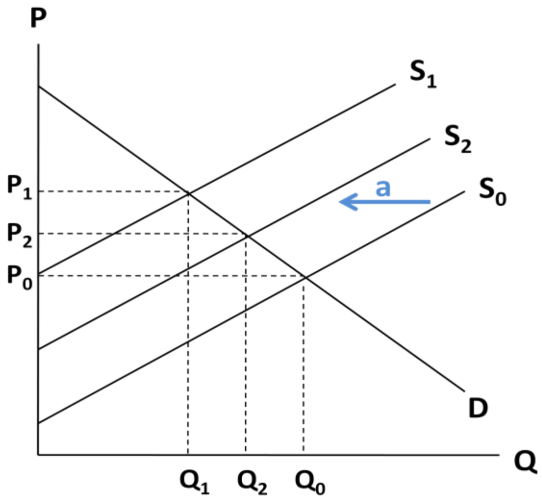

Figure 3.4: Supply effects of bird and rodent damage and control costs where (a) represents the production cost increase due to control expenditures and the loss in yield due to uncontrolled bird and rodent damage.

The following framework generally follows Choi et al. (2003) and Alamo et al. (2007) with the integration of a regional dissagration following Hoddle et al. (2003) and Jones et al. (2005). The assumptions set by Muth (1964) are followed. Those assumptions are: supply and demand curves are assumed to be linear and shift in a parallel manner, a static (single-period) model is used and dynamic issues are ignored, competitive market clearing is imposed, and Harberger's three postulated are assumed so standard surplus measures can be used to estimate changes in economic welfare.

Additional assumptions are that perfect competition exists within each crop and production region, and there is a closed economy. There is sufficient variability within and between the agricultural regions to allow for different cost and damage conditions. It is assumed that elasticities of endogenous supply and demand relationships are known and constant and that elasticities of supplies and demands, with respect to exogenous variables, are known and constant. It is assumed that the technology of production is known and constant. Traditional input use does not change in the simulation, only pest control inputs for affected acres. Displacements are restricted to be in the neighborhood of equilibrium and the supply and demand curves are linear and shift in a parallel manner. This EDM can be used to effectively measure changes in consumer and producer surplus due to the presence of damage.

Within an agricultural region, each crop or crop group has specific cost conditions, bird and rodent damage, and pest control expenditures; and potentially all 15 crops are grown in each per county, which are all analyzed. Each crop market can be described by a set of common structural equations (3.6 – 3.10).

$$S_{ij} = f(P_{ij}, A_{ij}, Y_{ij}, \delta_{ij}, C_{ij}) \tag{3.6}$$

(3.7)

$$D_{ij} = f(P_{ij}) \tag{3.8}$$

(3.9)

$$S_i = D_i \tag{3.10}$$

where equation 3.6 shows that supply for a crop within a region is a function of price (P), acreage planted (A), yield (Y), damage (δ), and cost of production (C). The subscripts are, $i = 1, \ldots, 22$ individual crops and $j = 1, \ldots, 8$ agricultural regions. Equation 3.7 shows that the aggregate supply for the state for each crop (S_i) is the summation of the supply in each of the 8 regions. Equation 3.8 represents demand for each crop in each region as a function or price and equation 3.9 is the aggregate demand for each crop in the state (D_i). Equation 3.10 is the equilibrium condition. Disaggregation into regions allows the modeling of difference in growing practices, damages, control efficacies, and prices.

The log-linear differential form of equations 3.6 – 3.10 were taken and the equations were expressed in terms of elasticities and percentage changes.

$$dlnY_{ij} = \delta_{ij} \tag{3.11}$$

$$dlnA_{ij} = \varepsilon_i dlnP_{ij} - \varepsilon_i dlnC_{ij} \tag{3.12}$$

$$dlnS_{ij} = \varepsilon_i dlnP_{ij} - \varepsilon_i dlnC_{ij} + \delta_{ij} \tag{3.6'}$$

(3.7')

$$dlnD_{ij} = - \eta_i dlnP_{ij} \tag{3.8'}$$

(3.9')

$$dlnS_i = dlnD_i \tag{3.10'}$$

The change in yield per acre (*Y*) is represented by equation 3.11, where δ denotes the percentage of change in the yield per acre due to bird and rodent damage. Equation 3.12 denotes the change in planted area (*dlnA*) as a summation of the change in price (*dlnP)* and change in production costs (*dlnC*) multiplied by the price elasticity of area planted (ε). This allows the damage and costs for each region to differ. The change in quantity supply for each crop in each region is represented by equation 3.6' and it is the sum of the percent changes in acreage and yield. Equation 3.7' is the total change in quantity supply for each crop within the state and it is the sum of the change in the share (λ) of production in each region. Equation 3.8' represents the change market demand for each crop and region (*dlnD*) as the change in price (*dlnP*) multiplied the price elasticity of demand (η). Equation 3.9' is the total change in quantity demanded for each crop within the stat and it is the sum of the change in the share (α) of consumption in each region. The market clearing condition is equation 3.10'.

There are two exogenous variables which shift the supply: δ is the yield reduction caused by bird and rodent damage, and *C* is the expenditure on pest control costs.

Equations 3.6' -3.10' are solved for the reduced form solutions for a change in price per crop and region (3.13), change in price per crop for California(3.14), change in acreage per crop and region (3.15), change in acreage per crop for California (3.16), change in quantity of crop per crop and region (3.17), change in quantity per crop for California (3.18), and change in producer revenue at the regional level (3.19) and state level (3.20):

$$\frac{\quad}{\quad} \qquad (3.13)$$

(3.14)

(3.15)

(3.16)

(3.17)

(3.18)

(3.19)

(3.20)

These equations give the percent changes in initial equilibrium price and quantity given changes in the right hand side variables. Equation 3.13 shows the change in price for each crop in each region. Two sets of equations (3.13, 3.16 and 3.17, 3.18) form the basis for the market and welfare analysis that follows.

To estimate a change in consumer surplus (ΔCS) and producer surplus (ΔPS), the following equations are used following Alston et al. (1995b) and Alamo et al. (2007):

$$\Delta CS = P_0Q_0Z(1 + 0.5Z\quad) \tag{3.21}$$

$$\Delta PS = P_0Q_0(K-Z)(1 + 0.5Z\quad) \tag{3.22}$$

$$\Delta TS = \Delta CS + \Delta PS = P_0Q_0K(1 + 0.5Z\quad) \tag{3.23}$$

where the change in price, relative to its initial (P_0) value, due to the supply shift is:

$$\overline{} \qquad (3.24)$$

$$K = -\{ \quad dln \quad - \quad \} \qquad (3.24)$$

where *K* is the vertical shift of the supply function expressed as a proportion of the initial price, η is the absolute value of the elasticity of demand, and ε is the elasticity of supply.

Four sets of variables have to be parameterized for each crop in each county including damage caused by birds and rodents, change in production costs due to a change in pest control costs, three -year average market price, three-year average quantities and market shares, and elasticities.

I have sufficient data to estimate this second model. Much of the same data as used in the previous model will be used in this model. The only addition is the use of elasticities and change in production costs. The use of elasticities allows me to estimate the changes in consumer and producer surpluses using the method described above. Additionally, because of the assumption of linear demand and supply curves, the use of elasticities also allows me to estimate the entire demand and supply curves. I would then be able to estimate total consumer and producer surpluses before and after the effects of bird and rodent damage, although with less confidence than estimating only the changes in surpluses. I have found price elasticity of demand and supply data for the majority of the crops modeled in this study (see section 4.5).

The direct financial cost model is used to estimate the direct economic cost associated with bird and rodent damage for each modeled crop in each region. These costs are estimated by identifying the change in profits corresponding to bird and rodent damage and/or pest control costs. This is because profit for an individual producer is the difference between total revenue and costs. This model assumes total revenue remains unchanged thus any changes in cost are directly reflected as changes in profit. Although the direct financial cost model does not take into account industry wide impacts on price, these results are useful in decision making by the individual producer and results could be used in input-output modeling.

The EDM will estimate how price and quantity changes in the presence and absence of damage. In other words, current agricultural output with bird and rodent damage and control costs is compared to a hypothetical estimated output in the absence of damage and control costs. Finally, the estimated changes in price (from the EDM) will be used in an economic surplus model to estimate the changes in the size and distribution of economic welfare between consumers and producers. This estimation is important because the results of this study can be used by California state government to ensure pest control is available to mitigate the negative impact cause by the pest species, by agricultural producers to make better decisions about the costs and benefits of production, to understand the effects of changing prices on consumers' budgets, and to explore the effects on international agricultural trade.

The following chapters describe available data and how data can be used in the economic models (Chapter 4).

CHAPTER 4: DATA SOURCES AND ANALYSIS

Chapter three provides the models to estimate the economic impact of birds and rodents to agriculture. The direct financial cost analysis has been applied in some cases to bird and rodent damage to California agriculture, and only rarely in any aggregation. On the other hand, there has not been a published study which uses EDM to estimate changes in economic welfare caused by bird and rodent damage to agriculture in California. Thus, this large scale project estimating the impacts to a variety of economically important crops to the nation's largest agricultural producer is important.

The models used in this dissertation are well known and often used in agricultural economic analyses but the difficulty lies in obtaining accurate estimates for each variable. One contribution of this dissertation is to apply these models to a unique set of data related to bird and rodent damage. Since I have a large database of 206 damage estimates from 43 studies related to 16 crops across 6 (of 8) regions of California (Table 4.1). These bird and rodent damage data have never been aggregated or analyzed with an EDM. With respect to my damage data, I use a meta-analysis to combine and describe the characteristics of the data. The analysis of such a large amount of data will be a unique contribution to the study of the economic impacts of crop damage in California. Unlike this analysis, the studies highlighted in Chapter 2 gathered data from a variety of sources to complete their studies. For example, Hoddle et al. used data collected by the author to estimate thrip damage to avocados. Jones et al. administered a survey to winter crop producers in the study area and used the results from the survey to estimate weed damage.

This chapter is focused on systematically identifying and organizing parameters for each of the economic models. For these two models, there are 58 counties in California separated into 8 agricultural regions, and potentially, all 15 crops are grown in each county with individual damage, expenditures on pest control, and other costs. The data requirements for this project are immense.

Section 1 (4.1) will discuss possible ways to aggregate the extensive data set collected in the damage matrix. I will provide a basic aggregation of my damage data, reviews the meta-analysis methodology, present the results of this meta-analysis, and provide a damage estimate (δ) for each crop group and region. Section 2 (4.2) describes the control expenditure data for each crop (C) and the cost of production data for each crop. Section 3 (4.3) provides detailed price, quantity, and production share data for each crop and county (P, Q). Section 4 (4.4) describes the elasticity estimates for each crop (ε, η).

4.1 Meta-regression Analysis Used to Identify Damage Parameter

The primary benefit of this study is the aggregation of an amount of damage data previously unanalyzed. However, a difficulty arises in determining how to best combine and filter this data. Previous authors relied on data from (1) a single field site or survey or (2) relied on a single previously published damage study. I, however, will analyze this large database of 206 damage estimates from 43 studies related to 16 crops across 6 (of 8) regions of California (Table 4.1). The analysis of such a large amount of data will be a unique contribution to the study of the economic impacts of crop damage in California. Through the inclusion of a more complete damage data set, the impact of this damage on consumer and producer surplus can be estimated with greater accuracy and yield predictive an interpretive value to the profession.

Table 4.1: Number of studies and observations by source type

	#	*# of observations*
Journal Article	11	72
Conference Proceedings	10	39
Published or Unpublished Report	10	55
Personal Interview	12	41
Total	*43*	*206*

A basic aggregation of the data for each crop grouping yielded damage estimates that ranged from 0.004% to 65% (Table 4.2).

Table 4.2: Summary of damage values of California Crops (%)

Crop Group	Low Value	High Value	Average of all studies
Tree Nuts	0.004	30.0	4.78
Tree Fruits	0.100	54.7	6.98
Annuals	0.100	65.0	6.85
Perennials	0.100	25.0	7.41
Alfalfa	6.970	53.8	24.87

To determine if it was appropriate to have different mean damage estimates for each crop group, I completed a three step process. First, I calculated conditional means to identify if there were differences in mean damage estimates between crop groups, regions, and study methods (Section 4.2.2). I then completed a meta-analysis to help explain the variation in mean damage presented in Table 4.2 (Sections 4.2.3-4.2.6). Finally, based on the results of the meta-analysis, I selected a range of damage estimates to be included in the equilibrium displacement analysis (Section 4.2.7). I concluded that it would be inappropriate to average all damage estimates to obtain a single mean damage estimate to use in this study.

4.1.1 Bird and rodent caused damage to California agriculture, a background

Countless different species of birds and rodents damage California crops. Native bird species, including the house finch, horned larks and crows, can cause extensive damage to agriculture in California. The house finch has been reported to damage more than 20 different crops through pecking at the fruit, seed removal, and disbudding, and was particularly damaging to grapes (Palmer, 1972; DeHaven, 1974; DeHaven and Hothem, 1981; Gadd, 1996; Berge et al. 2007). Horned larks damage lettuce seedlings (York et al., 2000) and are "one of the most notorious bird species that are known to reduce melon stands" by walking up and down the newly seeded rows pulling up seedlings (California Melon Research Advisory Board, 2003). Crows are a severe pest to almonds and other tree nuts (Delwiche et al., 2007; Hasey and Salmon, 1993; Simpson, 1972; Crabb et al., 1986).

Rodents, such as meadow mice or gophers, and rabbits can cause serious damage to orchards and forestry through eating fruit, debarking trees, grazing on young trees, root destruction, damage to irrigation drip lines, and seed consumption (Wood, 1994; Pearson, et al. 2000; Gusti, 2004; Wilen and Salmon, 2007). Pasture and field crops can be impacted through grazing, destroying roots, or reducing seed regeneration (Marsh, 1987; Wood, 1994; Whisson et al. 1999; Whisson et al, 2000). Fruit and vegetable damage includes eating of seedlings and young shoots of the plants, digging tunnels in fruit or vegetable beds, and eating the ripened fruit or vegetables (Salmon, 1986; LeBouf, 2002; NASS, 2002; Muramoto, 2005).

Two species of native California ground squirrels were particularly damaging to crops, the California ground squirrel, and the Belding's ground squirrel. The California ground squirrel damages much of California's farmland through eating fruit and nut crops, girdling of trees and their burrowing activity causes damage to tree roots and irrigation lines (Marsh, 1998; NASS, 1999; LeBouf, 2002; Muramoto, 2005). Belding's ground squirrels occur in meadows, grasslands, and agricultural fields throughout northeastern California and they were a significant pest of alfalfa production through eating the leaves, stems and roots of plants, destroying roots below the soil surface, and building burrow systems which interfere with harvesting (Sauer, 1984; Whisson et al., 1999; Whisson et al., 2000).

Bird and rodent caused damage can vary greatly through time and space because of the inconsistent and fluctuating nature of damage, the differing levels of control utilized by producers which reduce damage more or less effectively, and varying weather patterns that may influence pest numbers. Ideally, all bird and rodent damage to crops in California would be measured accurately and separately for each pest on an annual basis for each planted acre of crop. However, this perfect data collection scenario is impossible due to the high cost of annual grower surveys and/or field assessments. Due to these limitations, research on bird and rodent damage mainly consists of individual studies on either a single specie or multiple species impacting a single crop's final product (see Crase, 1976; Hothem et al., 1981; Gadd, 1996; Cummings et al., 2005; Berge et al., 2007; Delwiche et al., 2007) or a single specie impacting multiple crops' final product (see DeHaven, 1974; Marsh, 1998), although some research publications attempt to incorporate multiple pest species damage to multiple crops (see Razee, 1976; NASS, 1999; NASS, 2002). Because of the range and variety of damage, calculations of pest damage can be extremely difficult. For example, the main pest species to impact almonds is the crow (Hasey and Salmon, 1993), although Pearson et al. (2000) found that ground squirrels, yellow-billed magpies, scrub jays, common ravens, deer mice, western gray squirrels, wild pigs, and beaver also caused measurable damage.

Although birds and rodents can cause a variety of damage to the final fruit, nut or product of the plant; to the integrity of the bearing vine, plant, or tree; or to farm infrastructure or livestock, the estimate of primary damage used for this study was pest damage to the final fruit, nut, grain, vegetable, nursery or forest product. For example, primary bird damage to grapes occurs when the bird plucks whole fruit or pecks at the fruit resulting in decreased yield (Tobin, 1984), whereas pocket gophers would cause secondary damage through tunneling near and damaging a vine. The primary damage caused by ground squirrels to alfalfa is the direct consumption of the alfalfa plant which reduces the marketable quantity of alfalfa (Whisson et al., 1999). Secondary damage occurs when livestock break their legs after stepping into a burrow (Marsh, 1998). Based on the data collected, a matrix of primary damage estimates was developed (see Appendix A).

4.1.2 Conditional Means

The first step in determining an appropriate mean was to group the damage estimates based on agricultural practices and California statistical reporting methods. The groups I identified included: study method (i.e., interview/survey or field study), crop groups (i.e., tree nuts, tree fruits, annuals, and perennials) all shown in Table 4.3, and region (i.e., eight California agricultural statistical districts show in Fig. 4.1). Second, I identified a conditional mean for each group (Figures 4.2-4.6, the bars represent the standard errors).

Results suggested a difference in the mean damage estimates between interviews (6.73%) and field studies (10.94%) when observing all data. However, this difference diminished when separating the data into crop groups. Additionally, differences in mean damage existed between crop groups (in particular tree nuts and alfalfa). Tree nuts are damaged less than average and alfalfa is damaged more than average. Regional differences did exist, in particular, in Regions 2 and 3. The regional differences are due most likely to an upward bias in these two regions caused by high levels of alfalfa damage and alfalfa damage studies completed in these regions. Differences between tree nut and tree fruit damage appear to be relatively nonexistent between regions.

Figure 4.1: Eight California Agricultural Statistical Districts

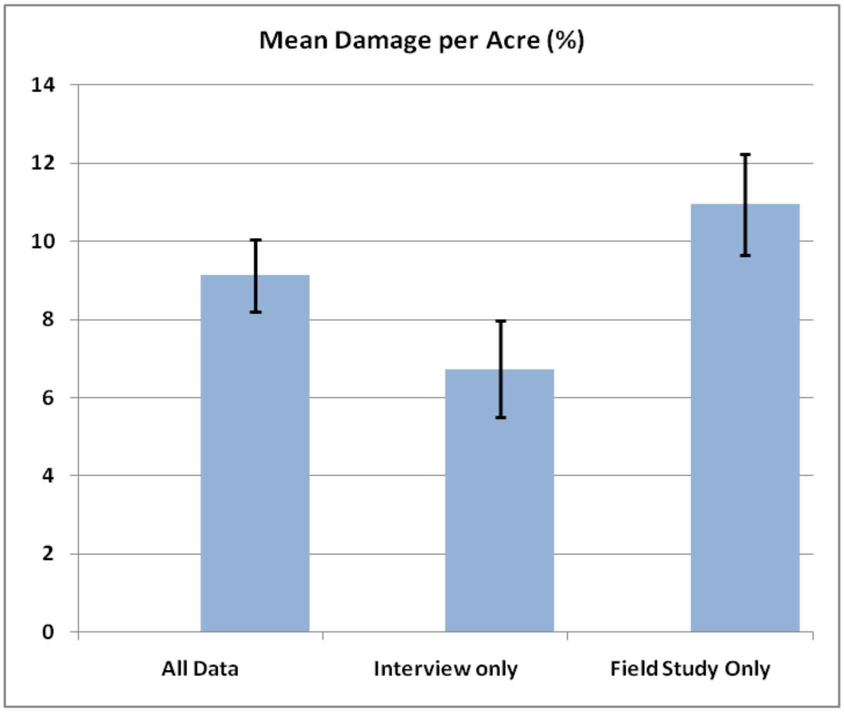

Figure 4.2: Conditional means for all data and study method.

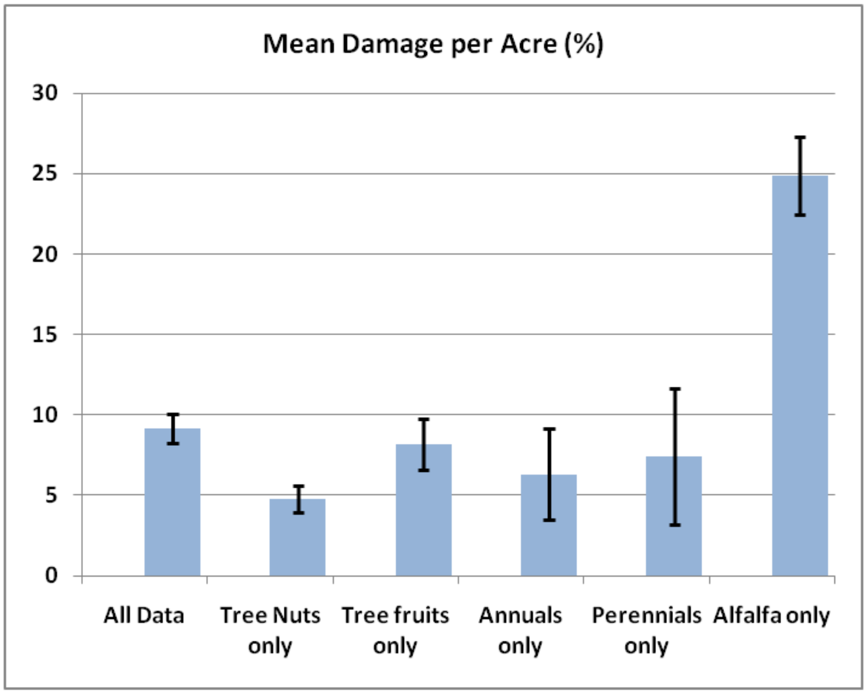

Figure 4.3: Conditional means for all data and crop groups.

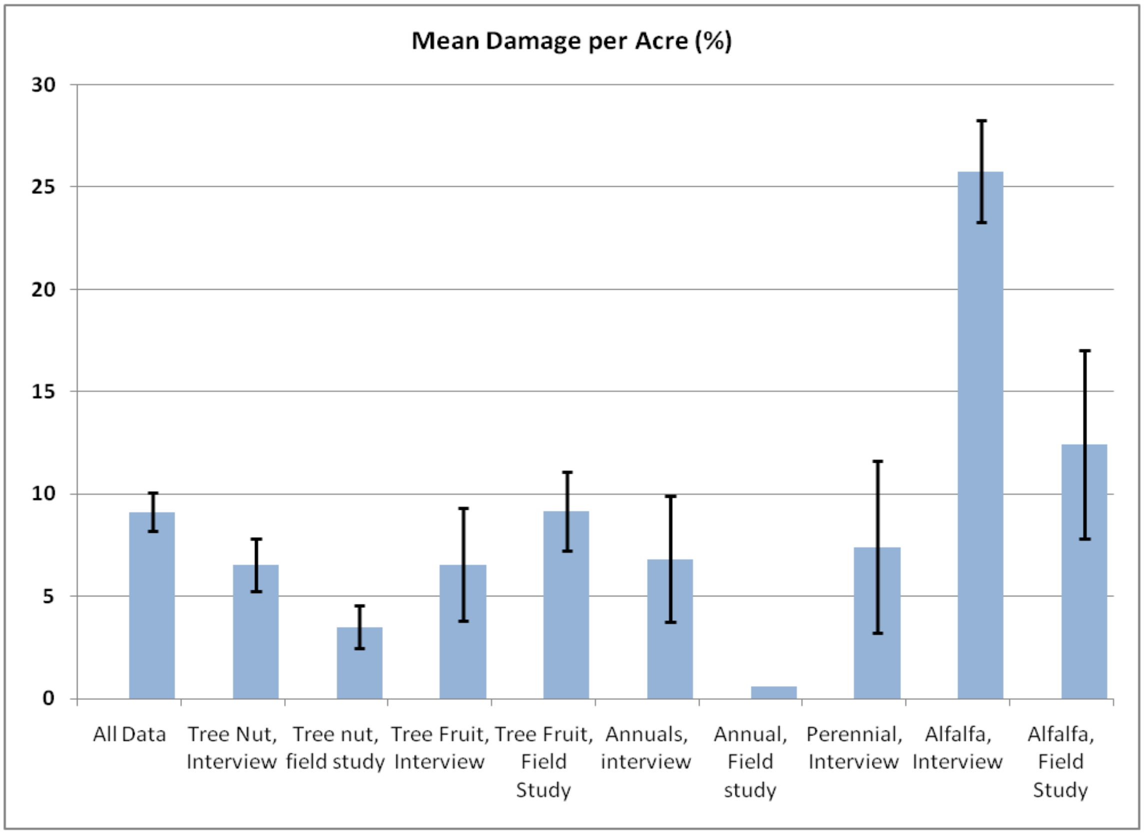

Figure 4.4: Conditional means for all data and crop groups with study method.

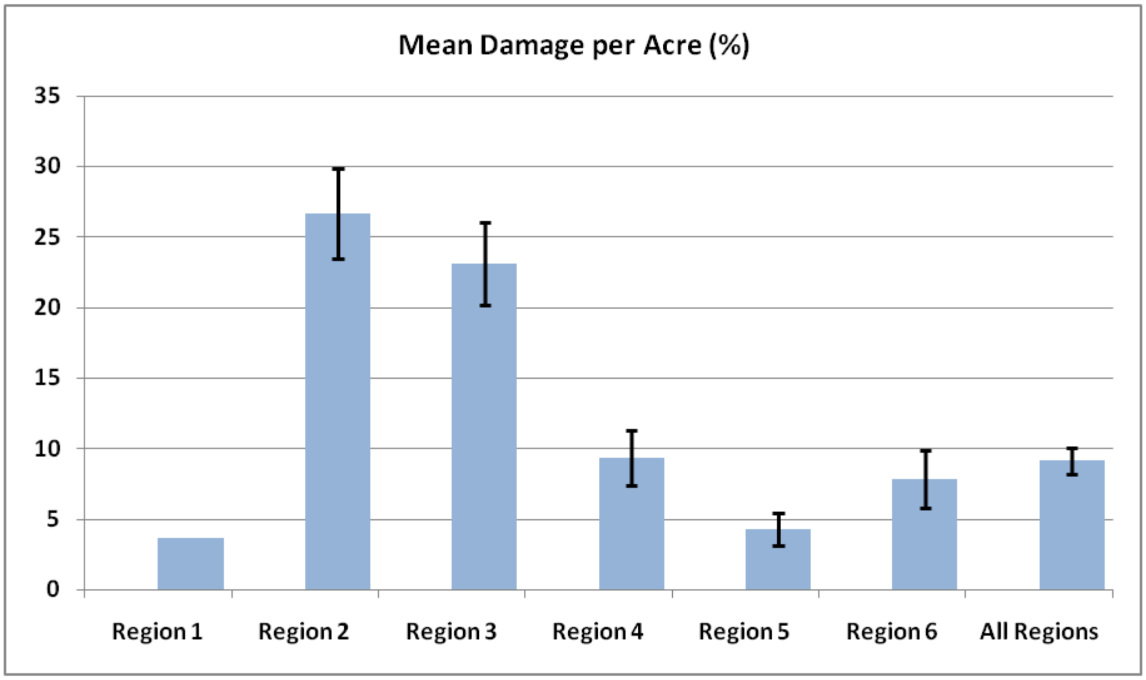

Figure 4.5: Conditional means for all data and regions.

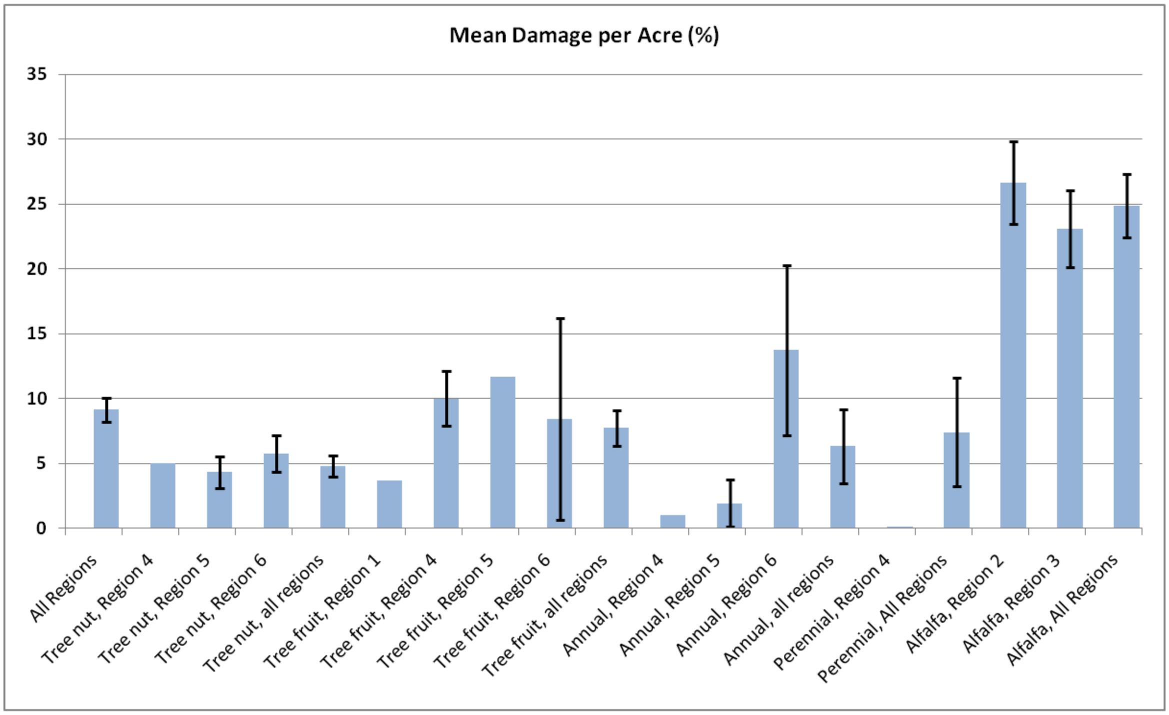

Figure 4.6: Conditional means for all data and crop groups with regions.

Table 4.3: Conditional Mean Results, Summary Data

	Mean	**Standard Error**	**No. of Obs**
All Data	**9.13**	**0.92**	209
Interview only	6.73	1.24	90
Field Study Only	10.94	1.30	119
Tree Nuts only	4.78	0.83	74
Tree fruits only	8.19	1.58	74
Annuals only	6.31	2.84	25
Perennials only	7.41	4.21	6
Alfalfa only	24.87	2.42	30
Tree Nut, Interview	6.54	1.28	31
Tree nut, field study	3.51	1.07	43
Tree Fruit, Interview	6.55	2.76	27
Tree Fruit, Field Study	9.14	1.92	47
Annuals, interview	6.83	3.06	23
Annual, Field study	0.60	*n/a*	1
Perennial, Interview	7.41	4.21	6
Alfalfa, Interview	25.76	2.50	28
Alfalfa, Field Study	12.42	4.59	2

	Mean	Standard Error	No. of Obs
Region 1	3.70	*n/a*	1
Region 2	26.65	3.20	21
Region 3	23.09	2.94	7
Region 4	9.34	1.98	52
Region 5	4.32	1.15	39
Region 6	7.85	2.00	47
All Regions	9.13	0.92	209
Tree nut, Region 4	5.00	*n/a*	1
Tree nut, Region 5	4.32	1.25	35
Tree nut, Region 6	5.76	1.44	30
Tree nut, all regions	4.78	0.83	74
Tree fruit, Region 1	3.70	*n/a*	1
Tree fruit, Region 4	9.99	2.12	48
Tree fruit, Region 5	11.70	*n/a*	1
Tree fruit, Region 6	8.40	7.77	7
Tree fruit, all regions	7.72	1.38	99
Annual, Region 4	1.00	*n/a*	1
Annual, Region 5	1.93	1.78	3
Annual, Region 6	13.73	6.57	10
Annual, all regions	6.31	2.84	25
Perennial, Region 4	0.10	*n/a*	2
Perennial, All Regions	7.41	4.21	6
Alfalfa, Region 2	26.65	3.20	21
Alfalfa, Region 3	23.09	2.94	7
Alfalfa, All Regions	24.87	2.42	30

**** all regions = region 9 plus all other regions*

4.1.3 Meta-analysis

Meta-analysis is a research method using a statistical approach to review and summarize literature and previously obtained research results (Florax et al., 2002). "Meta-analysis refers to the statistical analysis of a large collection of results from individual studies for the purpose of integrating the findings, It connotes a rigorous alternative to the casual, narrative discussions of research studies which typify our attempt to make sense of the rapidly expanding research literature" (Glass, 1976).

Meta-anlaysis has been used extensively for more than 30 years in the medical, psychology, and scientific fields. Meta-analysis is now an accepted practice for evaluating conflicting scientific evidence. Meta-regression analysis is a form of meta-analysis specifically designed to apply to economic empirical research questions (Stanley, 2001). Some of the earliest uses of meta-analysis were in the field of environmental economics (see Button, 1995; Loomis and White, 1996). These studies used meta-analysis to evaluate the results from non-market valuation studies (e.g., contingent valuation, travel cost methods, or hedonic pricing) or in agricultural economics (e.g., analysis of wage elasticities by Espey and Thilmany, 2000). One important use of meta-analysis is the investigation of non-sampling issues (e.g., research design or model specification) (Florax et al., 2002). An additional function of a meta-analysis is the determination of how different research methods affect the results of the study (Stanley, 2001).

It has been suggested that meta-analysis is more objective than traditional literature reviews because meta-analysis uses a more systematic approach to analyze the variation in research results (Florax et al., 2002). Meta-analysis is a tool used to compare and/or combine outcomes of different experiments with similar research methods, data sets, research question, etc. This ability to compare and combine outcomes from different experiments with similar set-ups, leads to the discovery of more rigorous conclusions. Additionally, the multivariate regression framework of a meta-analysis sheds light on the marginal effects which would not be discovered in a traditional literature review (Florax et al., 2002).

Traditional literature reviews sometimes use vote counting to determine the size and direction of the true effect of the results (Florax et al., 2002). Vote counting, in which every study gets a vote, can lead to an incorrect conclusion. Wheser false conclusions may increase when additional research is published and is considered to be biased and obsolete (Hedges and Olkin, 1985). Vote-counting is somewhat ineffective in coming up with the correct answer because there is a bias towards the conclusion that the estimated relationship being reviewed is statistically insignificant (Florax et al., 2002). This is especially the case when a large or increasing number of studies become available because the Type-II errors (not rejecting a null hypothesis even though it is false) of individual studies do not cancel each other out but instead accumulate (Hedges and Olkin, 1980).

Additionally, traditional literature reviews can have large methodological selection bias because the reviewer can introduce bias by omitting portions of the literature for various reasons (Stanley, 2001). In contrast to literature reviews, a meta-analyses framework used to interpret and summarize literature removes any potential judgment of "good" and "bad" studies. Meta-analysis accomplishes this by including every study even those considered "misspecified" by the reviewer (Stanely, 2001).

In general, to conduct a quality meta-analysis, the topic chosen must have a number of studies in which the results are comparable (or able to be fit to become comparable) and are summarized in a quantitative format. Once the topic has been identified, the research papers have to be carefully codified to generate a database that summarizes the empirical knowledge about the topic studied. A typical database consists of publication details of the study, the estimate of the effect size to be considered, estimation characteristics (e.g., estimated elasticity and the associated standard error), and other variables (e.g., type of data used or geographical region) (Florax et al., 2002). Once this database is constructed, the use of meta-analysis can range from explaining the variation in effect sizes, to an analysis of variance representing differences in the conditional means for studies with different background characteristics, to a simple description of the effective size estimate (Florax et al., 2002). Meta-analysis can be used to determine the extent to which the particular choice of methods, design and data affect the reported results (Stanley, 2001).

In a meta-regression analysis, the dependent (i.e., left hand) variable is a summary statistic drawn from each study, while the independent (i.e., right hand) variables may include characteristics of the method, design and data used in the research studies. The steps to a meta-analysis as described by Stanley (2001) are: (1) include all relevant studies from a standard database and provide detail of the literature search so it can be repeatable; (2) choose a summary statistic and reduce the evidence to a common metric; (3) choose moderator variables through identifying and coding important characteristics of the study (e.g., different data sets, econometric modeling choice, and geographical region); (4) conduct a meta-regression analysis; and (5) subject the meta-regression analysis to specification testing.

Meta-analysis is an “analysis of analyses” (Glass, 1976) and is not without its problems. The largest issue is that a representative sample of the literature is often difficult to obtain (Florax et al., 2002). Although using search engines (e.g., EconLit, JStor, Google Scholar) eases the search for relevant literature, it is difficult to assess if the resulting literature is a representative sample because sometimes, published literature tends to be biased towards significant results. For a less biased sample of literature, the researcher should seek unpublished works for additional research results (Rosenthal, 1979). This “file drawer” problem of insignificant results being unpublished most likely results in an overestimation of the true experiment results (Stanley, 2001).

As mentioned before, meta-analysis is a “statistical analysis of a large collection of results from individual studies for the purpose of integrating the findings” (Glass, 1976). This type of analysis is appropriate to use to combine and interpret my large set of damage data. This method will allow me to use all damage data, therefore, providing a richer and more complete economic analysis of the welfare effects of bird and rodent damage to California agriculture.

4.1.4 Meta-analysis to determine causes of variation between damage estimates

The goal of this meta-analysis is to help explain the variation in mean damage presented in Table 4.2 and to give guidance or the appropriateness of choosing different levels of damage for each crop group or region included in the equilibrium displacement analysis. This meta-analysis explores the trends in pest damage over time, differences in damage between regions and/or crop groups, and if there is a difference in damage estimates between field studies and interviews or surveys.

Similar to medical trials, research to identify maximum bird and rodent damage to crops can be very expensive. Crop producers are often unwilling to suspend all damage mitigation techniques. Therefore, estimates of maximum levels of damage are unavailable. As a result, the damage studies included in this meta-analysis measure the level of damage using common control measures.

The available damage studies include an estimate of damage and additional data which can be thought of as the parameters for this meta-analysis. These data include: year of study, region in which the study was completed, crop studied, and study type (e.g., interview/survey or field study).

I have limited my data to studies from California. Bird and rodent pests vary among regions; therefore, it is not appropriate to use damage data from different states in this analysis. For example, two pest species native to California are the Belding's ground squirrel and the horned lark. The Belding's ground squirrel is a major pest of alfalfa fields and the horned lark feeds on lettuce seedlings and neither of these species are significant pests in other regions of the country. Therefore inclusion of damage estimates of a species not found in California would be spurious. In addition to different pests, due to California's unique characteristics, California leads the nation in the production of many goods (e.g., avocados, grapes, processing tomatoes) and often is the sole producer of others (e.g., almonds, artichokes, grapes, cling peaches, sweet rice, and walnuts) (CDFA, 2009). This means that damage estimates for these crops are unavailable for any other state in the nation because they are not grown anywhere else.

To overcome the potential issue of obtaining a biased sample of research studies, I performed a literature search using multiple online databases such as JStor, EconLit, and the Internet Center for Wildlife Damage Management (ICWDM). I also worked intensively with researchers in California to gather "file drawer" research during October 2008. JStor and EconLit are economics databases which contain published journal articles. The ICWDM is a database that contains a variety of material including conference proceeding papers from two relevant conferences (the Wildlife Damage

Management Conference and the Vertebrate Pest Conference). These conferences are held on alternate years and research on topics such as vertebrate pests and/or wildlife and their interaction with agriculture, wildlife or humans and human development. These conference proceeding papers provided a wealth of information on small field studies.

In addition to obtaining published data, I met with faculty from U.C. Davis including: K. Klonsky, Department of Agriculture and Resource Economics, Extension Coordinator; M. Delwiche, Department of Biological and Agricultural Engineering; R. Marsh, Professer emeritus from the Department of Wildlife, Fish and Conservation Biology; and W.P. Gorenzel, Department of Wildlife, Fish and Conservation Biology to discuss my study and request any data or research they may have related to this study. Since I worked for the USDA/APHIS/WS/NWRC during this research, I had the benefit of receiving data gathered by WS California, the opportunity to meet with the state director C. Coolihan and had lengthy discussions with multiple WS Operations Personnel in Napa, Fresno, Sacramento, and Kern Counties. I met with the director of the VPCRAC V. Hornbaker and physically went through her file cabinets to obtain data from past VPCRAC studies and general vertebrate pest damage data from the CDFA going back 50 years. I spoke with California County Agricultural Commissioners D. Witmer and B. Roach. I met with U.C. Davis Extension Specialists R. Molinar, S.J. Vasquez, and C. Wilen and interviewed them about current levels of pest damage in their region and area of expertise. I met with the pest control coordinator Fred Rinder for Fresno County and spent 2 days with him and his staff learning about stuff. I also met with pest control advisors and growers to discuss bird and rodent damage.

For this study, 206 damage estimates from 43 studies (Table 4.1) related to 15 crops across 6 (of 8) regions of California were included. These crops were grouped into 5 groups: tree nuts (almonds, pistachio, and walnut), tree fruits (peach, citrus, cherry and grape), annuals (broccoli, carrot, lettuce, tomato, rice, and melon), perennials (artichoke and strawberry), and alfalfa.

Data were aggregated into regions. This was done because (1) data were not detailed enough to complete a county analysis and (2) the composition of agricultural production varies regionally across the eight agricultural districts in California (Figure 4.1). For example, the San Joaquin Valley district produces the majority of the state's agriculture, including fruit, nut and vegetable products, whereas the North Coast district specializes in cattle and calves, milk, and some fruit-tree products (NASS, 2007). One study on alfalfa conducted in a southern Oregon county which borders California was included in this study.

The basic model to explain the variations in the mean estimated damage includes variables that economic theory and agricultural practices would suggest as important. This model is given in the following equation using "alfalfa" and "Region9" as baselines. A region was coded as Region9 if the study was not conducted in a specific region, but instead related to "California".

$$
\begin{aligned}
\mathit{Mean\ Damage} = {} & B_0 + B_1\mathit{YEAR} + B_2\mathit{FieldStudy} + B_3\mathit{Region1} + B_4\mathit{Region2} + B_5\mathit{Region3} \\
& + B_6\mathit{Region4} + B_7\mathit{Region5} + B_8\mathit{Region6} + B_9\mathit{TreeNut} + B_{10}\mathit{TreeFruit} \\
& + B_{12}\mathit{Annual} + B_{13}\mathit{Perennial}, \qquad \mathit{eq.\ 5.1}
\end{aligned}
$$

where MeanDamage is the average damage estimate using producer determined pest control methods; YEAR is the year the study was preformed; FieldStudy is coded 1 for a study that was a controlled field study, 0 for a survey or interview; Region1 is 1 if the study was conducted in the North Coast region; Region2 is 1 if the study was conducted in the North Mountain region; Region3 is 1 if the study was conducted in the Northeast Mountain region; Region4 is 1 if the study was conducted in the Central Coast region; Region5 is 1 if the study was conducted in the Sacramento Valley region; Region6 is 1 if the study was conducted in the San Joaquin Valley region; TreeNut is 1 if the crop is a tree nut; TreeFruit is 1 if the crop is a tree fruit; Annual is 1 if the crop is an annual; Perennial is 1 if the crop is a perennial.

The signs in front of the variables indicate their hypothesized effect on average damage. I would predict that the year effect would have a negative sign indicating decreasing damage over the years. Currently California advocates integrated pest management (IPM). The University of California’s Department of Agriculture and Natural Resources supports the statewide IPM program through research, education, and outreach (UC IPM, 2009). IPM is not a single control method, but it is more of an adaptive management program which encompasses multiple control methods while being guided by management evaluations (EPA, 2009). This suggests that growers participating in an IPM program would closely observe pest pressure on their crops, treat when necessary and only treat the problem pests. But at the same time, this method has increased the time growers and/or pest control specialists spend observing and treating damage.

I would predict the sign on field study variable to be negative meaning that the mean damage estimates obtained from direct observation in a controlled field study application will be lower than estimates obtained from an interview or survey. This is consistent with the many of the conditional means presented in section 5.2.1. However, one recent study (Tzilkowski et al., 2002) found that growers' perception is comparable to field study estimates of wildlife-caused damage. The authors conducted a statewide field study effort in Pennsylvania during the 1995 growing season to quantify wildlife damage to corn. They also surveyed affected corn producers on their perception of deer-caused damage in early 1996. The result of the study was that there was no significant difference between the mean estimates of corn loss reported by farmers from the questionnaire (9.68 ± 0.899%) and estimates measured in the field (7.67 ± 1.27%). The study by Tzilkowski would suggest that if there is a negative sign on this study's field study variable, meaning interviews and surveys data resulted in a higher mean bird and rodent damage, it would not be statistically significant.

Predicting the signs in each region is more difficult because there is correlation between the crops grown, damage to those crops, and damage studies conducted in each region. For example, the majority of California's almonds are grown in the Central Valley (Sacramento and San Joaquin Valleys) so it is reasonable that the damage studies were conducted for almond orchards in the Central Valley. The implication is that the results of the meta-analysis would indicate that damage (for tree nuts) will be greater in the Central Valley as compared to other regions only because that is the region damage estimates were gathered. Another issue is that, in particular with field studies, damage studies are conducted where damage occurs. For example, the majority of alfalfa damage studies were completed in regions 2 and 3, with high levels of damage. But in the meta-analysis, regions 2 and 3 levels of damage are biased upward because only alfalfa was studied in these regions. Additionally, some of the damage data estimates referred to bird and rodent caused damage in “California,” not in a particular region. I combined all “California” damage estimates into a new region, Region 9. Region 9 estimates tended to be survey or interview data obtained from county commissioners or extension personnel on damage to a particular crop “in California.” These estimates were relatively close to the means for each of the crop groups (except alfalfa) reported in Table 4.2.

I would predict that certain types of crops are damaged more often by bird and rodent pests because of the varied efficacy, use, and cost of pest control methods. For example, compared to the baseline alfalfa, all other crop groups would have relatively low levels of damage. Alfalfa would have the greatest level of damage because the pesticide (zinc phosphate) used to control the main pest species (ground squirrels) is no longer available. Additionally, an equally effective substitute has not been developed or approved by the EPA. On the other hand, many low-cost bird scaring devices are available. This would suggest that the mean damage for crops that are damaged primarily by birds (e.g., almonds or pistachios) is lower because of the lower cost of pest control. Another issue that would add to high levels of damage in alfalfa compared to other crops is related to agricultural practices. Alfalfa is cut twice a year, and otherwise is seldom maintained or observed by the grower. In contrast, strawberries are picked continually through the growing season, therefore closely observed by the grower.

4.1.5 Results and discussion

Table 4.4 presents the results of the meta-analysis. From reviewing what is and is not significant from Table 4.4, some interesting observations can be made.

Table 4.4: Meta-analysis Results, Summary Data

		Coefficients	*Standard Error*
Constant		19.10***	6.25
YEAR		– 0.12*	0.08
Field Study		– 3.26	2.33
	1	0.11	11.84
	2	13.31**	6.75
	3	8.19	7.10
	4	7.31**	3.19
	5	3.82	3.32
	6	7.28***	2.76
Nuts		–14.43**	6.34
Fruit		–11.40*	5.92
Annuals		–11.98*	6.38
Perennials		– 9.46	7.49
Adjusted R^2		0.27	

Note: Single, double and triple asterisks (*) denote significance at the 10%, 5% and 1% levels, respectively.

As expected, the year effect has a negative sign indicating decreasing damage over the years. Although this annual change is small, it is significant. This result suggests that bird and rodent damage to these selected crops in California is decreasing over time. The sign on field study variable to is negative, reinforcing the results of Tzilkowski et al. (2002), but it is not statistically significant. This result suggests that growers' perception of bird and rodent caused damage for these crops in California is comparable to field study estimates of damage. Interestingly, while all regions have higher levels of damage when compared to Region 9, Regions 2, 4 and 6 have levels of damage that are significantly different. This may be due to differences in crop damage studies. For example, many of the alfalfa studies which generated the greatest levels of damage were in Region 2. This could be because these Region 9 estimates were obtained from individuals who may not have as much or as relevant growing experience for a particular crop as individuals giving estimates for individual crops grown in specific regions or counties. Also as expected, compared to the baseline alfalfa, all other crop groups except perennials have significantly lower levels of damage. This reflects the lack of control options for alfalfa. It also suggests that perennials in general, alfalfa included, have higher levels of damage. Perhaps this is due to the limited control options for many burrowing rodents such as the ground squirrel and pocket gopher.

This meta-analysis explored the trends in pest damage over time, differences in damage between regions and/or crop groups, and the lack of difference in damage estimates between field studies and interviews or surveys. There are several remaining potential issues. For example, field study selection bias exists. Several locations of crop acreage selected for the field studies were chosen specifically because they had a history of damage and some had a history of severe damage. Although the degree of damage was never compared to other fields in the region, this may cause an upward bias the damage estimate for field studies. If this is the case, the difference between field studies and interviews or surveys may become significant.

Another issue is that large amounts of damage data exist for crops that tend to have higher market values (e.g., wine grapes or tree nuts). This bias towards research on bird and rodent caused damage to high dollar crops makes theoretical sense because any given marginal decrease in damage will lead to greater marginal benefit for the producers of crops that sell for $1000 per ton compared to $28 per ton. This result does not necessarily mean that high dollar crops are damaged more; it only means that damage to these crops has been studied more.

Another issue is, even with the extraordinary effort I undertook to find all damage studies; the damage data are still not comprehensive. For example, many of the published studies which include an estimate for bird and/or rodent damage were studies to test the efficacy of a new control measure (see Delwiche et al., 2007; Salmon et al., 2000; Whisson et al., 1999). These studies, in general, only measured damage caused by one species to a particular crop and ignored damage caused by other species. This means that damage reported in these studies are most likely an underestimate of the total damage that occurs in a particular field, orchard, or vineyard. This damage data can be applied to other farms or areas because the quantity of bird and rodent damage tends to be exogenous or out of the control of the producer.

Damage studies for a specific crop are highly correlated with region. This could potentially cause inaccurate variations in damage between regions. This may be important if the crop is grown throughout California (e.g., alfalfa) but not as important for crops grown in certain regions or counties (e.g., lettuce, strawberries).

A final issue is that several regions only have damage studies related to one crop group (e.g., Regions 1, 2 and 3) or have no damage data on the crop studied (e.g., Regions 7 and 8). Although these damage data are vast, the lack of depth of data in some regions limits the subsequent economic analysis.

4.1.6 Final damage estimates for crop groups and regions

Based on the results of this meta-analysis, the damage parameter used in the direct financial cost and EDM models can be tailored appropriately. For my analysis, I will use a range for each estimate of damage. In general, tree nuts had the lowest levels of damage and alfalfa and perennials had the highest. Regions 2, 4 and 6 had the highest levels of damage compared to Regions 1, 3 and 5. Based on these results, the damage estimate for tree nuts will the lowest in all regions but 4 and 6. On the other hand, alfalfa in Regions 1, 2, and 3 will have the highest level of damages. I based the "mid" level of damage on the means estimated in section 4.1.2. The "low" and "high" estimates were the mid estimate scaled down or up, respectively, by 50%. The following table (Table 4.5) shows the range of damage estimates I will use for each crop group in each region.

Table 4.5: Final Damage Estimates (%)

Crop group: Region	**Low**	**Mid**	**High**
All data average		**9.13**	
Tree Nut: 4, 6	1.35	5.38	6.73
Tree Nuts: all other regions	1.08	4.32	5.40
Tree fruits: 4, 6	2.30	9.20	11.49
Tree fruits: all other regions	2.39	9.55	11.94
Annuals: 4,6	1.84	7.37	9.21
Annuals: all other regions	0.48	1.93	2.41
Perennials: 4, 6	3.75	15.00	18.75
Perennials: all other regions	1.75	7.00	8.75
Alfalfa: all regions	6.23	24.87	31.0875

4.2 Control cost and cost of production data

In California and throughout the world, pests increase the cost of agricultural production. Growers face a loss of crops, reductions in crop yield, and loss of crop quality relative to the potential yield and quality that would be possible without pests. This potential decrease in yield and quality necessitates the input requirement of pest control (Jones et al., 2005; Sexton et al., 2007).

A variety of pest control measures are used in California to prevent bird and rodent damage. Types of control measures include: chemical pesticides and repellents such as DRC-1339 or Mesurol; live or instant kill traps; scare tactics like Mylar tape, propane cannons, or biosonics; introduction or use of predators like owls or raptors; and many others. Selection of a control measure depends on crop type, geographical region, grower preference, state regulations, and depredating species. The use of specific control measures change over time as a result of new technology, pesticides development or cancelation, or the presence of a new or invasive pest species.

Control cost data was more difficult to compile than damage estimates due to the nature of the literature and the emphasis in California on Integrated Pest Management (IPM). Although dozens of field studies relating to bird and rodent control exist, the vast majority only examine the efficacy of the control measure, not the cost of implementing the control measure (see Gadd, 1996; Salmon et al., 1997; Delwiche et al., 2007) and few authors have surveyed growers in an attempt to identify control costs per acre for various crops (see Crase and De Haven, 1973; Marcum and Gorenzel, 1994; Hueth et al., 1998; and Salmon et al., 2000). Another factor that increases the difficulty of accurate control expenditure estimates is that California emphasizes the use of IPM. The University of California's Department of Agriculture and Natural Resources supports the statewide IPM program through research, education, and outreach (UC IPM, 2009). IPM is a not a single control method, but is more adaptive through encompassing multiple control methods while being guided by management evaluations (EPA, 2009). This means that expenditures on control will vary based on type and severity of damage, time of year the damage occurs, and type of pest causing the damage.

Control costs were identified through reviewing a large body of literature which detailed the development, use, and efficacy of different control measures in California (see Marcum and Gorenzel, 1994; Moore et al., 1998; and Salmon et al., 2000). Additional data were gathered through personal interviews of agricultural extension specialists, County Agricultural Commissioners, crop producers, and other knowledgeable wildlife damage specialists from across California. These experts were asked to estimate the amount of control costs per acre to combat damage caused by birds and rodents in dollar terms for a particular crop. Estimates of control costs per acre were also obtained through cost and return studies developed and published by the University of California, Davis, Department of Agricultural and Resource Economics (DARE, 2009). Cost and return studies are developed to identify costs to establish different crops in California. Cost and return studies are available for most crops and types of cropping systems in California although few provide estimates for vertebrate pest control expenditures. Based on the data collected, a matrix of pest control expenditure estimates was developed (see Appendix B).

Control cost data was not as comprehensive as damage data. Therefore, to obtain an estimate of control costs for each crop, a simple average of all estimated pest control expenditure per acre was used to identify the estimate for pest control cost for this economic study (Table 4.6).

Table 4.6: Estimated control costs per acre damaged.

Crop	**Control costs *($ per acre)***
Almond	33.50
Artichoke	90.00
Broccoli	5.00
Cherries	36.00
Citrus	7.50
Grapes	100.00
Alfalfa	12.00
Lettuce	42.50
Melons	7.50
Peaches	10.00
Pistachios	82.00
Rice	22.00
Strawberry	21.00
Tomato	22.50
Walnut	15.50

Cost of production data was also obtained from cost and return studies completed by the Department of Agricultural and Resource Economics, Extension and Outreach at the University of California, Davis. I used the most recent cost information available (2004-2010) for each crop. The total cost estimate I chose was the total cost per acre grown for an established producer. Since I am using my calculated control cost per acre for the simulations, I subtracted any vertebrate pest control costs from the total cost (if applicable) as to eliminate double counting of control costs. For several crops, multiple studies were completed to reflect varying regional cost conditions. If this was the case, I used the specific cost estimates for the producing region and then averaged the cost conditions for the other regions aggregating the regions into three large similar-cost regions. The regions aggregated together were (1) Regions 1-3 and 7, (2) Regions 4, 5, and 6, and (3) Region 8. If there was only one estimate available, I used this estimate for all producing regions in California. The following table (Table 4.7) shows the total cost for each producing region and crop.

Table 4.7: Cost of producing one acre.

Crop and region(s)	Total annual cost of production per acre ($)	Sources
Almond		Connell et al., 2006 and Duncan et al., 2006
5	2,983	
6	3,647	
Pistachio		Beede et al., 2008
5, 6, 8	2,552	
Walnut		Hasey et al., 2006 and Grant et al., 2007
1, 2, 7	3,299	
4, 5, 6	6,953	
Citrus		O'Connell et al., 2009 and 2010
4, 5, 6, 7, 8	5,862	
Cherries		Grant et al., 2005
4, 5, 6, 8	13,226	
Grapes		Klonsky et al., 2009; McGourty et al., 2008; Vasquez et al., 2007; and Peacock et al., 2005
1, 7	1,972	
4	10,093	
5	9,041	
6	7,990	
8	6,214	
Peach		Day et al., 2009
4, 5, 6, 7, 8	10,425	
Broccoli		Meister, 2004a
4, 6, 8	4,053	
Lettuce		Smith et al., 2009a and 2009 b
4, 6, 8	8,923	
Rice		Mutters et al., 2007
2, 5, 6, 7	1,279	
Tomato		Stoddard et al., 2007 and Miyao et al., 2007
4, 5, 6, 8	4,086	
Melon		Fake et al., 2009
5, 6, 8	15,116	
Artichoke		Meister, 2004b
4, 8	4,282	

Crop and region(s)	Total annual cost of production per acre ($)	Sources
Strawberry		Bolda et al., 2006a, 2006b and Takele et al., 2006
2, 7	32,949	
4, 5, 6	29,129	
8	36,769	
Hay (alfalfa and others)		
1, 2, 3, 7	560	Frate et al., 2008; Long et al., 2008; and Orloff et al., 2007
4	1,295	
5	1,043	
6	1,546	
8	1,000	

The variable included in this analysis is not total cost of production. Instead, it is the percent increase in the cost of production caused by expenditures on pest control. This variable was estimated by dividing the cost of pest control (which is the change in costs, Table 4.6) by the cost of production listed above (Table 4.7) The increase in the cost of production ranged from 0.001% for peach, to 0.13% for citrus, to 3.2% for pistachios, and for some grape growing regions, the increase in the cost of production was 5.1%. The average change in cost of production was an increase of 0.93%.

4.3 Identification of Current Price and Quantity Data

Price and quantity data for all modeled crops was available through California Department of Agriculture's County Agricultural Commissioner annual reports. The three year average (2005-2007) for all price and quantity data was taken. Tables in Appendix C show detailed crop production data including bearing acreage, total production value, price per acre, and share of regional production for each crop group by county and by region.

For many of the crops, I was able to obtain data for 100% of the crop grown in California. For some crops, the data provided in the annual reports were not specific enough for this study to represent 100% of the crop grown. For example, some counties lump crops together in the report when the total production is relatively small. The following table (Table 4.8) details the crops analyzed in this study, the average three-year acreage, the weighted three-year average yield and price, the total revenue, and percent this total revenue represents of the aggregate all of California total revenue.

Table 4.8: Production data.

Modeled Crops	Acres	Y (tons per acre)*	P ($ per acre)*	TR for modeled crops ($)	% of state TR^
Almond	661,048	0.93	4,413	2,707,428,458	100
Pistachio	120,172	1.44	3,648	630,605,874	100
Walnut	239,407	1.64	1,748	686,975,586	83
Citrus	255,521	12.87	507	1,666,141,788	700
Cherry	28,277	2.16	4,027	246,498,767	76
Grape	848,024	6.46	528	2,894,590,579	80
Peach	73,972	13.11	474	459,247,248	85
Broccoli	130,754	7.27	614	583,630,952	98
Lettuce	280,108	16.25	323	1,471,546,163	76
Rice	536,552	3.69	297	586,686,534	86
Tomato	341,367	22.22	208	1,574,347,131	100
Melon	64,857	17.20	282	314,190,034	100
Artichoke	7,827	6.91	1,377	74,471,910	81
Strawberry	34,703	29.62	1,343	1,380,502,937	85
*Alfalfa***	1,660,588	6.14	133	1,360,379,321	86

* Weighted average
** all hay
^ equals (TR for modeled crop)/(TR for crop reported in all of California) as reported by the CDFA 2009

4.4 Elasticity Data

For this study, I used price elasticity of demand (η) and supply (ε) estimates from the most current empirical study specifically related to California agriculture whenever possible. If empirical elasticity data were unavailable, I used estimated elasticities obtained from research on California agriculture. If estimate elasticities were unavailable, I used national estimates reevaluated to be applicable to California agriculture (Table 4.9).

Table 4.9: Estimated elasticities of demand and supply.

Crop	**η**	**ε**
Tree nuts		
Almonds	-0.69*°	0.24*°
Pistachio	-1.00°	1.00°
Walnut	-0.48*°	0.15*°
Tree fruits		
Citrus	-0.72*°	1.00°
Cherry	-0.45*	1.00°
Grape	-0.24*°	0.60*°
Peach	-0.89*°	1.00°
Annuals		
Broccoli	-0.19*°	0.57*°
Lettuce	-0.44*°	0.40*°
Rice	-0.36*°	0.45*°
Tomato	-0.25*°	0.27*°
Melon	-2.22*°	1.04*°
Perennials		
Artichoke	-0.22°	0.75°
Strawberry	-0.28*	1.25°
Alfalfa	-0.11*°	0.50*°

* Empirically based estimate
° Estimate based on California crop

Russo et al. (2008) completed a study estimating the supply and demand elasticities of several California commodities. From this study, I obtained price elasticity of demand and supply estimates for alfalfa, almonds, rice, tomatoes and walnuts. For pistachio, there were no specific empirical elasticity data available for California. Therefore, I followed Alston et al. (2006) to obtain the estimated elasticities. In that study, the authors evaluated the effects of the California pistachio marketing order on demand, prices, and consumer and producer surpluses.

For California peaches and citrus (lemons and oranges) price elasticity of demand, I use estimates provided by Nuckton (1978). Nuckton estimated the demand for various California tree fruits. For broccoli, lettuce and melon (cantaloupe and honeydew) price elasticity of supply and demand estimates, I followed Sunding et al. (1993). In that study, the authors estimated the economic impact of an insect, the silverleaf whitefly, on certain California crops.

Grape price elasticity of demand was obtained from two sources (Alston et al., 1997; Volpe et al., 2008). Alston et al. conducted a study estimating the economic impacts of a table grape promotion program. Volpe et al. estimated the supply of California wine grapes using a system of equations. Cherry and strawberry price elasticity of demand was unavailable for California so I based my estimate on research completed by You et al. (1996). You estimated national η for cherries to be small (-0.32). In 2007, California bearing cherry acreage represented approximately 36% of the nation's total bearing cherry acreage (NASS, 2010). I would predict that price elasticity of demand for California cherries would be slightly more elastic than the national estimate, but still inelastic. Therefore, I will use -0.45 as my cherry estimate. You also estimated the national η for strawberries to be small (-0.28). California leads the nation in strawberry production therefore I will also use You's estimate for my estimate.

For the remaining estimates (i.e., price elasticity of demand for artichoke, price elasticity of supply for peach, citrus, cherry, artichoke and strawberry), I used estimated elasticities from Jetter et al. (2004). That study examined the direct economic benefits and costs of Californian consumers adopting four alternative recommended diets (e.g., 5-a-day recommendation for fruits and vegetables). The study focused on the direct economic consequences from changes in quantities demanded and supplied, and on price responses.

In general, the estimated demand elasticities are small with the exception of the estimated pistachio elasticity (unit elastic). The same observation is true on the supply side; most of the short-run price elasticities are small except for the empirical estimate for melon and the estimated elasticities for pistachio, peach, citrus, cherry, and strawberry.

CHAPTER 5: RESULTS AND CONCLUSION

Results of this analysis indicate that bird and rodent caused damage to California crops has large negative impacts to both the producers and consumers of those crops. The first section (Section 5.1) provides the results from the direct financial cost analysis. The second section (Section 5.2) provides the results from the equilibrium displacement and economic surplus models. The third section (Section 5.3) is a sensitivity analysis of the EDM and economic surplus models. The fourth section (5.4) is a discussion of the implications on consumer and producer surpluses if assumption of perfect competition does not hold. The final section (Section 5.5) is a discussion of the conclusions of this dissertation.

5.1 Direct Financial Cost Analysis Results

The value of yield loss and pest control expenditures associated with current management practices was derived and was used to determine the direct financial costs to producers. The result of the direct financial cost analysis is presented in Tables 5.1 and 5.2. Compared to a situation where there is no bird and rodent damage, the total crop losses attributed to bird and rodent damage were calculated as a range depending on the level of modeled damage. For a low level of damage, total crop loss was calculated as \$975 m (Table 2). A mid-level of modeled damage caused a loss of \$1,267 m in damage. When the modeled level of damage was high, the cost of damage in terms of crop loss was $1,548 m. Expenditure on control was calculated as $178 m with the majority of the control expenditures in Regions 4 ($36 m), 5 ($27 m), and 6 ($98 m) (Table 5.2).

Results were separated into losses for each crop by region, total loss by crop, and total loss by region. This allows observations to be made about the financial cost of damage by crop and region. For example, the financial cost of bird and rodent damage to lettuce and strawberries was the greatest in Region 4 ($67 m and $89 m, respectively).

The combined direct financial cost of bird and rodent damage was the sum of the crop loss at each damage level and the expenditure on control. This was calculated as a range from $1,153 m to $1,726 m (Table 5.2).

Table 5.1: Result: Annual financial cost of bird and rodent damage by crop ($).

		Damage Level		
Crop	**Region**	*low*	*mid*	*high*
Almond				
	5	14,115,766	18,626,171	23,044,144
	6	87,562,658	115,260,088	142,259,406
	Total	*101,678,423*	*133,886,260*	*165,303,550*
Pistachio				
	5	249,312	328,974	407,004
	6	24,142,944	31,779,733	39,224,037
	8	5,670	7,482	9,256
	Total	*24,397,926*	*32,116,189*	*39,640,297*
Walnut				
	2	13,176	17,386	21,510
	5	8,552,172	11,284,844	13,961,515
	6	14,006,412	18,436,858	22,755,635
	7	209,984	277,080	342,801
	Total	*22,781,744*	*30,016,168*	*37,081,461*

		Damage Level		
Crop	**Region**	*low*	*mid*	*high*
Citrus				
	4	1,543,166	2,014,240	2,465,888
	5	180,648	235,614	288,236
	6	79,640,731	103,952,201	127,261,176
	7	66,326	86,507	105,828
	8	27,005,441	35,222,524	43,089,084
	Total	*108,436,312*	*141,511,086*	*173,210,212*
Cherry				
	4	872,499	1,138,842	1,394,202
	5	169,146	220,613	269,884
	6	14,842,389	19,373,241	23,717,260
	8	25,220	32,894	40,240
	Total	*15,909,254*	*20,765,589*	*25,421,587*
Grape				
	1	3,122,641	4,072,782	4,982,393
	4	69,113,925	90,211,937	110,439,963
	5	12,259,433	15,989,672	19,560,788
	6	85,889,506	112,108,505	137,246,350
	7	1,497,238	1,952,810	2,388,949
	8	16,000,787	20,869,428	25,530,383
	Total	*187,883,529*	*245,205,135*	*300,148,826*
Peach				
	4	58,385	76,207	93,295
	5	3,255,957	4,246,663	5,195,108
	6	25,780,840	33,650,810	41,196,258
	7	644,697	840,862	1,028,659
	8	24,251	31,630	38,694
	Total	*29,764,129*	*38,846,172*	*47,552,014*
Broccoli				
	4	15,048,433	19,720,481	24,234,985
	6	2,415,992	3,166,079	4,591,630
	8	3,567,070	4,733,580	5,889,098
	Total	*21,031,496*	*27,620,140*	*34,715,714*
Lettuce				
	4	51,338,265	67,277,123	82,678,513
	6	9,792,707	12,833,023	18,611,191
	8	4,333,645	5,750,841	7,154,684
	Total	*65,464,616*	*85,860,987*	*108,444,388*

Crop	**Region**	*low*	*mid*	*high*
		Damage Level		
Rice				
	2	66,234	87,893	109,349
	5	7,992,763	10,606,571	13,195,749
	6	572,643	750,430	922,222
	7	156,028	207,053	257,597
	Total	*8,787,668*	*11,651,947*	*14,484,917*
Tomato				
	4	1,762,980	2,310,328	2,839,218
	5	9,245,287	12,268,697	15,263,619
	6	37,196,616	48,744,952	59,903,873
	8	2,598,636	3,448,446	4,290,249
	Total	*50,803,518*	*66,772,424*	*82,296,959*
Melon				
	5	162,259	215,321	267,883
	6	12,032,364	15,768,020	19,377,709
	7	1,040,973	1,381,394	1,718,607
	Total	*13,235,595*	*17,364,735*	*21,364,199*
Artichoke				
	4	6,987,259	9,012,551	10,909,930
	8	268,146	351,680	432,526
	Total	*7,255,404*	*9,364,231*	*11,342,457*
Strawberry				
	4	69,241,800	89,311,887	108,114,389
	5	53,539	70,218	86,360
	6	125,933	162,435	196,632
	7	47,127	61,808	76,017
	8	34,543,505	45,304,721	55,719,600
	Total	*104,011,903*	*134,911,069*	*164,192,997*
Hay (alfalfa and others)				
	1	584,467	740,487	881,707
	2	7,615,502	9,648,417	11,488,489
	3	8,927,927	11,311,186	13,468,368
	4	2,726,059	3,453,766	4,112,441
	5	17,958,525	22,752,451	27,091,623
	6	126,026,235	159,668,219	190,118,914
	7	2,575,179	3,262,608	3,884,828
	8	47,259,983	59,875,766	71,294,812
	Total	*213,673,878*	*270,712,900*	*322,341,182*

Table 5.2: Result: Annual financial cost of bird and rodent damage by region, control expenditures by region, and state total financial cost ($).

Region	Damage Level			Control Expenditures
	low	*mid*	*high*	
1	3,707,107	4,813,269	5,864,100	1,674,052
2	7,694,912	9,753,696	11,619,348	1,234,757
3	8,927,927	11,311,186	13,468,368	1,410,204
4	218,692,770	284,527,361	347,282,825	36,081,878
5	74,194,805	96,845,810	118,631,914	27,104,983
6	520,027,969	675,654,595	827,382,292	97,935,912
7	6,237,552	8,070,122	9,803,285	1,398,215
8	135,632,355	175,628,992	213,488,627	11,236,456
State Total	**975,115,396**	**1,266,605,032**	**1,547,540,760**	**178,076,457**

Results from the direct financial analysis indicate that birds and rodents have a direct financial impact in reducing income from lower production and increasing production costs. These results provide an important reference point for identifying the impacts of birds and rodents to agriculture. The losses for each region and crop are highly correlated with the crop's relative importance to California agriculture. For example, the financial cost of bird and rodent damage to lettuce and strawberries was the greatest in Region 4 ($67 m and $89 m, respectively). This is expected because the majority of those crops are grown in that region. Additionally, regions 4 and 6 sustained the greatest amount of loss, $219 m and $520 m respectively (low damage estimate). This makes sense because the majority of modeled crops are grown in these two regions.

5.2 EDM and economic surplus model results

Table 5.3 provides the estimated effect of a complete elimination of bird and rodent damage on selected California crops under alternate damage parameters. If damage and control costs were absent, equilibrium price would fall and quantity would increase for all modeled crops. For example, consider the market for almonds. Comparing the current situation to the situation of complete elimination of bird and rodent damage and any costs associated with control and if a mid-level of damage is assumed (second row under "almond"), it is estimated that the equilibrium price of almonds would fall by 5.6%, and equilibrium quantity produced would increase by 3.86%. As a result, it is predicted that the industry total revenue would fall by 1.23%.

Total changes in consumer and producer surpluses are presented in Table 5.4. The estimated gain in consumer surplus resulting from an absence of bird and rodent damage and an elimination of control costs is between $689.6 m and $1,148.5 m. The estimated gain in producer surplus is between $396.0 m and $658.8 m.

Table 5.3: Result: Measuring the costs of bird and rodent damage when damage is completely eliminated.

Crop	**δ**	**Change In (%)**				**Change In ($)**	
Almond		***P***	***Q***	***TR***	***A***	***CS***	***PS***
	Low	-4.20	2.90	-1.23	-1.37	27,174,099	78,125,533
	Mid	-5.60	3.86	-1.66	-1.71	36,189,775	104,045,603
	High	-7.00	4.83	-2.09	-2.04	45,237,219	129,904,785
Pistachio							
	Low	-2.01	2.01	0.00	-6.83	12,562,427	12,562,427
	Mid	-2.68	2.68	0.00	-7.50	16,693,125	16,693,125
	High	-3.35	3.35	0.00	-8.17	20,866,406	20,795,433
Walnut							
	Low	-5.86	2.81	-3.02	-1.12	6,055,329	19,377,052
	Mid	-7.81	3.75	-4.03	-1.41	8,067,990	25,817,570
	High	-9.77	4.69	-5.05	-1.70	10,084,988	32,248,837

Crop	**δ**	**Change In (%)**				**Change In ($)**	
Citrus		***P***	***Q***	***TR***	***A***	***CS***	***PS***
	Low	-4.05	2.91	-1.11	-4.31	66,451,442	47,845,038
	Mid	-5.40	3.89	-1.49	-5.66	88,165,118	63,478,885
	High	-6.74	4.86	-1.87	-7.01	110,206,398	78,955,483
Cherry							
	Low	-4.76	2.14	-2.51	-5.10	11,603,335	5,221,501
	Mid	-6.35	2.86	-3.39	-6.68	15,415,304	6,936,887
	High	-7.93	3.57	-4.26	-8.27	19,269,130	8,639,715
Grape							
	Low	-8.24	1.98	-5.58	-7.53	142,665,893	57,066,357
	Mid	-10.99	2.64	-7.67	-9.18	189,841,590	75,936,636
	High	-13.74	3.30	-9.75	-10.83	237,301,987	94,730,995
Peach							
	Low	-3.68	3.28	-0.40	-3.91	16,564,956	14,742,811
	Mid	-4.91	4.37	-0.53	-5.13	21,964,463	19,548,372
	High	-6.14	5.46	-0.67	-6.36	27,455,579	24,299,579
Broccoli							
	Low	-4.99	0.95	-3.97	-2.90	16,478,668	5,492,889
	Mid	-6.65	1.26	-5.31	-3.84	21,946,136	7,315,379
	High	-8.52	1.62	-6.83	-4.91	28,066,687	9,343,019
Lettuce							
	Low	-5.73	2.52	-3.08	-2.59	32,630,528	35,893,581
	Mid	-7.64	3.36	-4.15	-3.35	43,426,956	47,769,652
	High	-9.79	4.31	-5.35	-4.21	55,911,298	61,367,496
Rice							
	Low	-0.95	0.34	-0.61	-2.23	21,511,684	17,209,347
	Mid	-1.58	0.57	-1.01	-2.52	28,667,777	22,934,222
	High	-2.21	0.80	-1.42	-2.80	35,834,721	28,653,309
Tomato							
	Low	-7.42	1.85	-5.35	-2.29	27,502,777	25,465,534
	Mid	-9.89	2.47	-7.20	-2.96	36,633,751	33,920,140
	High	-12.36	3.09	-9.06	-3.62	45,792,189	42,357,793
Melon							
	Low	-1.38	3.07	1.67	-1.54	4,358,760	9,304,277
	Mid	-1.84	4.09	2.23	-2.02	5,775,580	12,328,642
	High	-2.30	5.11	2.79	-2.50	7,219,475	15,314,477
Artichoke							
	Low	-11.11	2.45	-7.40	-9.05	6,170,034	1,809,877
	Mid	-14.82	3.26	-10.29	-11.83	8,200,720	2,405,545
	High	-18.52	4.08	-13.18	-14.61	10,250,900	2,997,400

Crop	**δ**	**Change In (%)**				**Change In ($)**	
Strawberry		***P***	***Q***	***TR***	***A***	***CS***	***PS***
	Low	-5.20	1.46	-3.71	-6.58	91,848,545	20,574,074
	Mid	-6.93	1.94	-4.95	-8.74	122,024,648	27,333,521
	High	-8.67	2.43	-6.20	-10.91	152,530,811	34,043,680
Hay (alfalfa and others)							
	Low	-30.58	3.36	-26.44	-16.43	206,063,518	45,333,974
	Mid	-40.77	4.48	-35.51	-21.52	273,974,706	60,274,435
	High	-50.96	5.61	-44.58	-26.62	342,468,382	75,129,465

Table 5.4: Result: Total change in consumer and producer surplus.

	Change in ($ m)	
δ	***Consumer surplus***	***Producer surplus***
low	689.6	396.0
mid	917.0	526.7
high	1,148.5	658.8

When analyzing the equilibrium displacement model and economic surplus results, as expected, equilibrium prices fell and quantities increased for each crop in each region. This is consistent with the hypothesized shift out of the supply curve. These impacts are relatively small in terms of individual price and Q change, but are large when aggregated. Strength of the price and quantity changes depends on the elasticity assumptions. With relatively lower supply elasticity, price decreases less and quantity increases less comparable to the case with higher supply elasticity. With relatively lower demand elasticity, price falls more and quantity increases less as compared to the case with higher demand elasticity. In this analysis, citrus, cherry, grape, peach, broccoli, rice, tomato, artichoke, strawberry and alfalfa have price elasticities of supply greater than the price elasticities of demand. Almond, walnut, lettuce and melon have supply elasticities that were less elastic than their demand elasticities. Only pistachio was modeled with an identical price elasticities of supply and demand. In the case of pistachios, the assumption that the elasticities of supply and demand are unitary resulted in an equal price and quantity change.

When reviewing the changes in producer and consumer surplus, the general conclusion is that consumers gain relatively more than producers. In the case where the price elasticity of supply is greater than the price elasticity of demand, consumers gained more than producers when there was an elimination of damage. In the case of pistachios, an identical gain in consumer and producer surplus existed.

Each modeled market experienced a decrease in total revenue except for melons. In each case, except for melons, the change in price was greater than the change in quantity. Change in total revenue will be larger the greater the relative change in price compared to the change in quantity. This is evident in the markets for grapes, broccoli, artichoke, and alfalfa. In these markets, the change in price was at least 100% greater than the change in quantity. Melons were the only modeled crop that experienced an increase in total revenue. In this market, both elasticities were greater than 1 and the demand elasticity was greater than 2. This caused the quantity to increase more than the price decrease leading to an increase in total revenue.

Additionally, acres in production fell for all modeled crops. This is not necessarily a bad result. This result indicates that the growers are getting higher yields per acre without bird and rodent damage than with the damage causing the productivity per acre to increase.

5.3 Sensitivity analysis

The above analysis is for the case that bird and rodent damage is completely eliminated. In recognizing that the complete elimination of bird and rodent damage may be unattainable, I have conducted a sensitivity analysis. The results of this sensitivity analysis are presented in Tables 5.5 and 5.6. I assumed that damage was reduced at 50% of the level of the estimated low, mid, and high rates presented in Table 4.5. I also assumed that there would be no change in control costs. This modeled scenario would represent a possible improvement in bird and rodent control methods which reduce damage by 50% while maintaining current control costs.

Table 5.5: Sensitivity analysis: Measuring the costs of bird and rodent damage when damage is reduced by 50%.

Crop	δ	Change In (%)				Change In ($)	
Almond		***P***	***Q***	***TR***	***A***	***CS***	***PS***
	Low	-2.10	1.45	-0.65	-0.50	13,610,875	39,131,265
	Mid	-2.80	1.93	-0.87	-0.67	18,137,244	52,144,576
	High	-3.50	2.41	-1.08	-0.84	22,671,555	65,142,666
Pistachio							
	Low	-1.01	1.01	0.00	-1.01	6,313,151	6,313,151
	Mid	-1.34	1.34	0.00	-1.34	8,403,340	8,403,340
	High	-1.68	1.68	0.00	-1.68	10,504,175	10,486,432
Walnut							
	Low	-2.93	1.41	-1.52	-0.44	3,030,916	9,698,932
	Mid	-3.91	1.88	-2.03	-0.59	4,039,776	12,927,285
	High	-4.88	2.34	-2.54	-0.73	5,049,721	16,153,325
Citrus							
	Low	-2.02	1.46	-0.57	-2.02	33,471,423	24,099,425
	Mid	-2.70	1.94	-0.76	-2.70	44,519,363	32,053,941
	High	-3.37	2.43	-0.94	-3.37	55,649,204	39,969,146

Crop	**δ**	**Change In (%)**				**Change In ($)**	
Cherry		***P***	***Q***	***TR***	***A***	***CS***	***PS***
	Low	-2.38	1.07	-1.31	-2.38	5,833,060	2,624,877
	Mid	-3.17	1.43	-1.75	-3.17	7,763,461	3,493,558
	High	-3.97	1.78	-2.18	-3.97	9,704,327	4,359,099
Grape							
	Low	-4.12	0.99	-3.13	-2.47	71,546,471	28,618,589
	Mid	-5.50	1.32	-4.18	-3.30	95,300,395	38,120,158
	High	-6.87	1.65	-5.22	-4.12	119,125,494	47,602,748
Peach							
	Low	-1.84	1.64	-0.20	-1.84	8,351,184	7,432,554
	Mid	-2.45	2.18	-0.27	-2.45	11,104,376	9,882,895
	High	-3.07	2.73	-0.34	-3.07	13,880,471	12,319,647
Broccoli							
	Low	-2.49	0.47	-2.02	-1.42	8,253,633	2,751,211
	Mid	-3.33	0.63	-2.69	-1.90	10,998,489	3,666,163
	High	-4.26	0.81	-3.45	-2.43	14,065,956	4,685,516
Lettuce							
	Low	-2.86	1.26	-1.60	-1.15	16,360,497	17,996,547
	Mid	-3.82	1.68	-2.14	-1.53	21,793,893	23,973,282
	High	-4.89	2.15	-2.74	-1.96	28,059,331	30,831,531
Rice							
	Low	-0.95	0.34	-0.61	-0.43	2,480,698	1,984,558
	Mid	-1.27	0.46	-0.81	-0.57	3,306,646	2,645,317
	High	-1.59	0.57	-1.01	-0.71	4,133,308	3,305,695
Tomato							
	Low	-3.71	0.93	-2.78	-1.00	13,771,986	12,751,839
	Mid	-4.94	1.24	-3.71	-1.33	18,353,494	16,993,976
	High	-6.18	1.54	-4.63	-1.67	22,941,867	21,231,874
Melon							
	Low	-0.69	1.53	0.84	-0.72	2,199,687	4,695,485
	Mid	-0.92	2.04	1.12	-0.96	2,923,891	6,241,382
	High	-1.15	2.56	1.40	-1.20	3,654,863	7,777,646
Artichoke							
	Low	-5.56	1.22	-4.33	-4.17	3,099,638	909,227
	Mid	-7.41	1.63	-5.78	-5.56	4,126,352	1,210,397
	High	-9.26	2.04	-7.22	-6.95	5,157,940	1,510,613

Crop	**δ**	**Change In (%)**				**Change In ($)**	
Strawberry		***P***	***Q***	***TR***	***A***	***CS***	***PS***
	Low	-2.60	0.73	-1.87	-3.25	46,171,816	10,342,487
	Mid	-3.47	0.97	-2.50	-4.33	61,452,402	13,765,338
	High	-4.33	1.21	-3.12	-5.42	76,815,502	17,175,867
Hay (alfalfa and others)							
	Low	-15.29	1.68	-13.61	-7.64	103,468,625	22,763,097
	Mid	-20.39	2.24	-18.14	-10.19	137,764,004	30,308,081
	High	-25.48	2.80	-22.68	-12.74	172,205,005	37,831,706

Table 5.6: Sensitivity analysis: Total change in consumer and producer surplus when damage is reduced by 50%.

	Change in ($ m)	
δ	***Consumer surplus***	***Producer surplus***
low	338.0	192.1
mid	450.0	255.8
high	563.6	320.4

Table 5.5 provides the estimated effect of a 50% reduction of the damage caused by birds and rodents on selected California crops. If damage was reduced and control costs were at the same level, equilibrium price would fall and quantity would increase for all modeled crops. For example, consider the market for walnuts. Comparing the current situation to the situation of a 50% reduction of bird and rodent damage with no change in costs associated with control and if a mid-level of damage is assumed (second row under "walnut"), it is estimated that the equilibrium price of walnuts would fall by 3.91%, and equilibrium quantity produced would increase by 1.88%. As a result, it is predicted that the industry total revenue would fall by 2.03%.

Total changes in consumer and producer surpluses of this sensitivity analysis are presented in Table 5.6. The estimated gain in consumer surplus resulting from a 50%

reduction of bird and rodent damage is between $338.0 m and $563.5 m. The estimated gain in producer surplus is between $192.1 m and $320.4 m.

5.4 Implications on consumer and producer surpluses if assumption of perfect competition does not hold

Within the food supply chain, it is possible that market power can exist at any step, from the farm supplier to the consumer. This is an important issue because when there is market power market participants have some influence on market price and an alternative model to perfect competition is required. Two potential institutional sources of producer market power exist in California agricultural markets: federal and state marketing programs and grower cooperatives.

When looking at market power arising from marketing orders, two crops with active quantity control programs (almonds and pistachios) have the greatest potential to have market power. But, in the limited economic literature that has analyzed the impact on price taking behavior caused by these marketing orders, the majority of authors treat these two markets in California as perfectly competitive. For example, Crespi and Sexton (2005) evaluated the effectiveness of California almond promotion and modeled almonds as a perfectly competitive market and Kinnucan and Christian (1997) measured returns to nonprice export promotion applied to a perfectly competitive almond market. In both of these studies, the authors analyzed an impact on the demand for almonds.

In the case of an analysis of between different levels of the supply chain for food (see Figure 3.1), it may be reasonable in some scenarios to assume that perfect competition does not hold. As an example scenario, consider the market for almonds.

The most common path an almond takes from the tree to your door is relatively complicated. There are multiple levels of processing and marketing, often completed by different firms, in the almond supply chain. Crops that have strong cooperatives (such as almonds and the Almond Board of California) or a dominant firm (such as cranberry and Ocean Spray) may act as a monopolist. Producers in a cooperative market their product as a group which can lead to different pricing and output decisions which may impact producer and consumer surpluses. A simple monopoly model is shown in Figure 5.1.

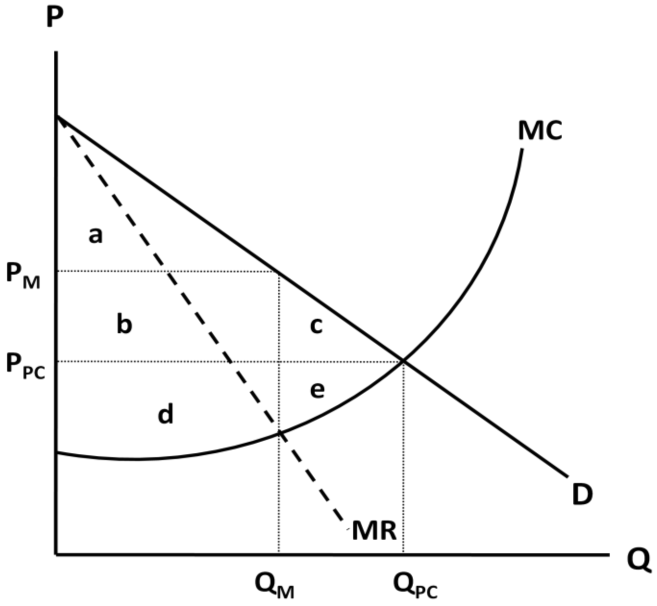

Figure 5.1: A simple monopoly model.

The pricing and quantity outcome for a monopoly is different than a perfect competitor. If the market was characterized as perfectly competitive, the market price would be P_{PC}, the market quantity would be Q_{PC}, consumer surplus would be areas $a+b+c$, and producer surplus would be areas $d+e$. If instead this market is dominated by a monopoly, output would be restricted to Q_M and price would be higher (P_M). Consumer surplus is smaller (only area a) and producer surplus is now areas $b+d$. A monopoly gains from their market power if area *d* is larger than area *e*. There is a net loss to society (deadweight loss) due to this market power represented by areas *c+e*. When this distortion of market power exists, the general conclusion is that the producers gain less than the consumers (and society) lose (Just et al., 2004). An interesting result of research related to cooperatives is that the existence of the check-off program for almonds can act as a procompetitive factor that diminishes a dominant firm's attempts at excluding competition (Crespi and Marette, 2009). This is applicable to almond market or the cranberry market where there is a dominant firm (Blue Diamond and Ocean Spray, respectively).

There can also be the case of a bilateral monopoly. A bilateral monopoly is a market where a monopsonist and a monopolist exist. When this is the market scenario, both the buyer and the seller are in a bargaining situation where there is no prediction on who will get the better part of the bargain. In general, the monopoly power and the monopsony power will tend to counteract each other. The outcome will not be a perfectly competitive outcome, but it will be closer to the perfectly competitive outcome as compared to a monopoly or monopsony outcome. A bilateral monopoly could exist if a cooperative was selling to a dominant handler and packer.

5.5 Conclusion and future work

California is the nation's most important agricultural state with more than $36 billion in agricultural production. Bird and rodent damage to these crops impose costs on its producers. These producers face a loss of crops, reduction in crop yield, and loss of crop quality relative to the potential yield and quality that would be possible without pests. In cases where pest damage is significant and impacts multiple producers, the loss in yield can have broad economic significance. The importance of California agriculture implies that negative impacts (e.g., bird and rodent damage or drought) to agricultural production can have a major effect on the state's economy and consumers throughout the U.S. and around the world. Understanding the aggregate impact of damage caused by birds and rodents to multiple economically important crops in California agriculture is crucial. The results of this study indicate that bird and rodent have caused negative impacts on California producers and consumers.

In this dissertation, I reviewed previous analyses related to crop damage caused by pest species and the economic theory used to analyze this crop damage. I then developed a model based on the theory. I gathered data, analyzed my data, and then completed my analysis. The contribution of this dissertation is twofold. The first contribution is the aggregation and analysis of an amount of damage data previously unanalyzed. This study analyzed a large database of 206 damage estimates from 43 studies related to 15 crops across 6 (of 8) regions of California. These bird and rodent damage data have never been aggregated or analyzed with an EDM. With respect to my damage data, I use a meta-analysis to combine and describe the characteristics of the data. The analysis of such a large amount of data is a unique contribution to the study of the economic impacts of crop damage in California. The second contribution is an estimate of the welfare impacts of bird and rodent damage. Results indicate that the negative impacts of damage can be substantial. Through the inclusion of a more complete damage data set, the impact of this damage on consumer and producer surpluses was estimated with greater accuracy and yielded predictive and interpretive value to the profession.

This study is just the beginning of all the analyses that could be completed related to bird and rodent damage in California. One future study would be to integrate the results of this study with additional supply or demand shocks. For example, these results can be used to measure the changes in welfare of consumers and producers with respect to changes in pest control policies, changes in pest control licensure requirements, or changes to the laws related to the threatened and endangered species.

These results can be used by the California state government to ensure that pest control is available to mitigate the negative impact cause by the pest species. One future step that can be taken with this data and this study is to conduct an analysis of the marginal benefits of pest control. Currently available data is insufficient to estimate, on a broad scale, the marginal efficacy of any single control method.

The results of this model are beneficial to agricultural producers because there is increased information and transparency of the costs and benefits of production. Certain crops and regions experience more damage than others. Producers in these hardest hit regions can use these results to more efficiently implement management strategies and techniques to mitigate the negative impact.

The agricultural sector is a fundamental segment of the California economy not only because it contributes substantially to general economic activity and employment in the state, but also because it provides inputs to almost all other sectors in the economy. An additional study would be to use the information from this study in an input-output analysis to determine the regional multiplier effects of damage.

Another study that could be completed would be to analyze the impacts to consumers because food prices decrease when there is an absence of bird and rodent damage. Although their budget share spent on food is low, any change in price of agriculture will impact the amount of agricultural products purchased by consumers. The consequences of increased food prices include changing consumption patterns with impacts on nutrition.

Additionally, a future study could include the integration of additional data such as long-run elasticities, income elasticities, trade, or the inclusion of related markets. This analysis could be expanded through the inclusion of separate short and long run price elasticities. Long-run price elasticities are all greater than their short-run counterparts so that the long run results would be expected to cause a smaller price decrease and a larger quantity increase. It has been estimated that the long-run price supply elasticities for almonds and alfalfa are greater than one. Furthermore, in general, income elasticities are all less than one for the modeled crops which would mean that these crops are viewed as necessities. Agriculture producers in California export a large volume of crops. The United States is a net exporter of food and because bird and rodent damage cause higher prices, this indicates that agricultural producers in the U.S. are not as competitive as they could be. Analyzing how trade would be impacted if bird and rodent damage was eliminated would be an interesting extension of this study. Finally, the inclusion of related markets could be through the integration of cross-price elasticities into the EDM model (horizontal integration of related markets) or through estimating the impact of the changes in price and quantity in a production process (vertical integration of related markets).

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APPENDIX A

Identification of Bird and Rodent Damage

Table A1: Almond damage matrix

Damage per acre (%)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
3.00	*4.00*	*15.00*	Vertebrate pests	California	2008	Marsh, 2008.
-	*1.52 - 2.07*	*5.05*	Vertebrate pests	Fresno County	2008	Sagardia and Sagardia, 2008.
-	*15.00*	-	Vertebrate pests	Fresno County	2008	Taber, 2008.
-	*0.0065*	-	Birds, crows	Fresno County	2003	Delwiche et al., 2007.
-	*0.0335*	-	Birds, crows	Fresno County	2003	Delwiche et al., 2007.
-	*0.33525*	-	Birds, crows	Yuba County	2003	Delwiche et al., 2007.
-	*0.004*	-	Birds, crows	Fresno County	2003	Delwiche et al., 2007.
-	*0.058*	-	Birds, crows	Fresno County	2003	Delwiche et al., 2007.
-	*0.0315*	-	Birds, crows	Yuba County	2003	Delwiche et al., 2007.
-	*0.0065*	-	Birds, crows	Fresno County	2002	Delwiche et al., 2007.
-	*0.242*	-	Birds, crows	Fresno County	2002	Delwiche et al., 2007.
-	*0.94*	-	Birds, crows	Yuba County	2002	Delwiche et al., 2007.
-	*0.006*	-	Birds, crows	Fresno County	2002	Delwiche et al., 2007.
-	*0.0755*	-	Birds, crows	Fresno County	2002	Delwiche et al., 2007.
-	*0.06675*	-	Birds, crows	Yuba County	2002	Delwiche et al., 2007.
-	*0.0989*	-	Crows	Sacramento Valley	1999	Salmon et al., 2000.
-	*2.03*	-	Crows	Sacramento Valley	1999	Salmon et al., 2000.
-	*0.0465*	-	Crows	Sacramento Valley	1999	Salmon et al., 2000.
-	*0.0407*	-	Crows	Sacramento Valley	1999	Salmon et al., 2000.
-	*0.023*	-	Crows	Sacramento Valley	1999	Salmon et al., 2000.
-	*0.71*	-	Crows	San Joaquin Valley	1999	Salmon et al., 2000.
-	*7.05*	-	Crows	Sacramento Valley	1999	Salmon et al., 2000.
-	*0.97*	-	Crow, Magpie, Scrub Jay	Sacramento Valley	1998	Salmon et al., 1999.
-	*1.39*	-	Crow, Magpie, Scrub Jay	Sacramento Valley	1998	Salmon et al., 1999.
-	*6.10*	-	Crow, Magpie, Scrub Jay	Sacramento Valley	1998	Salmon et al., 1999.

Table A1: Almond damage matrix cont.

Damage per acre (%)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
-	*3.25*	-	Crow, Magpie, Scrub Jay	Sacramento Valley	1998	Salmon et al., 1999.
-	*2.44*	-	Crow, Magpie, Scrub Jay	Sacramento Valley	1998	Salmon et al., 1999.
-	*0.128*	-	Crows	Sacramento Valley	1998	Salmon et al., 1999.
-	*0.03 - 0.04*	-	Deer mice	Central Valley and Sacramento Valley	1997 - 99	Pearson et al., 2000.
-	*0.07 - 0.10*	-	Deer mice	Central Valley and Sacramento Valley	1997 - 99	Pearson et al., 2000.
-	*0.10 - 0.16*	-	Birds, crows, magpies	Central Valley and Sacramento Valley	1997 - 99	Pearson et al., 2000.
-	*0.06 - 0.09*	-	Western gray squirrel	Central Valley and Sacramento Valley	1997 - 99	Pearson et al., 2000.
-	*2.34*	-	Crows	Yolo County	1997	Salmon et al., 1997.
-	*1.32*	-	Crows	Yolo County	1997	Salmon et al., 1997.
-	*29.53*	-	Crows	Sutter County	1997	Salmon et al., 1997.
-	*10.57*	-	Crows	Sutter County	1997	Salmon et al., 1997.
-	*4.22*	-	Crows	Sutter County	1997	Salmon et al., 1997.
-	*3.50*	-	Vertebrate pests	California	1996 - 97	Hueth et al., 1997.
3.00		*4.00*	Crows	Yuba and Sutter Counties	1988	Hasey and Salmon, 1993.
1.00-5.00	*6.00-10.00*	*11.00-50.00*	Crows	Yuba and Sutter Counties	1987	Hasey and Salmon, 1993.
-	*4.10*	-	Crow, Scrub Jay, Magpie	Merced County	1984	CDFA, 1984.
-	*3.00*	-	Crow, Scrub Jay, Magpie	San Joaquin County	1984	CDFA, 1984.
-	*1.50*	-	Crow, Scrub Jay, Magpie	Butte County	1984	CDFA, 1984.
-	*30.00*	-	Crow, Scrub Jay, Magpie	Fresno County	1984	CDFA, 1984.
-	*6.00*	-	Crow, Scrub Jay, Magpie	Colusa County	1984	CDFA, 1984.

Table A1: Almond damage matrix cont.

Damage per acre (%)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
-	*1.00*	-	Crow, Scrub Jay, Magpie	Kings County	1984	CDFA, 1984.
-	*1.80*	-	Crow, Scrub Jay, Magpie	Glenn County	1984	CDFA, 1984.
-	*16.00*	-	Crow, Scrub Jay, Magpie	Tulare County	1984	CDFA, 1984.
-	*0.12*	-	Crow, Scrub Jay, Magpie	Solano County	1984	CDFA, 1984.
-	*5.00*	-	Crow, Scrub Jay, Magpie	Contra Costa County	1984	CDFA, 1984.
6.00	-	*18.00*	Crows	Tulare County	1966	Simpson, 1972.
-	*7.00*	-	Birds, linnets, crows, jays, etc.	Sacramento Valley	1935 - 36	Emlen, 1937.
-	*21.00*	-	Birds, linnets, crows, jays, etc.	Sacramento Valley	1935 - 36	Emlen, 1937.
-	*28.00*	-	Birds, linnets, crows, jays, etc.	Sacramento Valley	1935 - 36	Emlen, 1937.

Table A2: Artichoke damage matrix

Damage per acre (%)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
20.00	-	*30.00*	Voles, gophers	California	2008	Roach, 2008.
1.50	*3.00*	-	Vertebrate pests	California	2008	Marsh, 2008.
-	*15.00*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table A3: Broccoli damage matrix

Damage per acre (%)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
-	*0.60*	-	Birds and rodents	Fresno County	2008	Strmiska, 2008.
-	*0.10*	-	Vertebrate pests	California	2008	Marsh, 2008.
-	*100.00*	-	Ground squirrels	Santa Cruz County	2003-04	Muramoto et al., 2005.

Table A4: Cherries damage matrix

Damage per acre (%)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
5.00	-	*6.00*	Vertebrate pests	California	2008	Marsh, 2008.
-	-	*50.00*	Birds	Fresno County	2008	Taber, 2008.
7.62	-	*10.00*	Birds	California	1975-76	DeHaven et al., 1979.

Table A5: Citrus damage matrix

Damage per acre (%)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
-	*3.50*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.
-	*0.50*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table A6: Table grapes damage matrix

Damage per acre (%)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
0.76	-	*0.95*	Birds	Fresno County	2008	Pitts, 2008.
0.07	-	*0.14*	Rodents	Fresno County	2008	Pitts, 2008.
-	-	*25 - 35*	Birds	Fresno County	2008	Vasquez, 2008.
-	*0.50 – 1.00*	-	Rodents	Fresno County	2008	Vasquez, 2008.
-	*0.87*	-	Wildlife damage	California	1998	NASS, 1999.
-	*3.50*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.
0.43	-	*0.71*	Birds	California	1976	Razee, 1976.
-	*1.00*	-	Birds	California	1973	Stone, 1973.
0.10	*9.60*	*30.00*	Birds	California	1973	Crase et al., 1976.

Table A7: Wine grapes damage matrix

Damage per acre (%)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
-	-	*25 - 35*	Birds	Fresno County	2008	Vasquez, 2008.
-	*0.50 – 1.00*	-	Rodents	Fresno County	2008	Vasquez, 2008.
-	-	*30 - 35*	Birds	Napa County	2008	Goymerac, 2008.
3.00	*5.00*	-	Birds	Napa County	2008	Goymerac, 2008.
0.50	-	*2.00*	Birds	Fresno and Napa Counties	2008	Taber, 2008.
50.00	-	*60.00*	Birds	Fresno and Napa Counties	2008	Taber, 2008.
1.00	*13.00*	*20.00*	Birds	Napa County	2008	Witmer, 2008.
-	*11.10*	-	Birds	Napa and Sonoma Counties	2005	Berge et al., 2007.
-	*14.90*	-	Birds	Napa and Sonoma Counties	2005	Berge et al., 2007.
-	*7.70*	-	Birds	Napa and Sonoma Counties	2005	Berge et al., 2007.
-	*2.80*	-	Birds	Napa and Sonoma Counties	2005	Berge et al., 2007.
-	*6.50*	-	Birds	Napa and Sonoma Counties	2005	Berge et al., 2007.
-	*3.80*	-	Birds	Napa and Sonoma Counties	2005	Berge et al., 2007.
-	*0.70*	-	Birds	Napa and Sonoma Counties	2005	Berge et al., 2007.
-	*7.70*	-	Birds	Napa and Sonoma Counties	2004	Berge et al., 2007.
-	*11.60*	-	Birds	Napa and Sonoma Counties	2004	Berge et al., 2007.
-	*5.30*	-	Birds	Napa and Sonoma Counties	2004	Berge et al., 2007.
-	*8.50*	-	Birds	Napa and Sonoma Counties	2004	Berge et al., 2007.
-	*8.40*	-	Birds	Napa and Sonoma Counties	2004	Berge et al., 2007.
-	*2.00*	-	Birds	Napa and Sonoma Counties	2004	Berge et al., 2007.
-	*1.20*	-	Birds	Napa and Sonoma Counties	2004	Berge et al., 2007.
-	*0.50*	-	Birds	Napa and Sonoma Counties	2004	Berge et al., 2007.
-	*0.87*	-	Wildlife damage	California	1998	NASS, 1999.
-	*1.02*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.
-	*11.00*	-	House finch	Sonoma County	1996	Gadd, 1996.
-	*2.50*	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.

Table A7: Wine grapes damage matrix cont.

Damage per acre (%)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
-	*1.50*	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.
-	*4.75*	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.
-	*2.00*	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.
-	*2.50*	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.
-	*2.00*	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.
-	*1.25*	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.
-	*1.00*	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.
-	*7.75*	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.
-	*5.50*	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.
-	*3.25*	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.
-	*13.30*	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.
-	*7.75*	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.
-	*4.00*	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.

Table A7: Wine grapes damage matrix cont.

Damage per acre (%)			Pest	Region	Year of study	Source
Low	Mid	High				
-	2.50	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.
-	2.50	-	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Hothem et al., 1981.
-	1.40	-	House finches, quail, and robins	Napa, Sonoma, and San Joaquin Counties	1977-78	DeHaven and Hothem, 1980.
-	2.60	-	House finches, quail, and robins	Napa, Sonoma, and San Joaquin Counties	1977-78	DeHaven and Hothem, 1980.
-	6.30	-	House finches, quail, and robins	Napa, Sonoma, and San Joaquin Counties	1977-78	DeHaven and Hothem, 1980.
-	9.80	-	House finches, quail, and robins	Napa, Sonoma, and San Joaquin Counties	1977-78	DeHaven and Hothem, 1980.
-	15.10	-	House finches, quail, and robins	Napa, Sonoma, and San Joaquin Counties	1977-78	DeHaven and Hothem, 1980.
-	76.80	-	House finches, quail, and robins	Napa, Sonoma, and San Joaquin Counties	1977-78	DeHaven and Hothem, 1980.
0.43	-	0.71	Birds	California	1976	Razee, 1976,
-	1.00	-	Birds	California	1973	Stone, 1973.
0.10	9.60	30.00	Birds	California	1973	Crase et al., 1976.
-	10.00	-	Birds	Alameda County	1973	DeHaven, 1974a.
-	3.70	-	Birds	Mendocino County	1973	DeHaven, 1974a.
-	11.40	-	Birds	Monterey County	1973	DeHaven, 1974a.
-	16.90	-	Birds	Napa County	1973	DeHaven, 1974a.
-	17.80	-	Birds	San Benito County	1973	DeHaven, 1974a.
-	54.70	-	Birds	Santa Clara County	1973	DeHaven, 1974a.
-	11.70	-	Birds	Solano County	1973	DeHaven, 1974a.
-	14.70	-	Birds	Sonoma County	1973	DeHaven, 1974a.

Table A8: Alfalfa hay damage matrix

Damage per acre (%)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
-	*17.00*	*50.00*	Vertebrate pests	California	2008	Marsh, 2008.
-	*7.60*	-	Belding's ground squirrel	Surprise Valley	1999	Whisson et al., 2000.
-	*6.97*	-	Belding's ground squirrel	Butte Valley	1999	Whisson et al., 2000.
-	*9.50*	-	Belding's ground squirrel	Butte Valley	1998	Whisson et al., 2000.
-	*10.76*	-	Belding's ground squirrel	Surprise Valley	1998	Whisson et al., 2000.
-	*7.60*	-	Belding's ground squirrel	Butte Valley	1997	Whisson et al., 2000.
-	*7.83*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.
-	*37.00*	-	Belding's ground squirrel	Siskiyou County, Butte Valley	1996	Whisson et al., 1999.
-	*45.90*	-	Belding's ground squirrel	Siskiyou County, Butte Valley	1996	Whisson et al., 1999.
-	*34.60*	-	Belding's ground squirrel	Siskiyou County, Butte Valley	1996	Whisson et al., 1999.
-	*18.30*	-	Belding's ground squirrel	Siskiyou and Modoc Counties	1995	Whisson et al., 1999.
-	*48.00*	-	Belding's ground squirrel	Siskiyou and Modoc Counties	1995	Whisson et al., 1999.
-	*36.10*	-	Belding's ground squirrel	South central Oregon	1977	Kalinowski et al., 1981.
-	*53.80*	-	Belding's ground squirrel	South central Oregon	1977	Kalinowski et al., 1981.
-	*42.80*	-	Belding's ground squirrel	South central Oregon	1977	Kalinowski et al., 1981.
-	*40.00*	-	Belding's ground squirrel	South central Oregon	1977	Kalinowski et al., 1981.
-	*28.80*	-	Belding's ground squirrel	South central Oregon	1977	Kalinowski et al., 1981.
-	*28.80*	-	Belding's ground squirrel	South central Oregon	1977	Kalinowski et al., 1981.
-	*29.80*	-	Belding's ground squirrel	South central Oregon	1977	Kalinowski et al., 1981.
-	*17.60*	-	Belding's ground squirrel	South central Oregon	1977	Kalinowski et al., 1981.
-	*17.90*	-	Belding's ground squirrel	South central Oregon	1977	Kalinowski et al., 1981.

Table A8: Alfalfa hay damage matrix cont.

Damage per acre (%)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
-	*17.60*	-	Belding's ground squirrel	South central Oregon	1977	Kalinowski et al., 1981.
-	*20.30*	-	Belding's ground squirrel	South central Oregon	1977	Kalinowski et al., 1981.
-	*17.50*	-	Belding's ground squirrel	Siskiyou and Modoc Counties	1975-78	Sauer, 1984.
-	*28.40*	-	Belding's ground squirrel	Siskiyou and Modoc Counties	1975-78	Sauer, 1984.
-	*19.50*	-	Belding's ground squirrel	Siskiyou and Modoc Counties	1975-78	Sauer, 1984.
-	*21.10*	-	Belding's ground squirrel	Siskiyou and Modoc Counties	1975-78	Sauer, 1984.
-	*19.50*	-	Belding's ground squirrel	Siskiyou and Modoc Counties	1975-78	Sauer, 1984.
-	*38.50*	-	Belding's ground squirrel	Siskiyou and Modoc Counties	1975-78	Sauer, 1984.
-	*17.10*	-	Belding's ground squirrel	Siskiyou and Modoc Counties	1975-78	Sauer, 1984.

Table A9: Lettuce damage matrix

Damage per acre (%)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
-	*1.00*	-	Birds	Santa Cruz and Monterey Counties	2008	Bolda, 2008.
3.00	-	*4.00*	Birds	Fresno County	2008	Maya, 2008.
0.00	-	-	Rodents	Fresno County	2008	Maya, 2008.
-	-	*50.00*	Birds	Fresno County	2008	Maya, 2008.
1.00	-	*2.00*	Rodents	Fresno County	2008	Maya, 2008.
30.00	-	*100.00*	Birds and rodents	Fresno County	2008	Strmiska, 2008.
-	*20.00*	-	Rodents	Fresno County	2008	Strmiska, 2008.
2.00	-	*3.00*	Vertebrate pests	California	2008	Marsh, 2008.
-	*30.00*	-	Birds	Fresno County	2008	Taber, 2008.
-	*0.60*	-	Horned lark	San Joaquin Valley	1999	York et al., 2000. .
-	*3.75*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table A10: Melon damage matrix

Damage per acre (%)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
10.00	-	*20.00*	Rodents	Fresno County	2008	Strmiska, 2008.
-	*1.00*	-	Rodents	Fresno County	2008	Strmiska, 2008.
-	*1.38*	-	Vertebrate pests	California	2008	Marsh, 2008.
-	*0.10*	-	Birds	Fresno County	2008	Taber, 2008.
-	*1.38*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table A11: Peaches damage matrix

Damage per acre (%)			Pest	Region	Year of study	Source
Low	***Mid***	***High***				
-	*0.10*	-	Birds	Fresno County	2008	Taber, 2008.
1.00	-	*2.00*	Vertebrate pests	California	2008	Marsh, 2008.
3.00	-	*4.00*	Vertebrate pests	California	2008	Marsh, 2008.
-	*0.68*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table A12: Pistachio damage matrix

Damage per acre (%)			Pest	Region	Year of study	Source
Low	***Mid***	***High***				
3.00	*4.00*	*15.00*	Vertebrate pests	California	2008	Marsh, 2008.
-	*15.00*	-	Birds	Fresno County	2008	Taber, 2008.
-	*5.75*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.
-	*0.91*	-	Crows	California	1993	Hasey and Salmon, 1993.
-	*4.00*	-	Birds	Tulare County	1985	Crabb et al., 1986.
-	*7.87*	-	Birds	Tulare County	1985	Crabb et al., 1986.
-	*12.20*	-	Birds	Tulare County	1985	Crabb et al., 1986.
2.00	*4.00*	*10.00*	Crow, Raven, Jay, Starling, Magpies	California	1984	Crabb et al., 1986.
-	*24.00*	-	Crow, Scrub Jay, Magpie	Tulare County	1984	CDFA, 1984.

Table A13: Rice damage matrix

Damage per acre (%)			Pest	Region	Year of study	Source
Low	***Mid***	***High***				
-	*1.00*	-	Blackbirds	California	2001	Cummings et al., 2005.
0.10	*0.20*	*3.00*	Birds	Sacramento Valley	1972	Stone, 1973.
-	*0.10*	-	Birds	Sacramento Valley	1971	DeHaven, 1971.

Table A14: Rice (wild) damage matrix

Damage per acre (%)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
1.00	-	*10.00*	Blackbirds	Sacramento Valley	1993	Marcum and Gorenzel, 1994.

Table A15: Strawberry damage matrix

Damage per acre (%)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
-	*0.10*	-	Vertebrate pests	Santa Cruz and Monterey Counties	2008	Bolda, 2008.
-	*0.10*	*10.00*	Vertebrate pests	Santa Cruz and Monterey Counties	2008	Molinar, 2008.
-	*1.28*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table A16: Tomatoes (fresh and processing) damage matrix

Damage per acre (%)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
0.10	*1.00*	-	Vertebrate pests	California	2008	Marsh, 2008.
-	*1.38*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.
-	*0.50*		Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table A17: Walnut damage matrix

Damage per acre (%)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
-	*0.00*	-	Vertebrate pests	California	2008	Marsh, 2008.
-	*3.00*	*5.00*	Birds	Fresno County	2008	Taber, 2008.
-	*2.80*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.
-	*4.00*	-	Crow, Scrub Jay, Magpie	Tulare County	1984	CDFA, 1984.
-	*0.90*	-	Crow, Scrub Jay, Magpie	Butte County	1984	CDFA, 1984.
-	*6.00*	-	Crow, Scrub Jay, Magpie	Merced County	1984	CDFA, 1984.
6.00		*18.00*	Crows	Tulare County	1966	Simpson, 1972.

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APPENDIX B

Identification of Pest Control Expenditures

Table B1: Almond control cost matrix

Control cost per acre ($)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
-	*26.00*	-	Gopher and squirrel	San Joaquin Valley	2006	Duncan et al., 2006a; 2006b.
-	*15.00*	-	Gopher and squirrel	San Joaquin Valley	2007	Holtz et al., 2007a.
-	*20.00-30.00*	-	Vertebrate	Fresno County	2008	Sagardia and Sagardia, 2008.
-	*10.00-15.00*	-	Crows	San Joaquin Valley	1999	Salmon et al., 2000.
-	*37.00*	-	Crows	Sacramento Valley	1999	Salmon et al., 2000.
-	*150.00-200.00*	-	Birds	Fresno County	2008	Taber, 2008.
-	*20.00*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.
-	*10.00 (+75 to construct bait stations)*	-	Pocket gophers and ground squirrels	Sacramento Valley	2006	Connell et al., 2006.
10.00	*19.00*	*23.00*	Pocket gophers and ground squirrels	San Joaquin Valley	200 2008	Freeman et al., 2008.

Table B2: Artichoke control cost matrix

Control cost per acre ($)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
-	*90.00*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table B3: Broccoli control cost matrix

Control cost per acre ($)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
-	*115.00 – 120.00*	-	birds and rodents	Fresno County	2008	Strmiska, 2008.

Table B4: Cherries control cost matrix

Control cost per acre ($)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
-	*36.00*	*50.00*	Birds	Fresno County	2008	Taber, 2008.

Table B5: Citrus control cost matrix

Control cost per acre ($)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
-	*10.00*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.
-	*5.00*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table B6: Table grapes control cost matrix

Control cost per acre ($)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
-	*570.51*	-	Birds	California	1973	Crase and DeHaven, 1973.
-	*10.00 – 20.00*	-	Birds	Fresno County	2008	Pitts, 2008.
-	*1.00 – 2.00*	-	rodents	Fresno County	2008	Pitts, 2008.
-	*15.00*	-	Vertebrate	San Joaquin Valley (south)	2007	Vasquez et al., 2007.
-	*26.00*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.
-	*15.00*	*40.00*	Pocket gophers and ground squirrels	San Joaquin Valley	2007	Peacock et al., 2007.
-	*15.00*	-	Vertebrate	Fresno County	2008	Vasquez, R., 2008.

Table B7: Wine grapes control cost matrix

Control cost per acre ($)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
-	*570.51*	-	Birds	California	1973	Crase and DeHaven, 1973.
-	*100.00*	-	Vertebrate	North Coast, Sonoma County	2004	Smith et al., 2004.
-	*11.00*	-	Pocket gophers and ground squirrels	North Coast, Lake Valley	2008	McGourty et al., 2008.
-	*15.00*	-	Vertebrate	Fresno County	2008	Vasquez, 2008.
-	*21.00*	-	Pocket gophers and ground squirrels	North Coast, Lake Valley	2008	McGourty et al., 2008.
-	*250.00*	-	Birds	Napa County	2008	Goymerac, 2008.
-	*45.00*	-	Birds	Napa County	2008	Taber, 2008.
-	*11.00*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table B8: Alfalfa hay control cost matrix

Control cost per acre ($)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
-	*6.00*	-	Pocket gophers and ground squirrels	Siskiyou and Butte counties	2007	Orloff et al., 2007.
-	*25.00*	-	Belding's ground squirrel	Butte and Surprise Valleys	1997-99	Whisson et al., 2000.
-	5.00	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table B9: Lettuce control cost matrix

Control cost per acre ($)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
-	*5.00*	-	Birds	Santa Cruz and Monterey Counties	2008	Bolda, 2008.
-	*65.00*	-	Birds	Fresno County	2008	Maya, 2008.
-	*1.00 – 2.00*	-	Rodents	Fresno County	2008	Maya, 2008.
-	*100*	-	Birds	Fresno County	2008	Strmiska, 2008.
-	*15.00 – 20.00*	-	Rodents	Fresno County	2008	Strmiska, 2008.
-	*24.00*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table B10: Melon control cost matrix

Control cost per acre ($)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
-	*5.00*	-	Rodents	Fresno County	2008	Strmiska, 2008.
-	*10.00*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table B11: Peaches control cost matrix

Control cost per acre ($)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
-	*10.00*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table B12: Pistachio control cost matrix

Control cost per acre ($)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
-	*53.00*	-	Gopher, squirrel	San Joaquin Valley	2007	Beede et al., 2007.
-	*150.00-200.00*	-	Birds	Fresno	2008	Taber, 2008.
-	*20.00*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table B13: Rice control cost matrix

Control cost per acre ($)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
-	*22.00*	-	Bird management	Sacramento Valley	2007	Mutters et al., 2007.

Table B14: Rice (wild) control cost matrix

Control cost per acre ($)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
-	*56.00*	-	Birds	Intermountain Region, Shasta and Lassen Counties	2005	Marcum et al., 2005.
29.84	*30.90*	*39.97*	Blackbirds	Sacramento Valley, northern California	1993	Marcum and Gorenzel, 1994.

Table B15: Strawberry control cost matrix

Control cost per acre ($)			Pest	Region	Year of study	Source
Low	*Mid*	*High*				
-	*21.00*	-	Rodents	Santa Cruz and Monterey Counties	2006	Bolda et al., 2006.
-	*21.00*	-	Pocket gophers	Santa Cruz and Monterey Counties	2006	Bolda et al., 2006.
-	*10.00*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table B16: Tomatoes (fresh and processing) control cost matrix

Control cost per acre ($)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
-	*5.00*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.
-	*40.00*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

Table B17: Walnut control cost matrix

Control cost per acre ($)			**Pest**	**Region**	**Year of study**	**Source**
Low	***Mid***	***High***				
-	*36.00*	-	Rodents	North Coast - Lake County	2005	Elkins et al., 2005.
-	*18.00*	-	Gopher and squirrel	Lake County	2007	Elkins et al., 2007.
-	*12.00*	-	Gopher	San Joaquin Valley	2005	Grant et al., 2007.
-	*3.00*	-	Gopher	Sacramento Valley	2006	Hasey et al., 2006.
-	*10.00*	-	Gopher and squirrel	Sacramento Valley	2007	Krueger et al., 2007.
-	*14.00*	-	Vertebrate pests	California	1996-97	Hueth et al., 1997.

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APPENDIX C

Three Year Crop Production Acreage, Yield, and Price Data

Table C1: Alfalfa crop data

Alfalfa					**Regional**		
Region		A	Y	P per A	Total A	Ave Y	Ave P
1	Del Norte	2211.33	3.00	262.70	4328.00	3.00	859.04
	Humboldt	2116.67	3.00	1482.05			
	Mendocino						
2	Shasta	23366.67	4.28	653.84	92360.67	5.13	524.51
	Siskiyou	68994.00	5.42	489.92			
	Trinity						
3	Lassen	64000.00	3.54	356.77	117517.00	3.98	483.27
	Modoc	45883.67	4.77	623.02			
	Plumas	7633.33	2.92	397.74			
4	Alameda	4501.00	2.76	293.19	44918.67	2.63	386.05
	Contra Costa	4926.67	4.54	577.74			
	Lake						
	Marin	1921.67	2.48	173.03			
	Monterey	779.00	3.07	351.73			
	Napa	188.00	1.25	217.91			
	San Benito	13130.00	1.42	126.15			
	San Francisco						
	San Luis Obispo	10830.00	3.22	452.57			
	San Mateo	508.33	2.55	329.84			
	Santa Clara	3668.00	2.99	559.85			
	Santa Cruz	116.00	2.66	113.99			
	Sonoma	4350.00	2.27	262.15			
5	Butte	1810.33	6.03	742.96	218483.67	5.10	522.87
	Colusa	11916.67	5.52	677.23			
	Glenn	60894.00	5.73	213.49			
	Sacramento	19753.67	5.20	574.60			
	Solano	37159.67	5.68	699.66			
	Sutter	10064.00	4.25	720.56			
	Tehama	10329.33	3.41	363.20			
	Yolo	64712.33	4.50	699.96			
	Yuba	1843.67	3.01	220.03			
6	Fresno	100633.00	7.10	956.58	797719.00	6.86	1004.96
	Kern	206333.00	6.94	947.70			
	Kings	66066.67	6.76	1006.72			
	Madera	40633.33	6.89	975.71			
	Merced	120620.00	6.35	920.25			
	San Joaquin	99133.00	5.50	817.29			

	Stanislaus	62500.00	6.37	896.90			
	Tulare	101800.00	8.78	1378.89			
7	Alpine	7.67	2.00	234.78	23698.50	4.96	691.24
	Amador	1653.33	5.95	349.95			
	Calaveras	290.00	0.98	106.90			
	El Dorado	251.67	1.70	199.47			
	Inyo	4850.00	5.07	722.29			
	Mariposa						
	Mono	13766.67	5.41	764.88			
	Nevada						
	Placer	979.17	2.17	243.71			
	Sierra	1900.00	3.08	425.18			
	Tuolumne						
8	Imperial	277190.33	6.27	756.30	361562.67	6.69	831.48
	Los Angeles	8418.67	6.78	1230.40			
	Orange						
	Riverside	59016.33	7.77	995.51			
	San Bernardino	12013.67	12.31	1097.73			
	San Diego**						
	Santa Barbara	4923.67	3.40	431.97			
	Ventura						

**omitted because data was unreliable

Table C2: Artichoke crop data

Artichoke					**Regional**		
Region		A	Y	P per A	Total A	Ave Y	Ave P
1	Del Norte						
	Humboldt						
	Mendocino						
2	Shasta						
	Siskiyou						
	Trinity						
3	Lassen						
	Modoc						
	Plumas						
4	Alameda				7156.17	6.97	9655.48
	Contra Costa						
	Lake						
	Marin						
	Monterey	6839.00	7.03	9718.38			

	Napa						
	San Benito	237.50	5.97	8098.13			
	San Francisco						
	San Luis Obispo						
	San Mateo	79.67	4.50	7379.37			
	Santa Clara						
	Santa Cruz						
	Sonoma						
5	Butte						
	Colusa						
	Glenn						
	Sacramento						
	Solano						
	Sutter						
	Tehama						
	Yolo						
	Yuba						
6	Fresno						
	Kern						
	Kings						
	Madera						
	Merced						
	San Joaquin						
	Stanislaus						
	Tulare						
7	Alpine						
	Amador						
	Calaveras						
	El Dorado						
	Inyo						
	Mariposa						
	Mono						
	Nevada						
	Placer						
	Sierra						
	Tuolumne						
8	Imperial				670.67	6.30	8015.44
	Los Angeles						
	Orange						
	Riverside	670.67	6.30	8015.44			
	San Bernardino						

	San Diego		
	Santa Barbara		
	Ventura		

Table C3: Strawberry crop data

Strawberry					**Regional**	
Region		A	Y	P per A	Total A	Ave Y
1	Del Norte					
	Humboldt					
	Mendocino					
2	Shasta					
	Siskiyou					
	Trinity					
3	Lassen					
	Modoc					
	Plumas					
4	Alameda				13810.50	33.45
	Contra Costa					
	Lake					
	Marin					
	Monterey	9248.00	34.69	51745.67		
	Napa					
	San Benito					
	San Francisco					
	San Luis Obispo	1004.33	32.17	41457.35		
	San Mateo	15.33	27.57	17422.60		
	Santa Clara	82.50	12.39	18905.23		
	Santa Cruz	3460.33	31.02	45970.68		
	Sonoma					
5	Butte				93.33	5.30
	Colusa					
	Glenn					
	Sacramento	93.33	5.30	11500.00		
	Solano					
	Sutter					
	Tehama					
	Yolo					
	Yuba					
6	Fresno				134.33	10.70

	Kern						
	Kings						
	Madera						
	Merced	134.33	10.70	9270.47			
	San Joaquin						
	Stanislaus						
	Tulare						
7	Alpine				36.67	9.97	
	Amador						
	Calaveras						
	El Dorado						
	Inyo						
	Mariposa						
	Mono						
	Nevada						
	Placer	36.67	9.97	25766.67			
	Sierra						
	Tuolumne						
8	Imperial				20627.67	27.33	
	Los Angeles	113.00	12.92	33250.74			
	Orange	1417.00	25.24	31383.32			
	Riverside	323.33	7.89	13115.28			
	San Bernardino	124.67	23.73	19818.98			
	San Diego	830.33	33.00	38346.46			
	Santa Barbara	6047.00	32.15	41162.14			
	Ventura	11772.33	25.41	28775.80			

Table C4: Melon crop data

Melon					**Regional**		
Region		Acres	Yield	Price	Total A	Ave Y	Ave P
1	Del Norte						
	Humboldt						
	Mendocino						
2	Shasta						
	Siskiyou						
	Trinity						
3	Lassen						
	Modoc						
	Plumas						
4	Alameda						

	Contra Costa						
	Lake						
	Marin						
	Monterey						
	Napa						
	San Benito						
	San Francisco						
	San Luis Obispo						
	San Mateo						
	Santa Clara						
	Santa Cruz						
	Sonoma						
5	Butte				4211.33	12.82	2700.30
	Colusa						
	Glenn						
	Sacramento						
	Solano						
	Sutter	2550.33	15.68	2836.94			
	Tehama						
	Yolo	1661.00	8.44	2310.40			
	Yuba						
6	Fresno	32673.00	14.45	4537.08	46441.00	18.00	4949.55
	Kern	3722.00	41.69	5375.96			
	Kings	811.67	14.57	4261.60			
	Madera						
	Merced	5383.00	19.16	4405.54			
	San Joaquin	2070.00	32.09	8518.68			
	Stanislaus	1781.33	15.33	3328.41			
	Tulare						
7	Alpine						
	Amador						
	Calaveras						
	El Dorado						
	Inyo						
	Mariposa						
	Mono						
	Nevada						
	Placer						
	Sierra						
	Tuolumne						
8	Imperial	10347.67	15.51	5346.07	14204.67	15.87	5136.07
	Los Angeles						

	Orange						
	Riverside	3715.67	17.31	4647.37			
	San Bernardino						
	San Diego	141.33	4.60	1652.30			
	Santa Barbara						
	Ventura						

Table C5: Rice crop data

Rice					**Regional**		
Region		A	Y	P per A	Total A	Ave Y	Ave P
1	Del Norte						
	Humboldt						
	Mendocino						
2	Shasta	5100.00	0.69	910.19	5100.00	0.69	910.19
	Siskiyou						
	Trinity						
3	Lassen						
	Modoc						
	Plumas						
4	Alameda						
	Contra Costa						
	Lake						
	Marin						
	Monterey						
	Napa						
	San Benito						
	San Francisco						
	San Luis Obispo						
	San Mateo						
	Santa Clara						
	Santa Cruz						
	Sonoma						
5	Butte	101235.67	3.95	1123.76	506676.80	3.73	1105.57
	Colusa	142516.67	3.96	1117.03			
	Glenn	84660.00	4.11	1091.87			
	Sacramento	4752.00	3.95	1745.34			
	Solano						
	Sutter	102091.30	3.87	1097.03			
	Tehama	266.67	3.50	819.00			
	Yolo	35695.83	0.79	898.60			

		A	Y	P per A	Total A	Ave Y	Ave P
	Yuba	35458.67	3.77	1019.46			
6	Fresno	3910.00	2.90	685.51	13275.67	3.41	824.03
	Kern						
	Kings						
	Madera						
	Merced	3256.00	3.53	839.78			
	San Joaquin	4663.00	3.67	884.91			
	Stanislaus	1446.67	3.64	890.09			
	Tulare						
7	Alpine				11500.00	3.58	950.89
	Amador						
	Calaveras						
	El Dorado						
	Inyo						
	Mariposa						
	Mono						
	Nevada						
	Placer	11500.00	3.58	950.89			
	Sierra						
	Tuolumne						
8	Imperial						
	Los Angeles						
	Orange						
	Riverside						
	San Bernardino						
	San Diego						
	Santa Barbara						
	Ventura						

Table C6: Tomato crop data

Tomato					**Regional**		
Region		A	Y	P per A	Total A	Ave Y	Ave P
1	Del Norte						
	Humboldt						
	Mendocino						
2	Shasta						
	Siskiyou						
	Trinity						
3	Lassen						
	Modoc						

	Plumas						
4	Alameda				4164.00	33.78	8088.22
	Contra Costa	1416.33	45.95	3349.26			
	Lake						
	Marin						
	Monterey	606.00	19.27	12205.72			
	Napa						
	San Benito	1605.00	34.10	6818.59			
	San Francisco						
	San Luis Obispo						
	San Mateo						
	Santa Clara	536.67	17.09	9979.30			
	Santa Cruz						
	Sonoma						
5	Butte				80110.67	36.35	2866.56
	Colusa	19516.67	38.59	2235.34			
	Glenn						
	Sacramento	3458.33	32.35	1851.74			
	Solano	10000.00	36.48	8375.10			
	Sutter	6666.67	35.04	2027.30			
	Tehama						
	Yolo	40469.00	35.79	2021.05			
	Yuba						
6	Fresno	133200.00	2.90	3016.20	252905.67	17.16	2809.71
	Kern						
	Kings	22989.00	40.31	2243.39			
	Madera	5100.00	35.59	2684.77			
	Merced	26878.33	27.28	3924.03			
	San Joaquin	47867.00	31.96	2612.84			
	Stanislaus	16871.33	34.59	2727.13			
	Tulare						
7	Alpine						
	Amador						
	Calaveras						
	El Dorado						
	Inyo						
	Mariposa						
	Mono						
	Nevada						
	Placer						
	Sierra						
	Tuolumne						

8	Imperial				4186.33	45.57	43504.52
	Los Angeles						
	Orange	12.00	7.73	11303.15			
	Riverside	186.00	7.15	10370.30			
	San Bernardino	50.00	18.26	9260.00			
	San Diego	2316.00	41.43	33990.98			
	Santa Barbara						
	Ventura	1622.33	57.01	54222.31			

Table C7: Lettuce crop data

Lettuce					**Regional**		
Region		A	Y	P per A	Total A	Ave Y	Ave P
1	Del Norte						
	Humboldt						
	Mendocino						
2	Shasta						
	Siskiyou						
	Trinity						
3	Lassen						
	Modoc						
	Plumas						
4	Alameda				196508.67	16.60	4990.86
	Contra Costa						
	Lake						
	Marin						
	Monterey	176440.00	16.90	7670.61			
	Napa						
	San Benito						
	San Francisco						
	San Luis Obispo	8588.00	15.33	4876.57			
	San Mateo						
	Santa Clara	6304.33	6.80	3097.76			
	Santa Cruz	5176.33	20.38	4318.51			
	Sonoma						
5	Butte						
	Colusa						
	Glenn						
	Sacramento						
	Solano						
	Sutter						

	Tehama						
	Yolo						
	Yuba						
6	Fresno	28333.00	16.82	6426.28	29353.00	16.87	6373.33
	Kern	1020.00	18.12	5008.17			
	Kings						
	Madera						
	Merced						
	San Joaquin						
	Stanislaus						
	Tulare						
7	Alpine						
	Amador						
	Calaveras						
	El Dorado						
	Inyo						
	Mariposa						
	Mono						
	Nevada						
	Placer						
	Sierra						
	Tuolumne						
8	Imperial	31126.33	13.66	5469.02	54246.67	14.65	5598.90
	Los Angeles						
	Orange						
	Riverside	3616.33	13.06	6202.18			
	San Bernardino						
	San Diego	457.33	12.13	6775.11			
	Santa Barbara	17084.00	17.13	5668.46			
	Ventura	1962.67	12.33	5593.07			

Table C8: Broccoli crop data

Broccoli		**County**			**Regional**		
Region		A	Y	P	Total A	Ave Y	Ave P
1	Del Norte						
	Humboldt						
	Mendocino						
2	Shasta						
	Siskiyou						

	Trinity						
3	Lassen						
	Modoc						
	Plumas						
4	Alameda				60980.00	7.64	4714.33
	Contra Costa						
	Lake						
	Marin						
	Monterey	47038.00	7.73	4610.03			
	Napa						
	San Benito	581.00	7.21	4916.31			
	San Francisco						
	San Luis Obispo	13035.67	7.28	4912.09			
	San Mateo						
	Santa Clara						
	Santa Cruz	325.33	10.09	10294.98			
	Sonoma						
5	Butte						
	Colusa						
	Glenn						
	Sacramento						
	Solano						
	Sutter						
	Tehama						
	Yolo						
	Yuba						
6	Fresno	9267.00	7.29	4247.37	12027.00	6.73	3837.55
	Kern						
	Kings						
	Madera						
	Merced						
	San Joaquin						
	Stanislaus	2760.00	4.83	1760.75			
	Tulare						
7	Alpine						
	Amador						
	Calaveras						
	El Dorado						
	Inyo						
	Mariposa						
	Mono						
	Nevada						

	Placer						
	Sierra						
	Tuolumne						
8	Imperial	11606.67	8.18	4470.13	57747.33	7.00	4329.15
	Los Angeles						
	Orange						
	Riverside	16714.67	6.73	4023.51			
	San Bernardino						
	San Diego						
	Santa Barbara	28250.00	6.64	4396.86			
	Ventura	1176.00	8.05	5204.93			

Table C9: Citrus crop data

Citrus					**Regional**		
Region		A	Y	P per A	Total A	Ave Y	Ave P
1	Del Norte						
	Humboldt						
	Mendocino						
2	Shasta						
	Siskiyou						
	Trinity						
3	Lassen						
	Modoc						
	Plumas						
4	Alameda				3049.00	17.63	7845.21
	Contra Costa	38.67	2.70	7974.14			
	Lake						
	Marin						
	Monterey	1211.00	23.86	11190.20			
	Napa						
	San Benito						
	San Francisco						
	San Luis Obispo	1799.33	13.76	3941.46			
	San Mateo						
	Santa Clara						
	Santa Cruz						
	Sonoma						
5	Butte	162.00	5.70	3705.76	664.00	4.87	4070.45
	Colusa						
	Glenn	498.00	4.63	4218.88			

	Sacramento						
	Solano						
	Sutter	4.00	0.41	725.00			
	Tehama						
	Yolo						
	Yuba						
6	Fresno	37575.33	12.36	5573.38	193967.00	12.58	6364.39
	Kern	44838.00	15.19	8094.49			
	Kings	2607.00	8.26	7609.00			
	Madera	4283.33	13.81	1845.60			
	Merced						
	San Joaquin						
	Stanislaus	527.33	15.76	5183.94			
	Tulare	104136.00	11.57	5899.44			
7	Alpine				163.00	2.96	6088.00
	Amador						
	Calaveras						
	El Dorado						
	Inyo						
	Mariposa						
	Mono						
	Nevada						
	Placer	163.00	2.96	6088.00			
	Sierra						
	Tuolumne						
8	Imperial	4750.00	8.11	3739.65	57678.17	13.74	7005.16
	Los Angeles						
	Orange	90.50	7.73	1444.44			
	Riverside	10079.33	10.27	6255.36			
	San Bernardino	2565.00	9.34	3746.81			
	San Diego	13523.00	12.83	3099.53			
	Santa Barbara	1638.67	18.60	9325.79			
	Ventura	25031.67	16.85	9120.85			

Table C10: Cherry crop data

Cherry					**Regional**		
Region		A	Y	P per A	Total A	Ave Y	Ave P
1	Del Norte						
	Humboldt						
	Mendocino						

2	Shasta						
	Siskiyou						
	Trinity						
3	Lassen						
	Modoc						
	Plumas						
4	Alameda				1942.33	2.93	6962.91
	Contra Costa	331.67	1.57	4798.99			
	Lake						
	Marin						
	Monterey						
	Napa						
	San Benito	620.67	3.37	9055.12			
	San Francisco						
	San Luis Obispo						
	San Mateo						
	Santa Clara	990.00	3.10	5904.13			
	Santa Cruz						
	Sonoma						
5	Butte				547.67	2.13	4620.87
	Colusa						
	Glenn						
	Sacramento	547.67	2.13	4620.87			
	Solano						
	Sutter						
	Tehama						
	Yolo						
	Yuba						
6	Fresno	2673.00	2.15	10609.80	25634.00	2.12	8975.05
	Kern	2740.00	1.59	6623.24			
	Kings						
	Madera	310.00	4.42	13587.10			
	Merced						
	San Joaquin	16533.00	2.09	8364.95			
	Stanislaus	1930.00	2.67	10173.06			
	Tulare	1448.00	2.13	12035.68			
7	Alpine						
	Amador						
	Calaveras						
	El Dorado						
	Inyo						
	Mariposa						

	Mono						
	Nevada						
	Placer						
	Sierra						
	Tuolumne						
8	Imperial				153.33	0.60	2460.87
	Los Angeles	153.33	0.60	2460.87			
	Orange						
	Riverside						
	San Bernardino						
	San Diego						
	Santa Barbara						
	Ventura						

Table C11: Grape crop data

Grape					Regional		
Region		A	Y	P per A	Total A	Ave Y	Ave P
1	Del Norte				16189.33	4.03	2885.83
	Humboldt						
	Mendocino	16189.33	4.03	2885.83			
2	Shasta						
	Siskiyou						
	Trinity						
3	Lassen						
	Modoc						
	Plumas						
4	Alameda	2101.00	3.88	3650.80	256461.00	3.91	4177.28
	Contra Costa	1930.00	4.60	3566.49			
	Lake	7769.67	4.43	5354.28			
	Marin	157.00	1.03	4495.20			
	Monterey	38660.00	6.05	6244.20			
	Napa	165478.67	3.21	2986.24			
	San Benito	3755.33	4.73	5663.61			
	San Francisco						
	San Luis Obispo	34253.33	4.71	4749.29			
	San Mateo	91.67	3.84	5567.84			
	Santa Clara	1673.33	3.62	3848.67			
	Santa Cruz	591.00	2.18	5101.97			

	Sonoma						
5	Butte				54875.00	6.15	3342.52
	Colusa						
	Glenn	1265.67	9.33	4699.76			
	Sacramento	26059.33	7.61	3247.85			
	Solano	17081.00	3.22	2302.78			
	Sutter						
	Tehama	205.00	5.35	5441.95			
	Yolo	10172.67	7.00	4154.46			
	Yuba	91.33	1.20	1791.97			
6	Fresno	50765.00	11.22	4298.07	481214.00	8.09	2766.63
	Kern	229033.00	7.30	1106.45			
	Kings	4505.33	10.80	4704.28			
	Madera	43833.33	10.43	2772.93			
	Merced	10919.33	9.11	2419.62			
	San Joaquin	93014.67	6.36	2550.35			
	Stanislaus	11033.33	9.84	2846.86			
	Tulare	38110.00	9.14	8391.52			
7	Alpine				6842.00	3.26	3274.06
	Amador	3757.33	3.54	3653.24			
	Calaveras	583.33	2.56	2860.00			
	El Dorado	1839.00	2.97	3108.21			
	Inyo						
	Mariposa	95.00	1.19	1423.51			
	Mono						
	Nevada	364.33	3.87	1248.58			
	Placer	203.00	2.48	2371.60			
	Sierra						
	Tuolumne						
8	Imperial				32442.33	4.82	7379.17
	Los Angeles	331.67	3.63	6618.09			
	Orange						
	Riverside	10374.00	5.34	10253.79			
	San Bernardino	635.00	3.70	2759.06			
	San Diego	301.67	2.10	1689.18			
	Santa Barbara	20800.00	4.65	5892.01			
	Ventura						

Table C12: Peach crop data

Peach						**Regional**	
Region		A	Y	P per A	Total A	Ave Y	Ave P
1	Del Norte						
	Humboldt						
	Mendocino						
2	Shasta						
	Siskiyou						
	Trinity						
3	Lassen						
	Modoc						
	Plumas						
4	Alameda				157.33	3.69	5752.12
	Contra Costa	157.33	3.69	5752.12			
	Lake						
	Marin						
	Monterey						
	Napa						
	San Benito						
	San Francisco						
	San Luis Obispo						
	San Mateo						
	Santa Clara						
	Santa Cruz						
	Sonoma						
5	Butte				12842.33	14.74	3793.26
	Colusa						
	Glenn						
	Sacramento						
	Solano	139.00	2.16	2156.72			
	Sutter	8121.00	14.79	3772.74			
	Tehama						
	Yolo						
	Yuba	4582.33	15.03	3836.18			
6	Fresno	20584.00	10.47	9525.78	58122.00	12.83	6875.53
	Kern	1580.00	6.83	7080.59			
	Kings	5114.33	11.59	7323.40			
	Madera	1203.33	14.15	4082.83			
	Merced	5054.67	17.61	4427.39			
	San Joaquin	2430.00	19.12	4907.68			
	Stanislaus	8266.67	20.21	6496.57			

	Tulare	13889.00	10.10	5594.36			
7	Alpine				2767.67	12.39	3485.14
	Amador	2576.67	13.15	3464.81			
	Calaveras						
	El Dorado	103.67	2.60	6239.75			
	Inyo						
	Mariposa						
	Mono						
	Nevada						
	Placer	87.33	1.63	3107.30			
	Sierra						
	Tuolumne						
8	Imperial				83.00	3.37	4371.44
	Los Angeles						
	Orange						
	Riverside	83.00	3.37	4371.44			
	San Bernardino						
	San Diego						
	Santa Barbara						
	Ventura						

Table C13: Almond crop data

Almond					**Regional**		
Region		A	Y	P per A	Total A	Ave Y	Ave P
1	Del Norte						
	Humboldt						
	Mendocino						
2	Shasta						
	Siskiyou						
	Trinity						
3	Lassen						
	Modoc						
	Plumas						
4	Alameda						
	Contra Costa						
	Lake						
	Marin						
	Monterey						

	Napa						
	San Benito						
	San Francisco						
	San Luis Obispo						
	San Mateo						
	Santa Clara						
	Santa Cruz						
	Sonoma						
5	Butte	39475.33	0.82	3588.88	121816.00	0.83	3692.35
	Colusa	28566.67	0.97	4158.19			
	Glenn	28670.00	0.80	3740.23			
	Sacramento						
	Solano	2145.00	0.68	2015.47			
	Sutter	4394.33	0.57	2523.67			
	Tehama	8054.00	0.80	3548.89			
	Yolo	9408.33	0.76	3145.26			
	Yuba	1102.33	0.62	3011.49			
6	Fresno	101467.00	1.05	4683.82	539231.67	0.95	4186.77
	Kern	109500.00	1.09	4462.07			
	Kings	10854.00	0.88	3888.64			
	Madera	61333.33	0.90	3859.45			
	Merced	87591.67	0.76	3321.97			
	San Joaquin	44333.00	0.81	3525.98			
	Stanislaus	104666.67	0.96	4332.11			
	Tulare	19486.00	0.96	4282.84			
7	Alpine						
	Amador						
	Calaveras						
	El Dorado						
	Inyo						
	Mariposa						
	Mono						
	Nevada						
	Placer						
	Sierra						
	Tuolumne						
8	Imperial						
	Los Angeles						
	Orange						
	Riverside						
	San Bernardino						

	San Diego						
	Santa Barbara						
	Ventura						

Table C14: Pistachio crop data

Pistachio					**Regional**		
Region		A	Y	P per A	Total A	Ave Y	Ave P
1	Del Norte						
	Humboldt						
	Mendocino						
2	Shasta						
	Siskiyou						
	Trinity						
3	Lassen						
	Modoc						
	Plumas						
4	Alameda						
	Contra Costa						
	Lake						
	Marin						
	Monterey						
	Napa						
	San Benito						
	San Francisco						
	San Luis Obispo						
	San Mateo						
	Santa Clara						
	Santa Cruz						
	Sonoma						
5	Butte	609.67	1.12	3971.02	1777.00	1.22	4470.52
	Colusa						
	Glenn	976.33	1.35	4916.35			
	Sacramento						
	Solano						
	Sutter						
	Tehama	191.00	0.90	3031.41			
	Yolo						
	Yuba						
6	Fresno	17367.00	1.55	5358.73	117998.00	1.45	5275.35
	Kern	47267.00	1.55	5274.41			

	Kings	11239.33	1.65	6038.41			
	Madera	24533.33	1.11	4225.86			
	Merced	4097.33	0.85	3418.16			
	San Joaquin						
	Stanislaus						
	Tulare	13494.00	1.57	6159.08			
7	Alpine						
	Amador						
	Calaveras						
	El Dorado						
	Inyo						
	Mariposa						
	Mono						
	Nevada						
	Placer						
	Sierra						
	Tuolumne						
8	Imperial				397.33	0.11	454.70
	Los Angeles						
	Orange						
	Riverside						
	San Bernardino	397.33	0.11	454.70			
	San Diego						
	Santa Barbara						
	Ventura						

Table C15: Walnut crop data

Walnut					**Regional**		
Region		A	Y	P per A	Total A	Ave Y	Ave P
1	Del Norte	205.33	0.85	457.34	205.33	0.85	457.34
	Humboldt						
	Mendocino						
2	Shasta	918.00	0.85	1395.57	918.00	0.85	1395.57
	Siskiyou						
	Trinity						
3	Lassen						
	Modoc						
	Plumas						
4	Alameda				7619.67	0.85	1405.03
	Contra Costa	568.00	1.90	2738.85			

	Lake	2699.67	0.97	1090.36			
	Marin						
	Monterey	276.00	1.20	2099.03			
	Napa	101.67	0.45	181.15			
	San Benito	1872.00	0.69	1177.52			
	San Francisco						
	San Luis Obispo	1913.33	0.47	724.39			
	San Mateo						
	Santa Clara	189.00	1.13	1964.63			
	Santa Cruz						
	Sonoma						
5	Butte	28633.33	1.81	3044.51	105360.33	1.57	2610.68
	Colusa	4706.67	1.75	2857.51			
	Glenn	12282.33	1.60	2667.95			
	Sacramento						
	Solano	7360.67	1.52	2554.89			
	Sutter	17871.00	1.11	2950.98			
	Tehama	15971.00	1.62	1892.50			
	Yolo	9100.33	1.42	1555.80			
	Yuba	9435.00	1.67	2638.69			
6	Fresno	5638.00	1.60	2828.01	122695.67	1.77	3223.08
	Kern	1477.00	1.34	2363.35			
	Kings	9505.00	1.92	3565.56			
	Madera	1360.00	1.34	2332.84			
	Merced	5866.00	1.34	2370.50			
	San Joaquin	43700.00	1.61	2750.04			
	Stanislaus	27266.67	1.95	3507.31			
	Tulare	27883.00	1.95	3692.24			
7	Alpine				2608.33	1.41	1676.97
	Amador	392.33	1.81	453.02			
	Calaveras	750.00	0.70	1088.89			
	El Dorado						
	Inyo						
	Mariposa						
	Mono						
	Nevada						
	Placer	1466.00	1.66	2161.00			
	Sierra						
	Tuolumne						
8	Imperial						
	Los Angeles						
	Orange						

Riverside San Bernardino San Diego Santa Barbara Ventura	