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Blueberry production in Oregon is highly reliant upon the ecosystem services of native pollinators, which provide as much as a quarter of the total pollination services received by Blueberry growers. However, the health of these pollinator populations may be affected in yet unforeseen ways as growers adopt new pest management regimes to combat a new invasive pest, spotted wing Drosophila (*Drosophila susukii)*. In order to fully understand what is at stake with the usage of new regimes, this paper attempts to put monetary values to the services currently provided by native pollinators. The benefits of these services were analyzed from the perspective of both producers and consumers of Oregon blueberries through the use of the welfare measures of producer and consumer surplus. Welfare measures were derived for two separate scenarios, one of which holds Oregon blueberry prices constant while the other has Oregon blueberry prices fluctuate with supply. Using these methods, the calculated total welfare from native pollinator services ranged from $9 to a high of $41 million.

The Economic Value of Native Pollinators in Regard to Oregon Blueberry Production

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Daniel J. Ritter, Author

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DEDICATION

This thesis is dedicated to all of my comrades in the Coalition of Graduate Employees local 6069 AFT-OR, AFL-CIO. The passion of all its officers, stewards, activists, and members were a daily inspiration.

Chapter 1-Introduction

1.1 Blueberry Production in Oregon

Oregon is in the midst of a blueberry boom with the number of harvested acres increasing from 1,950 acres in 1995 to 6,100 in 2010, representing a 213% increase in acreage over the 15-year period (Julian et al. 2011; "Oregon Blueberry Production Experiencing Unprecedented Growth" 2013). As of 2011, Oregon held nearly 11% of the total harvested acreage in the United States and 15% of total national blueberry production (USDA/NASS Fr Nt 3-15, 2012). Oregon has also witnessed a change in the composition of blueberry production with a growing proportion of blueberries destined for fresh market sales. Where in the past processors absorbed most of Oregon's blueberry harvest, fresh blueberries now account for approximately half of total Oregon blueberry production (Julian et al. 2011).

The reasons behind this meteoric growth stem from both rising consumer demand for blueberries and the unique features of the Pacific Northwest that prove to be beneficial for berry production. On the demand side, per capita blueberry consumption in the US has exploded over the past 40 years. In 1970 the average person was consuming 6.9 ounces of blueberries a year, while in 2009 the average was 31.4 ounces, a 355% increase. This is in part attributable to rising disposable incomes as well as aggressive marketing by growers' organizations that emphasize the nutritional benefits of blueberries which are rich in vitamins and antioxidants (Kaiser, 2010). Interestingly, blueberry markets have not seen a jump in real prices accompanying this increase in consumption. In fact, blueberry prices in real terms have slightly declined since the

1970s, suggesting that supply has kept pace with demand (Kaiser, 2010; "Oregon Blueberry Production Experiencing Unprecedented Growth" 2013).

Aside from these demand factors, the climate of the Pacific Northwest is well suited for blueberry cultivation. This is reflected in both the quantity and quality of the berries. Some of the highest per acre yields in the U.S. are found in Oregon, which is in part attributable to its mild climate and dry summers that reduce the incidence of disease (Brazelton, 2011; USDA/NASS Fr Nt 3-15, 2012). Oregon's cool, summer night are also known to result in berries that are superior in taste and texture when compared to those from the Midwest and Southeast ("Oregon Blueberry Production Experiencing Unprecedented Growth" 2013). This climate-driven comparative advantage seems poised to fuel the boom for years to come, and given the 50 year lifecycle of the northern highbush blueberry plan**t** (*Vaccinium corymbosum*), blueberries are likely to remain a prominent feature in Oregon agriculture for quite some time (Strik and Finn, 2008).

1.2 Spotted Wing Drosophila and the Challenge to Growers

Drosophila suzukii, commonly known as Spotted Wing Drosophila (SWD), is an invasive vinegar fly native to Southeast Asia. It appeared in California in 2008 infecting numerous berry crops and stone fruits. In 2009, SWD began impacting berry producers within the Pacific Northwest and has since spread to the eastern United States, as well as Canada, Mexico, and Europe. The fly seems to prefer caneberries, but blueberry farmers have been hard hit due to later harvesting seasons, when the pressure from the fly is high. Fresh market producers have zero tolerance for infection, leading to product downgrades and lower prices for their berries. Commercial producers can tolerate at least some maggots in a small amount of the fruit depending on the usage (Bolda, et al. 2010; Dreves and Langellotto, 2013; Peerbolt, 2012; Strik and Finn, 2008).

Prior to the presence of SWD, Oregon growers had relatively few pests afflicting their blueberry crops. Standard practice for larger growers involved a single application of a synthetic pesticide during the harvest season with many conventional growers forgoing pesticides altogether. Pest management costs were thus significantly lower than in other regions of the US, providing a considerable financial advantage to Oregon growers (Brazelton, 2011; Peerbolt, 2012; DeFrancesco and Bell, 2013). The recent appearance of SWD in harvested blueberries has since changed this operational norm and new means of controlling the pest are currently under development. One tool currently being implemented includes pesticide applications every 5-7 days during the 6 week harvest period, requiring a significant investment in monitoring, pesticides, application equipment, and trained personnel. In the past, these investments have been cost prohibitive for smaller scale producers, which could leave them disproportionately affected by the pest. Furthermore, the frequency of applications could speed the rate at which SWD becomes resistant to current pesticide families. Growers will therefore be pushed to adopt alternative and typically more expensive pesticides, marking the beginning of a biological arms race between SWD and growers (Peerbolt, 2012).

There are also concerns as to how new spraying schedules will affect overall demand for blueberries. Consumers have expressed preference for blueberries that have not been sprayed with synthetic pesticides and in the case of u-pick operations, consumers are prohibited from picking blueberries for several days after a pesticide application due to the risk to human health (Peerbolt, 2012). It may also prevent growers from exporting produce to Asian markets, as current regulations prohibit the use of particular pesticides (Bolda et al. 2013; Peerbolt et al. 2013). To address these concerns, Oregon State University, in collaboration with USDA-ARS and other land grant universities are developing integrated pest management techniques (IPM) which would ideally reduce dependence on synthetic pesticides. Potential strategies include biological controls, sanitation practices, improved trap designs and attractants for monitoring, identification of high risk areas, and proper management of host plants on nearby lands which would be coupled with more targeted and controlled pesticide applications. However, it is too early to tell if these techniques will ultimately be cost effective (Dreves and Langellotto, 2013; Peerbolt, 2012).

1.3 Pest Management Impacts on Pollinators

Another unanswered question is how the new pest management regimes will impact the environment and non-target organisms. These concerns feed directly into the economic questions facing growers because negative environmental impacts may disrupt critical ecosystem services. Of obvious consideration would be the effects on non-target arthropods, many of which provide beneficial functions in the form of pollination, pest control, and seed dispersal (Kremen et al. 2007). Pollinators are of particular importance to blueberry bushes including highbush blueberries, the predominate cultivar of Oregon growers (Isaacs and Kirk, 2010; Strik and Finn, 2008; Rao et al. 2008). While not as dependent as varieties such as rabbiteye (*Vaccinium virgatum, Vaccinium ashei*) which are not self-fertile, highbush blueberries require the aide of pollinators if the berries are to be of marketable size and yield (Filmer and Marucci, 1963; Strik and Finn, 2008).

In order to satisfy pollination requirements, producers currently rent hives of honey bees (*Apis mellifera*) at the rate of approximately 1 to 4 hives per acre. However, this in and of itself will not guarantee that pollination requirements are being met Rao and Stephen, 2008; Rao and Stephen, 2010). There is a limited window of opportunity in which a flower can be properly pollinated, typically occurring within three days after its initial opening. Additionally, blueberries require a relatively large quantity of pollen to ensure that the fruit actually sets. It is therefore difficult to ensure that enough honey bees are available at the exact right moment, meaning that growers are receiving a substantial subsidy from the services of native pollinators. Studies have also found that native pollinators are generally more efficient in providing pollination services than commercial honey bees. Many species forage at lower temperatures than honey bees and even in adverse weather conditions such as rain, both of which are common during the blueberry bloom. Bumble bees (*Bombus spp.)* are particularly efficient due to a phenomenon known as vibratile pollination. This is where the wing muscles of the bee are vibrated during flower visitations releasing additional pollen from the anthers, which is especially beneficial to blueberries (Rao and Stephen, 2008; Rao and Stephen, 2010).

It is well known that pollinators are adversely affected by synthetic pesticides. Many pest management resources currently provide explicit warning as to the dangers they present to bees, recommending applications should be timed to minimize exposure (DeFrancesco and Bell, 2013). While growers have some control over exposure in regards to commercial bees, they have little ability to shelter native pollinators. The consequences of this collateral damage are often directly felt by growers. In one case study in Canada, applications of the pesticide, fenitrothion, to control gypsy moth were followed by a decline in both pollinator communities and blueberry production. The economic losses were such that growers pressured lawbreakers into passing a ban on the use of fenitrothion for gypsy moth control. Afterwards, both blueberry production and pollinator populations rebounded (Kremen et al. 2007).

The situation is somewhat parallel to Oregon's experience with extensive pesticide use to control SWD, the fear being that heavy pesticide use may lead to a smaller blueberry harvest. Research has shown that wild habitats adjacent to cultivated fruiting crops can provide refuge and protection for non-target species from crops sprayed regularly with pesticides (Otto et al. 2009). However, bordering habitat is also reported to be shared by SWD, which may lead some growers to spray these adjacent wildlands to help minimize SWD numbers (Dreves, unpublished data; Peerbolt, 2012). Spraying into non-crop agricultural lands could be devastating to native pollinator populations, which could increase grower reliance upon commercial honeybees. This, however, may not be a sustainable solution given that numbers of commercially available colonies have drastically declined due to colony collapse disorder (CCD) (Winfree et al.

2011). The shortages in some cases have been so acute that almond growers in 2004 prompted the United States Department of Agriculture to allow honeybees to be flown in from Australia to meet pollination needs (National Research Council of the National Academies, 2006).

While the evidence argues that highly pesticide dependent regimes are both economically and ecologically unsustainable, it is not clear that the IPM regimes under development would be at all better for native pollinators. New strategies may reduce the number of pesticide applications, but also require the modification of wildlands and habitats bordering blueberry fields. Pollinator responses to land-use changes are dependent on the spatial and temporal distribution of floral and nesting resources with the magnitude of the effect dependent upon the foraging and dispersal capabilities of the bees. The sensitivity to spatial variables cannot be overstated given the diversity of pollinator foraging behavior. Even seemingly small habitat boundaries such as roads or other such landscapes devoid of flowers can act as a barrier for pollinator movement (Kreyer et al. 2004; Kremen et al. 2007). Loss and fragmentation of habitats could adversely impact re-colonization and the ability of pollinator populations to persist both locally and regionally. Ideal habitat is found within fairly continuous areas which host a diverse number of flowering plant species that are associated with greater pollinator diversity and healthier pollinator populations (Kremen et al. 2007; Skyrm, 2011). Whether the effects are positive or negative depends upon the modifications being made as well as the specific spatial and temporal ranges at which the pollinator species operate (Kreyer et al. 2004; Kremen et al. 2007; Skyrm, 2011). Coincidentally, the plants that attract SWD are also beloved by many species of native pollinators, prime examples being Himalayan blackberry, dogwood, laurel, and flowering cherry (Lee and Dreves, unpublished data; Skyrm, 2011; Dreves and Langellotto, 2013). If growers go so far as to remove these plants from these regions they are also removing key sources of sustenance of native pollinators and thus risk reducing their populations. More research is needed in understanding what plants and habitat are critical in supporting pollinators.

Adding to the ambiguity is the difficulty in teasing out whether increased pesticide exposure or habitat destruction is the primary factor in pollinator decline. The volume of pesticide use is correlated with the decline of available floral and nesting resources from agricultural intensification (Kremen et al. 2002; Kremen et al. 2007; Tscharntke et al. 2005). This complicates any comparison between current pest management strategies and possible IPM solutions. Past research suggests that salubrious environments for pollinators occur when agriculture increases habitat heterogeneity. These landscapes typically include small field sizes, a variety of crops within or between fields, and patches of non-crop vegetation (hedgerows, fallow fields, etc.) (Kremen et al. 2007; Tscharntke et al. 2005). There is no reason why IPM techniques cannot encourage the above landscapes, but for that to happen the well being of native pollinators must become a priority in the initial design. Given the importance of pollination in regards to blueberry production, any new IPM regime should include assessments on how they impact pollinator populations and how these impacts will cost growers.

1.4 Thesis Summary

Given that benefit-cost analyses on the above pest management regimes are still forthcoming; this paper is not able to adequately provide estimates as to their respective impacts on the ecosystem services of native pollinators. It will instead provide a cross-sectional analysis of total consumer and producer welfare attributable to native pollinator services in regard to Oregon blueberry production. In this way, policy makers, growers, and researchers can have an understanding of the economic values at stake when considering possible changes to the practice of blueberry cultivation. Chapter 2 of this thesis will provide a survey of the literature on the different methods used in valuing the ecosystem services provided by pollinators. Chapter 3 will explain the methodology and assumptions adopted to analyze the benefits of pollinator services and provide a detailed description of the economic concepts used as well as their theoretical justification. More specifically, the sections of chapter 3 will be divided into sections concerning producer and consumer welfare under two separate Scenarios. On the consumer end, welfare will be calculated through estimates of consumer surplus as determined by possible demand functions for Oregon blueberries. Due to the fact that there are several plausible models of blueberry demand, there will be an additional sensitivity analysis that will address the merits of each respective model. On the producer end, a technique known as attributable net income will be used to estimate the welfare provided to producers. In essence, attributable net income is a measure of producer surplus that uses a bioeconomic model to parse out which pieces of producer surplus are in fact the ecosystem services provided by pollination. Chapter 4 will report the calculated results for each respective welfare measure. Chapter 5 will be a larger discussion on the implications of the results, how they can be improved upon, and how they can be put to use in determining the merits of differing agricultural systems as they relate to the environment.

Chapter 2- Literature Review

2.1 Introduction to Pollination Valuation Research

There is a great deal of variation among studies that attempt to place monetary values on pollination services which is in large part due to the variation in the methodologies used (Kremen et al. 2007). In their crudest form, values are assessed by summing the total market value of insect-pollinated crops (Costanza et al. 1997; Pimentel et al. 1997). The simplicity of the models used by Constanza et al. (1997) and Pimentel et al. (1997) is in part due to the fact that the studies address global ecosystem services more generally and are not solely directed towards pollinator values. A weakness of this method comes from the fact that a substantial proportion of these pollination services come from commercial pollinators which have an existing market value in the form of bee rentals (Kremen et al. 2007). This shortcoming to some extent acts as a rough dividing line in the literature, with one camp basing their analysis upon the market values of commercial pollination services (replacement cost method); and a second camp which further refines the above method that measures the value of agricultural production resulting from pollination (production value method) (Winfree et al. 2011).

2.2 Replacement Cost Method

The replacement cost method measures the number of commercial pollinators needed to replace the services currently provided by native pollinators and then calculates the cost of this substitution by using current bee rental rates (Allsopp et al. 2008; de Groot et al. 2002; Winfree et al. 2011). This concept is a variation of valuation through input or factor substitution. Under this replacement cost method, a change in net producer income associated with a change in an environmental factor is considered to be equivalent to the willingness to pay for that factor. Key assumptions are that prices of substitute inputs are constant, and purchases of the substitute input will occur only up to the point where the marginal cost of an additional input is equal to the marginal loss in net income due to a unit loss of the environmental factor (Point, 1994). In these specific cases, the substitutable input would be commercial pollinators which are purchased up to the point where there are no longer reductions in crop yield. This assumes that at all points the net income loss due to a unit loss in native pollinators exceeds the rental cost of commercial pollinator services. This could potentially lead to an inflated cost estimate if in fact rental costs at any point exceeded the marginal net income loss. In such a scenario, producers would no longer be maximizing profits and would thus be acting irrationally.

Many economic studies analyzing the services to crop production also incorporate alternative technologies aside from commercial pollinators, such as hand pollination. However, these techniques are currently very expensive and thus fail to give a realistic picture of the actual worth of native pollinator services (Allsopp et al. 2008; Winfree et al. 2011). An additional oversight of the replacement value method is that it does not incorporate the welfare pollinators provide to consumers. Substituting commercial bees for native bees will potentially have an impact on the price of the final good with potentially negative consequences to consumer welfare (Kremen et al. 2007). There a few ways in which this welfare loss can be calculated, which will be further explained in Chapter 3.

2.3 Production Value Method

The production value method is more widely used and focuses on the proportion of crop production that is truly attributable to pollination services. Instead of simply summing the market value of crops which are assisted by pollinators, these studies build bioeconomic models which introduce dependency ratios that account for the actual impact of pollination for each crop. A dependency ratio is defined as the share of a crop's yield that required the service of a pollinator. Using these ratios, these studies are able to calculate the loss of yield due to an absence of pollinators and then multiply this loss by the market value of the crop (Robinson et al. 1989; Morse and Calderone, 2000; Ricketts et al. 2004; Losey and Vaughan, 2006; Olschewski et al. 2006; Klein et al. 2007; Gallai et al. 2009; Chaplin-Kramer et al. 2011; Winfree et al. 2011). Four of the studies (Ricketts et al. 2004; Losey and Vaughan, 2006; Chaplin-Kramer et al. 2011; Winfree et al. 2011) attempt to separate the pollinator services provided by commercial and native pollinators. These data typically done by arduous observation of pollen deposition by various taxa of pollinating insects (Isaacs and Kirk, 2010; Winfree et al. 2011). From these observations the studies provide estimated shares of the deposition services provided by each species and then either directly apply these estimates, or in the case of one study, use them to build Monte Carlo simulations (Winfree et al. 2011) for extrapolation to larger geographical areas.

2.4 Net Attributable Income

Many studies studies do not account for the costs of production and thus overestimate the value of pollination services. The work of Olschewski and colleagues (2006) as well as that of Winfree and her contributors (2011) incorporate these costs into their bioeconomic model, creating what is another off-shoot of the production value method which Winfree calls “net attributable income.” Winfree’s study incorporates average variable costs into the model in such a way that the costs vary according to changes in output caused by an absence of pollinators. The assumption is that average variable costs will be an appropriate approximation for marginal costs and will fall by the same proportion that output declines. This method also defines the variation in net producer income associated with the variation of an environmental factor as equal to the producers’ willingness to pay for that factor (Point, 1994). The equations below show the explicit differences between the production value method (represented by equation 1) and net attributable income (represented by equation 2).

(1)

$$V\Delta_{pollination} = P \cdot Y \cdot D \cdot \rho$$

(2)

$$V\Delta_{pollination} = (P \cdot Y - VC) \cdot D \cdot \rho$$

Both equations represent the value of pollination where *P* is the price of the output, *Y* is the yield of the output, *VC* is the variable cost of production of the output, *D* is the dependence ratio of the crop, and ρ is the fraction of the pollination performed by the native pollinators. Olschewski et al. (2006) has a model that differs somewhat from equation (2) in that it includes total costs (TC) instead of variable costs (VC). However, total costs may be a less effective measure given that they include fixed costs, which do not vary with output (Winfree et al. 2011). Interestingly, the form of equation (2) without the bioeconomic variables of *D* and ρ is equivalent to producer surplus but neither paper explicitly draw this theoretical connection (Just et al. 1982).

2.5 Consumer Welfare from Pollination

While each method described previously sought to improve the production value method, they did not quantify the welfare losses to consumers. Two studies (Gallai et al. 2009; Southwick and Southwick Jr. 1992) have addressed this second piece of the welfare puzzle by calculating losses in consumer surplus which is assumed to represent a consumer's willingness to pay for the good in question. Southwick and Southwick Jr. (1992) incorporated values for pollination in the long-run. By assuming that supply is perfectly elastic in the long-run, they obviate the need to calculate returns to producers and instead focus entirely upon how shifts in supply impact consumer welfare. Linear demand curves are econometrically estimated for a variety of pollinator dependent crops which are used to see how the anticipated shifts in supply will change the equilibrium price for the respective crop in the face of a pollinator shortage. The loss in consumer surplus is thus calculated from this shift in supply and is considered the welfare attributable to pollinator services (Southwick and Southwick Jr., 1992).

Gallai et al. (2009) utilized an isoelastic demand curve to estimate changes in consumer surplus on a global scale. For each crop analyzed, a particular dependency ratio was used to estimate the loss of world supply given the absence of pollinators. From this change in quantity, the above isoelastic curve was then used to calculate the change in equilibrium price as well as the loss of consumer surplus. The authors used the same isoelastic curve for each crop which assumes that the crops all have the same price elasticity. To compensate for this oversimplification, the study presents resultant changes in consumer surplus under several plausible price elasticities, ranging from inelastic to elastic (-0.5 to -2.0). The authors also warn that assuming constant price elasticity is only reasonable with crops where price changes remain in the neighborhood of current prices. This is due to the fact that crops which are extremely dependent upon pollination services yield implausibly high consumer surplus losses when an isoelastic demand curve is used (Gallai et al. 2009).

Chapter 3-Methods

3.1 Assumptions of the Welfare Analysis

The challenge of any welfare analysis is that consumer and producer utility are inherently abstract and not directly observable, making it difficult to provide meaningful units of measurement. Commonly accepted economic practice denotes an individual’s “willingness to pay” and “willingness to accept” as satisfactory monetary measures of utility and there are two direct ways of calculating these values. The first is known as compensating variation (CV) and is defined as the sum of money, associated with a change in price, which is either given or taken away from the agent and leaves said agent just as well off as if the price did not change, assuming that it is free to adjust production/consumption in either case (Just et al. 1982; Nicholson, 2005). A mathematical representation is presented below:

(3)

$$CV = E\left(p_x^1, p_y, U_0\right) - E\left(p_x^0, p_y, U_0\right)$$

In the above equation, *CV* represents compensating variation, *E* represents the consumer's expenditure function, p_x^1 represents the new price of some good x, p_x^0 represents the original price of good x, p_y represents good y which could also represent all other goods, and U_0 represents a consumers utility before the price change. Stated simply, compensating variation is the necessary change to a consumer's income that would yield no changes in their original utility. Notice it could be positive or negative depending on whether or not the price change was in the consumer's favor. A price increase would yield a positive value. A price decrease would yield a negative value.

The second method is known as equivalent variation (EV) and is defined as the sum of money, associated with a price change, which is either given or taken away from the consumer so that even if prices reverted to their original values the consumer's utility is the same as it was after the price change (Just et al. 1982; Nicholson, 2005). A mathematical representation is presented below:

(4)

$$EV = E\left(p_x^0, p_y, U_1\right) - E\left(p_x^1, p_y, U_1\right)$$

The variables are the same as they are in Equation (3) with the exception of U_1, which represents utility after the price change. For example, if the price of good x increased, the EV would be the money the consumer would be willing to pay to have the price return to its original level. An example of the opposite scenario, if the price of good x decreased, the EV would be the amount of money the consumer would need to be just as well off if the price reverted to its original higher value.

Both CV and EV can also be applied to producers. It is in fact easier to assess these values for producers because their utility functions are to simply maximize profit. The expenditure functions would differ in that the prices would be in reference to the output and the required inputs but the basic principles remain the same (Just et al. 1982). It is a much taller order to know the preferences of every consumer with respect to every good and how differing combinations of goods affect utility. However, if the utility function is known then it is possible to derive the compensating demand curves, also known as Hicksian demand curves, which could be used to calculate either CV or EV. This is due to the fact that these demand curves hold utility constant so that for any resultant shifts in demand due to a price change, income will also adjust so to avoid any change in utility. These changes in income represent either CV or EV depending on the dynamics of the price change (Just et al. 1982; Nicholson, 2005).

As hinted above, utility functions are difficult to obtain because consumer utility is not observable and therefore Hicksian demand curves are not often used in applied settings. The more familiar demand curve is known as the Marshallian, which is also a function of prices but does not hold utility constant. Instead the consumer is assumed to have a fixed amount of income from which consumption decisions can be made. By not relying on an explicit utility requirement, Marshallian demand curves can be inferred from observed budgeting decisions made by consumers. It is from the Marshallian demand curve that the alternative welfare measure of consumer surplus (CS) can be derived.

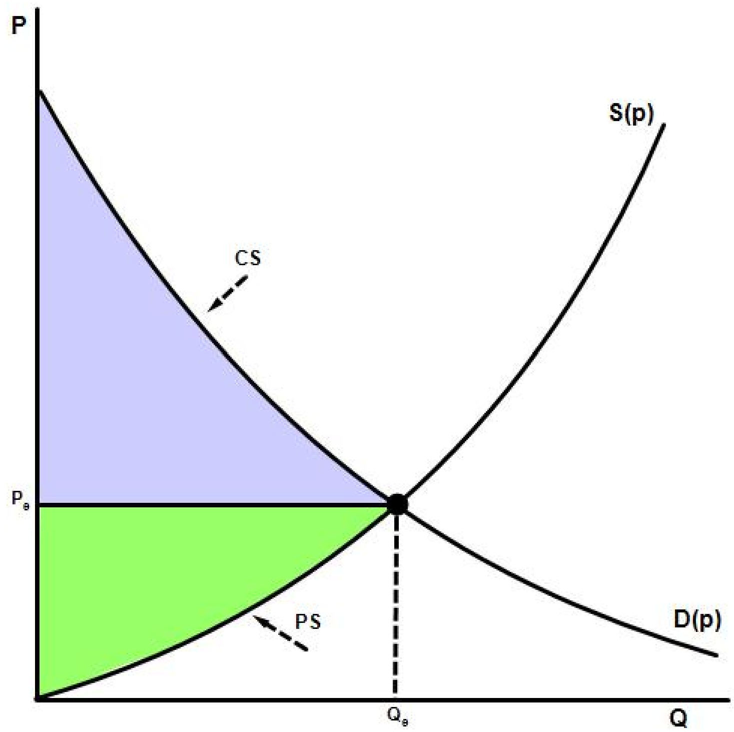
CS can be defined geometrically as the area beneath the demand curve, *D(p)*, and above the equilibrium price. In Figure 1 below, it is graphically represented by the area shaded blue. It acts as a measure of willingness to pay because each point on the demand curve represents the marginal willingness to pay for each quantity of a particular good. To illustrate why this is so, imagine that the consumer purchases a particular quantity of the good at the current market price. However, the consumer would have been willing to purchase a fraction of that consumed quantity at a higher price. The fortunate consumer was instead able to buy the entire quantity at a lower price which undoubtedly makes the consumer better off. The summation of the dollars saved at each point along the curve that is above the current market price represents a monetary measure of welfare. A mathematical representation is found below:

(5)

$$CS = \int_{p_x^e}^{p_x^*} D\left(p_x, p_y, m\right) dp_x$$

Whereas *CS* represents consumer surplus, *D* represents the demand function for quantity demanded of good x, p_x represents the price of good x, p_y represents the price of all other goods, m represents income, p_x^e represents the equilibrium price, and p_x^* represents the price at which the consumer will demand no amount of the good. It should be noted that CS does not represent a unique monetary measure of welfare because when the price of a good changes any resultant change in the quantity demanded is the result of both the substitution effect and the income effect. The substitution effect represents changes in the demand for a good when other goods become relatively more desirable/undesirable due to the change in price. This is the only effect that is captured with Hicksian demand curves. Marshallian demand curves have an additional income effect which is how the consumption of a good changes due to the impact on a consumers budget constraint (income) from a change in price. The increase/decrease in the price of a good changes the possible combinations of goods that an individual can select. This in part leads to the problem of "path dependence," in which consumer surplus is not necessarily well defined in cases where income and prices change simultaneously. For example, two different changes in consumer surplus will arise depending on whether price or income changes first, despite the fact that the magnitude of the changes is the same in both scenarios. As a consequence, a welfare change could have multiple representative monetary values and would thus make it not unique. The problem is obviated if the income effect is zero, which is an unrealistic assumption given that most goods have an income elasticity that is not zero. Fortunately, when it comes to applied work the income effect does not prove to be too problematic for goods that represent a small share of an individual's budget. If the consumption of the good claims only a negligible part of a person's income, then the CS measure will differ little from the more accurate CV and EV measurements (Perloff, 2007).

Figure 1



Calculations of producer welfare are less ambiguous with measures, such as producer surplus (PS), avoiding the problems of path dependence altogether. PS, also known as quasi-rent, is defined as a producer's net benefit resulting from the excess of gross receipts from the production of any commodities produced over their prime cost. Mathematically it is the difference between total revenue (TR) received and the total variable costs (TVC) incurred (Just et al., 1982).

(6)

$$PS = TR - TVC$$

Geometrically it can be defined as the area above the supply curve, *S(p),* and below the current market price of the commodity produced by the firm. In Figure 1 above, it is represented graphically by the green shaded area. The reasons PS avoids the problem of path dependence is that under profit maximization, the producer does not have any preferences over the use of any inputs except in regards to its impact on profits. A change in prices will lead to an expansion or contraction of the producer's budget but will not change the preferences of the producer's input consumption. Given that net income or profits are the only piece of the equation tied directly to welfare, any fluctuation in net income or profits associated with a change in input prices will be equivalent to those found in the measures of CV and EV. In contrast, the consumer has unique tastes and preferences associated with each good with differing amounts of utility associated with the consumption of each. Therefore, a change in a good's price will lead to both substitution and income effects between commodities as the consumer attempts to maximize utility under the new price regime. As described above, the order of the changes matters and leads to deviations from the unique monetary measures found through CV and EV (Just et al. 1982).

Given that the aggregated utility preferences of the consumers of Oregon blueberries are not known, compensating demand curves cannot be derived and instead this paper attempts to derive Marshallian demand curves for Oregon blueberries. CS and PS will thus be the chosen methods to measure consumer and producer welfare respectively. Fortunately blueberry consumption on average represents a small proportion of a consumer's budget constraint, so it is expected that CS deviations from CV and EV will be relatively small. The following model takes a partial equilibrium approach, which only looks at how pollinators affect the consumers and producers within the Oregon blueberry market and ignores how these effects may cascade and affect consumption and production decisions in other markets. Incorporating these outside consequences would constitute a general equilibrium approach and while pollination certainly has an impact on multiple economic sectors, their inclusion is beyond the scope of this paper (Just et al. 1982; Point, 1994). It should also be noted that the model only observes the Oregon blueberry market as witnessed in 2011 and therefore only analyzes welfare effects in the short-run. Assuming that the data used represents equilibrium in a competitive market, blueberry suppliers are considered to be price takers and have no ability to influence price through their own personal supply (Just et al. 1982).

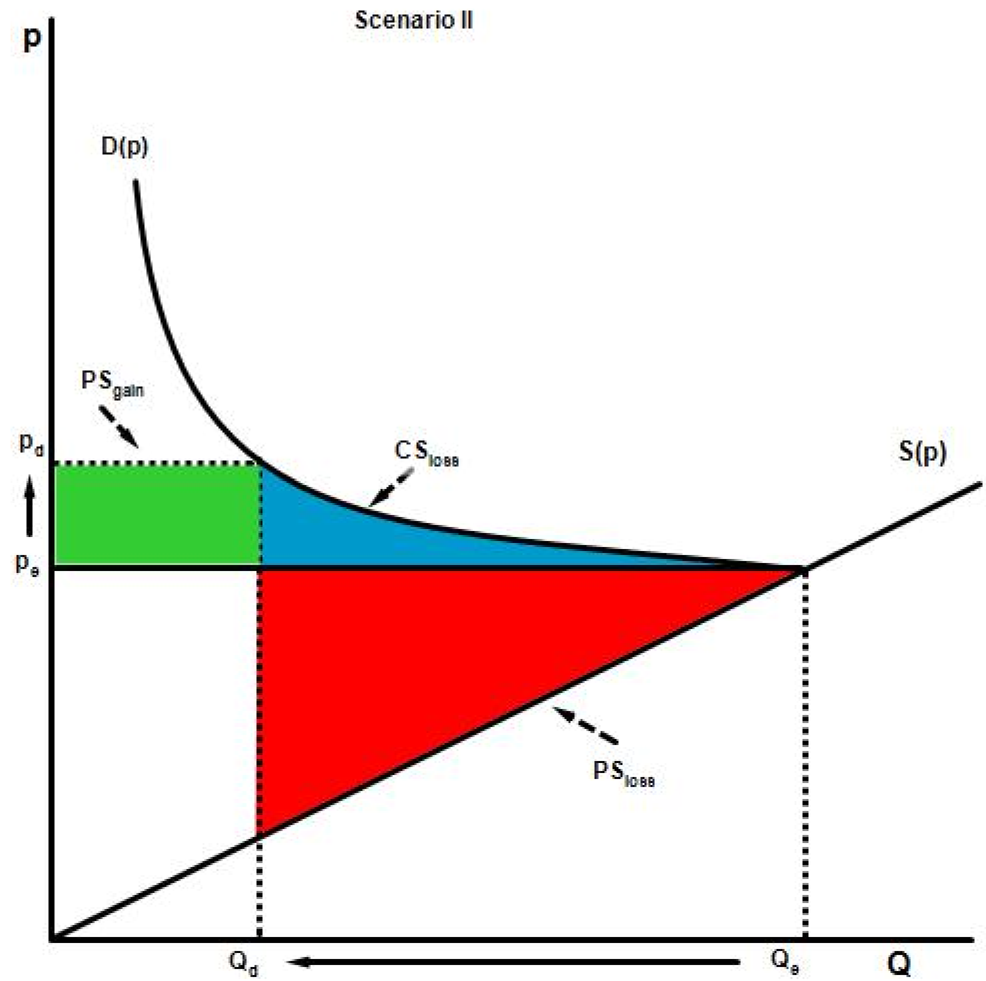
3.2 The Two Scenarios of Welfare Analysis

It is important to note that while this study largely adopts the net attributable income method used by Winfree and her colleagues (2011), there are significant differences in which this paper applies this method. For one, Winfree assumed that the disruptions in supply from a lack of pollination would have no price effects due to the fact that the area analyzed produced such a small share of the commodity nationally. They thus argued that there were no consequences to consumers and only observed how the change in supply affected producers. This analysis instead looks at Oregon blueberries as a commodity distinct from Washington blueberries or Michigan blueberries and thus it cannot use national market share to assume away all price effects. To address this issue there are two separate ways in which welfare from pollination is assessed. Simply put, there is one scenario without price effects and one with price effects.

Scenario I mimics the Winfree study and assumes no price effects. There are no price effects because Scenario I does not imagine potential yield losses from pollinator absence. It instead looks at the total welfare generated currently by Oregon blueberry consumption and teases out the share for which native pollinators are responsible. To put another way, it calculates the returns to producers and consumers due to the input of pollination from native pollinators. This is in contrast to Winfree's study, where the dependency ratio is used to assess a loss in yield due to pollinator absence. The scenario first assumes that native pollinators are a fixed factor of production that receives no compensation from blueberry producers for their services. It also assumes that the value of these native pollinators is embedded within the rental rates paid for another fixed factor, land. Land is a composite good with its price reflecting many of its attributes such as soil nutrients, climate of the location, environmental factors, etc. Ideal blueberry land is in part ideal because it is near to native pollinator populations and thus has higher yields than land without access to these pollinators. It is also true that producer surplus (PS) can be viewed as a return to fixed factors, which is why fixed costs are not subtracted out when calculating PS. Given that land is a composite good, each constituent part of land claims a piece for its contribution to producer surplus. Fortunately, the dependency ratio directly measures the contribution of native pollinators to yields and thus also represents the share of producer surplus that is attributable to native pollinators (Just et al. 1982). A similar logic works for CS which is defined as a measure of consumers' willingness to pay all the factors of production for the provisioning of a particular good. CS and PS are directly linked for there are no returns to fixed factors if there are no consumers willing to pay for the final output. Consequently, CS is essentially how much consumers' would have been willing to augment producers' returns to fixed factors. If that is the case, then the dependency ratio also represents the share of consumer welfare that is attributable to native pollinators.

In Scenario II, the logic is considerably less complicated. Yields are first reduced by the percentage indicated by the dependency ratio. The new market clearing price is then determined by the demand function for Oregon blueberries. Finally, the resultant losses in CS and PS are calculated and equated with the welfare attributable to native pollinator services. Assuming that the budget share of blueberry consumption is low, the measured changes will be close to measures found through EV and CV (Just et al. 1982; Point, 1994). It should be noted that the price increase caused by the decline in yields also causes a redistribution of CS to producers, requiring that this increase in welfare be accounted for in the determination of net effects. Price effects also impact consumer behavior by allowing them to change their purchases and minimize losses to welfare by consuming substitutable goods. This should lead to lower values of attributable welfare than those found in Scenario I which does not include price effects. A graphical depiction of Scenario II can be found in Figure 2.

Figure 2



With the decline in native pollinators comes a decline in yield from Q_e to Q_d. There is no shift in the supply curve, *S(p)*, because there is no change to the marginal costs associated with blueberry production. It is instead assumed that only a certain yield, $Q_{d\,,}$ can be possibly attained when there are no native pollinators, simulating a situation where information constraints prevented growers from purchasing additional commercial pollinators to meet the shortfall. Therefore the area shaded in red represents all of the PS lost from declines in blueberry yield. The price also increases from p_e to p_d with the area shaded in blue representing the CS lost. The area shaded in green is the PS gain which comes from the higher price producers can now for their produce, representing a redistribution of welfare from consumers to producers.

3.3 Pollinator Contributions to Producer Welfare

In order to calculate the contributions of native pollinators to producer welfare, this study utilizes two bioeconomic models to calculate the "attributable net income" that is due to native pollinator services (Winfree et al. 2011). Mathematical representations are found below with equation (7) pertaining to Scenario I without price effects and equation (8) pertaining to Scenario II with price effects:

(7)

$$PS_{native} = [(P_e \cdot Y) - (HC \cdot Y + VC \cdot TA)] \cdot (D \cdot \rho_{native})$$

(8)

$$PS_{loss} = [(P_e \cdot Y) - (HC \cdot Y + VC \cdot TA)] \cdot (D \cdot \rho_{native}) - (p_\Delta - p_e) \cdot Q_\Delta$$

Whereas PS_{native} represents the total value attributable to native pollinators, P_e represents the price of Oregon blueberries before the change in yield, P_Δ represents the price of Oregon blueberries after the change in yield, *Y* represents the yield of Oregon blueberries, *HC* represents the per pound harvest costs, *VC* represents all other per acre variable costs of operation, *TA* represents total harvested blueberry acreage in Oregon, *D* represents the dependency ratio of blueberry harvests on pollination services, ρ_{native} represents the proportion of the pollination services that are due to native pollinators and

Q_Δ which represents the quantity supplied after the removal of native pollinators. The only difference in the two equations is that equation (8) subtracts out the gains from the price increase in blueberries to determine the net effect on producers. The equations are used for both fresh and processed markets, but the results are calculated separately due to differences in price and particular costs. It is important to note that equation (8) presumes that all costs of production will be reduced proportionally with yield losses. This assumption is consistent with the calculation of attributable net value as found in Winfree et al. (2006), but may not always be valid depending on the specific crop in question. An alternative means of calculating PS losses for Scenario II is to have only harvest costs reduced proportionally with reductions in yields and have all remaining variable costs remain constant. Results using this alternative analysis are presented in Appendix C.

Prices, yields, and total harvested blueberry acreage are based on 2011 estimates from the 2012 USDA/NASS summary reports (USDA/NASS Fr Nt 3-15, 2012). Harvest costs per pound as well as most of the other variable costs are from reports from the Oregon State University Extension Service which provide estimated per pound harvest costs for the typical blueberry farm in Oregon (Julian et al. 2011). In order to incorporate the differences in variable costs associated with blueberry bushes of differing ages, data from the Oregon State Agricultural Information Database was used to approximate the number of harvested acres from each age group. From this distribution a weighted average of the per acre variable costs was calculated. More specific information on how these costs were calculated can be found in Appendix A.

While most of the cost variables are fairly straight forward, the biological variables are inferred from a number of sources. For the dependency ratio, the parameter is based off of a Michigan study (Isaacs and Kirk, 2010) that analyzed what percentage of total blueberry yields could be attributed to commercial pollinators (*Apis mellifera*) and native pollinators (*Bombus spp., Halictidae spp., Andrena spp.,* etc.) Researchers established field sites in numerous farms of varying size and observed the number of pollination visits from particular species. As a control, the blueberry bushes that were adjacent to the ones they were observing, they covered with netting that prevented pollinators from accessing the flowers. The study then directly compared the difference in yields and found that for farms below 5 hectares (small farms) 35% of the yield on average was due to pollinator activity and for farms greater than 5 hectares (large farms) on average had 63% of the yield on average was due to pollinator activity. These percentages represent dependency ratios and were used to derive a figure for Oregon. By adjusting for blueberry farm sizes in Oregon (19% or so are 14.9 acres or less and 81% or so are 15 acres or more), a weighted average was calculated with the resulting dependency ratio of 0.58. A similar process was used to calculate the proportion of pollination due to native pollinators (which also differs by farm size) with a resulting proportion of 0.25.

This of course assumes that the pollination environments in Michigan and Oregon are comparable, which is not unreasonable given that both states primarily cultivate highbush blueberries and are home to similar species of pollinators including a number of bumblebee species (*Bombus spp*.). The ratios are also in the neighborhood of past attribution studies. Klein et al. (2007) assessed the dependency ratios of numerous crops states a national average for blueberries to be 0.65, which is fairly close to 0.58. As for the proportion of pollination due to native pollinators, the ratio used by this paper is coincidently equivalent to the average of two parameters established by two separate studies (Losey and Vaughan, 2006; Chaplin-Kramer et al. 2011). While neither of the studies focused solely on Oregon, they do suggest that the range of values is reasonable and in line with values found for areas within the United States. More specific information on how these ratios were calculated can be found in Appendix B.

3.4 Measuring Pollinator Contributions to Consumer Welfare

Consumer demand for Oregon blueberries is modeled in this paper through a piecewise function which combines an isoelastic demand curve and a demand curve where elasticity increases at an exponential rate. The mathematical representation is found below:

(9)

$$Q(p) = \begin{cases} bp^{-e^{\frac{p}{v}}}, & p_a < p_t \\ ap^{\epsilon}, & p_a > 0 \end{cases}$$

Whereas Q represents quantity demanded, a and b are constants, p represents the price of Oregon blueberries, p_a represents the price of blueberries where demand is no longer isoelastic, p_t represents the price at which the quantity demanded is equal to 1% of current market share of Oregon blueberries, ϵ represents the price elasticity of blueberry demand, e is the natural number e, and v represents a constant used to represent the heterogeneity of Oregon blueberries relative to other substitutes. It is important to note that the function is asymptotic at Q = 0, which means the resulting integration would be undefined if the range of the function was unbounded. The range of the function is therefore truncated so that Q is never less than 1% of the 2011 total quantity of Oregon blueberries. This quantity will hence be referred to as the variable, Q_t and is associated with its respective market clearing price of p_t. This demand function is used for both Scenarios I and II as well for fresh and processed markets.

The functional form seeks to improve on the technique used by Gallai and colleagues (2009) who solely used isoelastic demand curves to derive consumer surplus. While constant elasticity is reasonable to assume over narrow price ranges, as the range increases the assumption begins to lose credibility. With higher prices, substitutes become all the more appealing and consumers are unlikely to behave in the same way as when price fluctuations were less noticeable. In equation (9), the function attempts to capture this phenomenon by selecting a particular price, p_a, in which consumers' price elasticity can no longer be assumed to be constant. From that point on, price elasticity becomes a function of the price of Oregon blueberries with increases in price corresponding to increases in the demand curve's elasticity. With this particular function, it is assumed that beyond p_a the price elasticity would grow at an exponential rate. This reflects the fact that Oregon blueberries are easily substituted with blueberries from other states or countries and that the quantity demanded will begin to decline dramatically as prices begin to noticeably rise above the prices for rival blueberries. At some point, only those with strong consumer preferences for Oregon blueberries, such as locavores, will still be in the market. The question then becomes at what point and how fast.

The variable, p_a, addresses at what price this transition in the demand curve occurs. There is some uncertainty but consumer surveys assessing preferences for local produce have provided some insight (Stephenson and Lev, 2004; Carpio and Isengildina-Massa, 2009; Onken et al. 2011;). Enthusiasm gradually declined for local produce in all three surveys as premiums increased but substantially began to fall off around premiums of 50%. The study by Stephenson and Lev (2004) focused exclusively on Oregon consumers and found this behavior holds over many socioeconomic statuses, age groups, and level of education. Onken and colleagues (2011) also found that the size of the premium changed with the base prices of the comparison nonlocal good. For example, if the hypothetical price of the nonlocal good was $3.00 then the average consumer was willing to pay a premium of 50% more. At $4.00 it was 25% more and at $5.00 it was 20% more. Interestingly, these premiums all represented roughly a dollar or so increase in price, suggesting that the percentage was less at issue with consumers. It seems consumers are literally willing to put forth that extra dollar to ensure that the good is local, but not much more (Onken et al. 2011). With that in mind, the selected range of values for p_a for fresh market blueberries were $3.50, $4.00, and $5.00 a pound, which roughly adhere to a 50% premium on the market price of blueberries from three different states (Washington, California, and Florida, respectively) (USDA/NASS Fr Nt 3-15, 2012). These prices are not exact because surveys suggest that consumers seem to think in discrete quantities such as a dollar or half dollar and thus a value such as $3.50 will illicit more of a reaction then $3.64.

For the processed market the ranges of p_a were narrower, being \$2.00, \$2.50, and \$3.00 and are not based off of processed berry prices from other states. Prices for processed berries are higher in Oregon than in other states, so a premium is already in a sense being paid (USDA/NASS Fr Nt 3-15, 2012). Also, the purchasers of processed berries are firms and packinghouses that see the berries as an input for a final product and therefore be assumed to be less tolerant of premiums for local produce.

As to the parameter ϵ, this paper assumes a value of -0.25. The literature on this issue is sparse with little to no studies providing estimates on the own price elasticity of blueberry demand (Yang, 2010). Only one analysis by Kaiser (2010) had actually econometrically derived a demand curve using a time-series analysis based on blueberry consumption patterns stretching back to the 1970s. His study found that the own price elasticity of blueberries was highly inelastic with a value of -0.25. This is consistent with the literature on fruit and vegetable consumption more generally which also tends to be own price inelastic (Southwick and Southwick Jr, 1992; Powell et al. 2009) . It is important to emphasize that this parameter is only used over a specific range in the demand function and is no longer assumed to represent own price elasticity past p_a.

The parameter v, in this study, acts as a way to dampen the explosive growth of the exponential function used to estimate the own price elasticity in the second half of the demand function. Without the parameter, consumption drops off precipitously with very small changes in price. However, it is difficult to know what value this parameter should take. To compensate for this uncertainty, the analysis presents three separate values to be used in the calculations: 5, 10, and 20. The larger the number, the slower the price elasticity grows leading to higher values for p_t. In this way, the parameter acts as a metric for the perceived heterogeneity of Oregon blueberries when compared to blueberries from other regions. At relatively low values of *v*, consumers are less apt to pay higher premiums for Oregon blueberries than at higher values of *v*. Blueberries from other states thus act as a stronger substitute suggesting that blueberries, regardless of origin, are perceived as a more or less homogenous product. High values of *v* suggest that consumers have a stronger preference for Oregon blueberries and believe them to be somehow distinct from berries elsewhere.

For both Scenarios of the welfare analysis, CS is derived through the integration of equation (9). The integrations are found in the two equations below:

(10) - Scenario I

$$CS_{native} = \left\{ \int_{p_e}^{p_a} ap^{\epsilon}\, dp + \int_{p_a}^{p_t} bp^{-e^{\frac{p}{v}}}\, dp - (p_t - p_e) \cdot Q_t \right\} \cdot (D \cdot \rho_{native})$$

(11) – Scenario II

$$CS_{\text{loss}} = \left\{ \int_{p_e}^{p_a} ap^{\epsilon}\, dp + \int_{p_a}^{p_{\Delta}} bp^{-e^{\frac{p}{v}}}\, dp \right\}$$

The variables, constants, and parameters are consistent with all of the previous equations. Equation (10) is used for Scenario I, because it integrates over the entire range of the demand function (p_e to p_t). It then attributes a proportion of the resulting consumer surplus by multiplying by the two dependency ratios, D and ρ_{native}. Equation (11) is used for Scenario II, because it only integrates over the price effects brought about by the reduced yields. The dependency ratios are no longer needed in equation (11) because they have already been accounted for through the change in yield. It should be noted that the sections of both equations integrate the part of the demand function that is not isoelastic and have no analytical solution. The integrations are therefore solved using numerical methods through the use of the program Wolfram Mathematica (*Wolfram Mathematica*).

Chapter 4- Results

4.1 Scenario I: Fresh Market

Using equation (7), it is found that the producer surplus attributable to native pollinators in the fresh blueberry market is equal to $2.491 million. Below is a table with the values of consumer surplus that are attributable to native pollinators under different parameter specifications. In this scenario and in all following scenarios, values are all assumed to be in 2011 dollars.

Table 1

		CS_{native} (in 000s)	
	p_a=3.50	p_a=4.00	p_a=5.00
v=5	9,738	11,392	14,096
v=10	12,956	14,633	16,529
v=20	17,150	19,005	20,035

4.2 Scenario I: Processed Market

Using equation (7), it is found that the producer surplus attributable to native pollinators in the processing blueberry market is equal to $2.402 million. Below is a table with the values of consumer surplus that are attributable to native pollinators under different parameter specifications.

Table 2

		CS_{native} (in 000s)	
	p_a=2.00	p_a=2.50	p_a=3.00
v=5	6,293	8,011	9,501
v=10	8,920	10,831	12,579
v=20	11,981	14,243	16,268

4.3 Total Effects for Scenario I: Fresh & Processed

The total value attributed to pollinators in Scenario I is calculated by totaling the producer and consumer values for both fresh and processed markets. The values range from $20.924 million to $41.196 million.

4.4 Scenario II: Fresh Market

Expected losses in PS and CS for the fresh blueberry market were calculated through the use of equations (8) and (11), respectively. The values for both under different parameter specifications are found in the tables below. Interestingly, all of the producer losses in welfare were negative which means they actually benefited from the loss of native pollinators. This is due to the resulting price increase in blueberries which actually more than compensates for producers' loss in yields. These gains came entirely at the expense of the consumer with the higher prices resulting in an actual redistribution of welfare to producers. Yield losses could be large enough that they would in the end hurt producers, but it would have to be at a point in the demand curve that was price elastic. Therefore any reduction in yields will be to producers' net benefit until the point at which the demand curve becomes unitary elastic.

Table 3

		PS_{loss} (in 000s)	
	p_a=3.50	p_a=4.00	p_a=5.00
v=5	-40,351	-46,232	-46,321
v=10	-40,631	-46,232	-46,321
v=20	-41,454	-46,232	-46,321

Table 4

		CS_{loss} (in 000s)	
	p_a=3.50	p_a=4.00	p_a=5.00
v=5	45,254	52,306	52,306
v=10	45,817	52,306	52,306
v=20	46,945	52,306	52,306

4.5 Scenario II: Processed Market

Expected losses in PS and CS for the processing blueberry market were calculated through the use of equations (8) and (11), respectively. The values for both under different parameter specifications are found in the tables below. Again, all of the producer losses in welfare were negative.

Table 5

		PS_{loss} (in 000s)	
	p_a=2.00	p_a=2.50	p_a=3.00
v=5	-13,839	-26,160	-34,840
v=10	-14,679	-26,719	-34,840
v=20	-15,519	-27,000	-34,840

Table 6

		CS_{loss} (in 000s)	
	p_a=2.00	p_a=2.50	p_a=3.00
v=5	18,086	31,160	39,979
v=10	18,972	31,728	39,979
v=20	19,842	32,014	39,979

4.6 Total Welfare Effects for Scenario II

The total losses from pollinator absence in Scenario II are calculated by totaling the producer and consumer values for both fresh and processed markets. The values range from $9.15 million to $11.124 million.

Chapter 5- Discussion and Conclusions

When both scenarios are compared directly, the results yield a range of values that stretch from a low of $9.15 million to a high of $41.196 million. As predicted, Scenario II with its inclusion of price effects yields lower values than those of Scenario I. Scenario II also has a narrower range of values being only a difference of approximately $2 million dollars compared to Scenario I's difference of $20 million. However, the values in and of themselves do not indicate which scenario is preferable when addressing questions of policy or pest management. This is because the scenarios are answering two similar but separate questions.

Scenario I addresses the question of what share of returns to fixed factors is due to native pollinators. It does not imagine any losses in yield or how consumers will react to price changes due to yield losses. It assumes that the value of native pollinator services is already embedded within the price of the land and uses the derived dependency ratios to tease out this value. On the consumer end, a share of total consumer surplus is credited with being due to native pollinator services, this share being equal to the dependency ratio. In short, Scenario I measures the welfare pollinators gave to society at one particular point in time.

Scenario II addresses the hypothetical question of how much welfare will be lost if all native pollinator services disappeared. It assumes the same demand functions of Scenario I and uses the functions to estimate changes in price due to losses in Oregon blueberry yields. After calculating the price change, changes in consumer and producer surplus are thus calculated. Herein lies why these welfare losses will not equal the welfare values of Scenario I. By not assuming price effects, Scenario I was not anticipating how consumers would react if the blueberries from native pollinators were taken away. While some consumers would still pay the higher price, they would likely buy less blueberries overall and some consumers would leave the market entirely and buy other substitutable goods. However, as revealed by the negative losses, the inelastic nature of blueberry demand meant that most consumers paid the higher price instead of consuming less. This resulted in a boon for producers. While yields dropped, prices increased just enough to end with a net overall gain. In summary, Scenario II is essentially a “what if” scenario instead of an investigation of the status quo.

The preferred scenario thus depends on the question being asked. If a policymaker is interested in how pollinator conservation incentives are impacting land prices, then some variant of Scenario I would be preferred. In the case of potential impacts of new pest management regimes on pollinator services, some version of Scenario II that imagines yield losses would be more relevant. In applying this conclusion to the particular case of SWD management, the losses in Scenario II are likely the more relevant figures. This of course assumes that native pollinators are absolutely devastated by the recommended pesticide applications to the point where they contribute no services whatsoever. Further studies analyzing native pollinator sensitivity to pesticide applications under differing circumstances are needed to verify whether the above assumption is warranted.

More information concerning distribution of the welfare impacts is also needed, particularly among producers. The current analysis aggregates the welfare of all producers and does not account for how particular classes of blueberry growers may be affected disproportionately by the disappearance of native pollinators. For example, the study by Isaacs and Kirk revealed that smaller growers received 82% of their pollination services from native pollinators while larger growers only received 11% of their pollination services from native pollinators. In the event of a pollinator decline, smaller growers would experience welfare losses that are overshadowed by the welfare gains of the largely unaffected larger farmers. This could lead to potentially undesirable concentrations of the blueberry industry where harvests are dominated by a handful of growers.

This study could also be improved through the adoption of more precise demand functions. While equation (9) is an improvement over the isoelastic curves used by other studies, the parameters within the equation could be more rigorously determined. Consumer surveys were used to develop plausible ranges for parameters p_a and v, but as shown there was considerable variation within the results due to the selected parameter values. Given that the above parameters largely try to capture how consumers substitute blueberry consumption as prices rise, a possible improvement would be a demand curve that incorporates additional variables such as the price of substitute goods. These could include the prices of blueberries from outside Oregon as well as that of other fruits and vegetables.

Scenario I, on the other hand, could be analyzed in another way through the use of hedonic price analysis. This would require the construction of a derived demand curve for blueberry land which would include variables such as native pollinator populations or indirect proxies such as the presence of pollinator friendly habitat. This of course involves the analysis of considerable volumes of data concerning the above ecological variables and other relevant factors such as soil quality, access to irrigation, climate, etc. If the ecological variables governing pollination are similar to those in Michigan, which is the assumption of this thesis, then the model should corroborate some of the results found in Scenario I. However, an additional advantage of a hedonic model is that it provides the marginal contributions of pollinator related variables to land values, providing insight as to what land management practices would be the most effective in maximizing returns from pollinators (Smith, 1996).

It should also be noted that this study does not attempt to quantify all of the ecosystem services provided by native pollinators. There are numerous additional uses of pollination services both within agriculture and the wider natural environment, meaning that the above calculations underestimate the total value of native pollinators. Certain non-use values are actually unable to be fully quantified. The utilitarian values presented in this paper are therefore irrelevant in the justification of their conservation because by other systems valuation these organisms have an a priori right to exist.

However, these enlightened viewpoints have yet to prevent native pollinators from becoming victims of collateral damage in the war against SWD. New tools are being developed and there are already reports of poor pollination from blueberry and caneberry growers with numerous fields experiencing a loss in yields. Coincidently, some of the caneberry growers saw declines as high as 25%, but it is important to note that the losses have not been directly tied to their pest management regimes (Peerbolt et al., 2013). This underscores the importance of pest management strategies that incorporate the broader ecological implications of their adoption. Growers, by being indifferent to the health of native pollinator populations, may be doing more harm than good to their own financial standing. This study will hopefully provide some context to growers, extension personnel, and policy makers as to the potential cost of this indifference.

Bibliography

Allsopp, Mike H., Willem J. de Lange, and Ruan Veldtman. 2008. “Valuing Insect Pollination Services with Cost of Replacement.” *PLoS ONE* 3 (9) (September 10): e3128. doi:10.1371/journal.pone.0003128.

Bolda, Mark P., Goodhue, Rachael E., and Zalom, Frank G. 2013. “Spotted Wing Drosophila: Potential Economic Impact of a Newly Established Pest.” *Giannini Foundation of Agricultural Economics*. Accessed June 3. http://giannini.ucop.edu/media/are-update/files/articles/v13n3_2.pdf.

Brazelton, Cort. 2011. “World Blueberry Acreage & Production”. U.S. Highbush Blueberry Council.

Carpio, Carlos E., and Olga Isengildina-Massa. 2009. “Consumer Willingness to Pay for Locally Grown Products: The Case of South Carolina.” *Agribusiness* 25 (3): 412–426. doi:10.1002/agr.20210.

Chaplin-Kramer, Rebecca, Karin Tuxen-Bettman, and Claire Kremen. 2011. “Value of Wildland Habitat for Supplying Pollination Services to Californian Agriculture.” *Rangelands* 33 (3): 33–41.

Costanza, Robert, Ralph d’ Arge, Rudolf de Groot, Stephen Farber, Monica Grasso, Bruce Hannon, Karin Limburg, et al. 1997. “The Value of the World’s Ecosystem Services and Natural Capital.” *Nature* 387 (6630) (May 15): 253–260. doi:10.1038/387253a0.

De Groot, Rudolf S, Matthew A Wilson, and Roelof M.J Boumans. 2002. “A Typology for the Classification, Description and Valuation of Ecosystem Functions, Goods and Services.” *Ecological Economics* 41 (3) (June): 393–408. doi:10.1016/S0921-8009(02)00089-7.

DeFrancesco, Joe, and Bell, Neil. 2013. “Blueberry Pests.” In *PNW Insect Management Handbook*, I1–I6. Pacific Northwest Extension.

Dreves, Amy J., and Langellotto, Gail. 2013. “EMERGING PEST: Spotted Wing Drosophila-A Berry and Stone Fruit Pest.” In *PNW Insect Management Handbook*. Pacific Northwest Extension. http://pnwhandbooks.org/insect/pnw-insect-management-handbook/emerging-pest-spotted-wing-drosophila.

Filmer, R. S., and P. E. Marucci. 1963. “The Importance of Honeybees in Blueberry Pollination.” *Proc.31st Annual Blueberry Open House, New Jersey Agric.Exp.Stn.* http://agris.fao.org/agris-search/search/display.do?f=2012/XE/XE1202.xml;XE2012200547.

Gallai, Nicola, Jean-Michel Salles, Josef Settele, and Bernard E. Vaissière. 2009. “Economic Valuation of the Vulnerability of World Agriculture Confronted with Pollinator Decline.” *Ecological Economics* 68 (3) (January 15): 810–821. doi:10.1016/j.ecolecon.2008.06.014.

Isaacs, Rufus, and Anna K. Kirk. 2010. “Pollination Services Provided to Small and Large Highbush Blueberry Fields by Wild and Managed Bees.” *Journal of Applied Ecology* 47 (4): 841–849. doi:10.1111/j.1365-2664.2010.01823.x.

Julian, James W., Strik, Bernadine C., and Yang, Wei. 2011. “Blueberry Economics: The Costs of Establishing and Producing Blueberries in the Willamette Valley”.

Technical Report AEB 0022. [Corvallis, Or.] : Oregon State University, Extension.

Just, Richard E., Darrell L. Hueth, and Andrew Schmitz. 1982. *The Welfare Economics of Public Policy*. E. Elgar. http://library.hse.ru/incoming/docs/book1843766884.pdf.

Kaiser, Harry M. 2010. “An Economic Analysis of Domestic Market Impacts of the U.S. Highbush Blueberry Council”. Technical Report. U.S. Highbush Blueberry Council. http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5088425.

Klein, Alexandra-Maria, Bernard E. Vaissière, James H. Cane, Ingolf Steffan-Dewenter, Saul A. Cunningham, Claire Kremen, and Teja Tscharntke. 2007. “Importance of Pollinators in Changing Landscapes for World Crops.” *Proceedings of the Royal Society B: Biological Sciences* 274 (1608) (February 7): 303–313. doi:10.1098/rspb.2006.3721.

Kremen, Claire, Neal M Williams, Marcelo A Aizen, Barbara Gemmill-Herren, Gretchen LeBuhn, Robert Minckley, Laurence Packer, et al. 2007. “Pollination and Other Ecosystem Services Produced by Mobile Organisms: a Conceptual Framework for the Effects of Land-use Change.” *Ecology Letters* 10 (4) (April): 299–314. doi:10.1111/j.1461-0248.2007.01018.x.

Kremen, Claire, Neal M. Williams, and Robbin W. Thorp. 2002. “Crop Pollination from Native Bees at Risk from Agricultural Intensification.” *Proceedings of the National Academy of Sciences* 99 (26) (December 24): 16812–16816. doi:10.1073/pnas.262413599.

Kreyer, Daria, Alexander Oed, Kerstin Walther-Hellwig, and Robert Frankl. 2004. “Are Forests Potential Landscape Barriers for Foraging Bumblebees? Landscape Scale Experiments with Bombus Terrestris Agg. and Bombus Pascuorum (Hymenoptera, Apidae).” *Biological Conservation* 116 (1) (March): 111–118. doi:10.1016/S0006-3207(03)00182-4.

LOSEY, JOHN E., and MACE VAUGHAN. 2006. “The Economic Value of Ecological Services Provided by Insects.” *BioScience* 56 (4) (April 1): 311–323. doi:10.1641/0006-3568(2006)56[311:TEVOES]2.0.CO;2.

Morse, Roger A., and Nicholas W. Calderone. 2000. “The Value of Honey Bees as Pollinators of US Crops in 2000.” *Bee Culture* 128 (3): 1–15.

National Research Council of the National Academies. 2006. “Status of Pollinators in North America”. Washington, D.C.: National Academy Press.

Nicholson, Walter. 2005. *Microeconomic Theory: Basic Principles and Extensions*. 9th ed. United States: Thomson South-Western.

“Noncitrus Fruits and Nuts 2011 Preliminary Summary.” 2012. Preliminary Summary 1948-2698. National Agricultural Statistics Service.

“OAIN (Oregon Agricultural Information Network).” 2013. Accessed July 8. http://oain.oregonstate.edu/.

Olschewski, Roland, Teja Tscharntke, Pablo C. Benítez, Stefan Schwarze, and Alexandra-Maria Klein. 2006. “Economic Evaluation of Pollination Services Comparing Coffee Landscapes in Ecuador and Indonesia.” *Ecology and Society* 11 (1): 7.

Onken, Kathryn A., John C. Bernard, and John D. Pesek Jr. 2011. "Comparing Willingness to Pay for Organic, Natural, Locally Grown, and State Marketing Program Promoted Foods in the Mid-atlantic Region." *Agricultural and Resource Economics Review* 40 (1): 33.

"Oregon Blueberry Production Experiencing Unprecedented Growth." 2013. Accessed June 2. http://www.opb.org/news/article/oregon-blueberry-production-experiencing-unprecedented-growth/.

Otto, Stefan, Luca Lazzaro, Antonio Finizio, and Giuseppe Zanin. 2009. "Estimating Ecotoxicological Effects of Pesticide Drift on Nontarget Arthropods in Field Hedgerows." *Environmental Toxicology and Chemistry* 28 (4): 853–863. doi:10.1897/08-260R.1.

Peerbolt, Tom, Will Unger, Nino Adams, and Jason Myer. 2013. "OBPI Grower Bullentin". Weekly Newsletter. Oregon Berry Packing, Inc. http://www.peerbolt.com/bulletins/obpi/2013/OBPI06-13-13.pdf.

Peerbolt, Tom. 2012. "Berry Grower Responses to SWD Provided by Peerbolt Crop Management" Interview by Ritter, Daniel J.

Perloff, Jeffrey M. 2007. *Microeconomics*. 4th ed. United States: Prentice Hall.

Pimentel, David, Christa Wilson, Christine McCullum, Rachel Huang, Paulette Dwen, Jessica Flack, Quynh Tran, Tamara Saltman, and Barbara Cliff. 1997. "Economic and Environmental Benefits of Biodiversity." *BioScience* 47 (11) (December 1): 747–757. doi:10.2307/1313097.

Point, Patrick. 1994. "The Value of Non-Market Natural Assets as Production Factor." In *Valuing the Environment: Methodological and Measurement Issues*, edited by Rüdiger Pethig, 23–57. Environment, Science and Society 2. Springer Netherlands. http://link.springer.com.ezproxy.proxy.library.oregonstate.edu/chapter/10.1007/978-94-015-8317-6_2.

Powell, Lisa M., Zhenxiang Zhao, and Youfa Wang. 2009. "Food Prices and Fruit and Vegetable Conssumption Among Young American Adults." *Health & Place* 15: 1064–1070.

Rao, S., W. P. Stephen, and L. White. 2008. "Native Bee Pollinator Diversity in Oregon Blueberries." In *IX International Vaccinium Symposium 810*, 539–548. http://www.actahort.org/books/810/810_71.htm.

Rao, Sujaya, and W. P. Stephen. 2010. "Abundance and Diversity of Native Bumble Bees Associated with Agricultural Crops: The Willamette Valley Experience." *Psyche: A Journal of Entomology* 2010 (February 9). doi:10.1155/2010/354072. http://www.hindawi.com/journals/psyche/2010/354072/abs/.

Ricketts, Taylor H., Gretchen C. Daily, Paul R. Ehrlich, and Charles D. Michener. 2004. "Economic Value of Tropical Forest to Coffee Production." *Proceedings of the National Academy of Sciences of the United States of America* 101 (34) (August 24): 12579–12582. doi:10.1073/pnas.0405147101.

Robinson, W.S., Nowogrodzki, R., and Morse, R.A. 1989. "The Value of Honey Bees as Pollinators of US Crops. II." *American Bee Journal (USA)* 129 (6): 411–423.

Skyrm, Kimberly M. 2011. “Environmental Impacts on Native Bumble Bee Pollinators in an Agricultural Landscape of Western Oregon.” http://ir.library.oregonstate.edu/xmlui/handle/1957/21339.

Smith, Vincent Kerry. 1996. *Estimating Economic Values for Nature: Methods for Non-market Evaluation*. Edward Elgar Publishing.

Southwick, Edward E., and Lawrence Southwick Jr. 1992. “Estimating the Economic Value of Honey Bees (Hymenoptera: Apidae) as Agricultural Pollinators in the United States.” *Journal of Economic Entomology* 85 (3): 621–633.

Stephenson, Garry, and Larry Lev. 2004. “Common Support for Local Agriculture in Two Contrasting Oregon Communities.” *Renewable Agriculture and Food Systems* 19 (4): 210–217.

Strik, Bernadine C. (Bernadine Cornelia), and Chad Elliott Finn. 2008. “Blueberry Cultivars for Oregon”. Technical Report. [Corvallis, Or.] : Oregon State University, Extension Service. http://ir.library.oregonstate.edu/xmlui/handle/1957/18937.

Tscharntke, Teja, Alexandra M. Klein, Andreas Kruess, Ingolf Steffan-Dewenter, and Carsten Thies. 2005. “Landscape Perspectives on Agricultural Intensification and Biodiversity – Ecosystem Service Management.” *Ecology Letters* 8 (8): 857–874. doi:10.1111/j.1461-0248.2005.00782.x.

Winfree, Rachael, Brian J. Gross, and Claire Kremen. 2011. “Valuing Pollination Services to Agriculture.” *Ecological Economics* 71 (November 15): 80–88. doi:10.1016/j.ecolecon.2011.08.001.

Wolfram Mathematica (version 8).

Yang, Jinbin. 2010. “Economic Analysis of Blueberry Investment in British Columbia”. University of British Columbia. https://circle.ubc.ca/bitstream/id/87239/ubc_2010_fall_yang_jinbin.pdf.

USDA/NASS “Noncitrus Fruits and Nuts 2011 Preliminary Summary.” 2012. Preliminary Summary 1948-2698. National Agricultural Statistics Service/ United States Department of Agriculture.

Appendix A

Producer Welfare Calculations

(12)

$$PS_{native} = [(P_e \cdot Y) - (HC \cdot Y + VC \cdot TA)] \cdot (D \cdot \rho_{native})$$

(13)

$$PS_{loss} = [(P_e \cdot Y) - (HC \cdot Y + VC \cdot TA)] \cdot (D \cdot \rho_{native}) - (p_\Delta - p_e) \cdot Q_\Delta$$

Fresh Market HC = \$0.64173 per lb; Y= 32,750,000 lbs; p_e = \$1.99

Processed Market HC= \$0.19063 per lb; Y = 32,750,000 lb; p_e = \$1.52

VC = \$3,315.1277 per acre (weighted average of the 2011 per acre costs found below)

Table 1

Age	2	3	4	5	6	Mature
% of TA	14.8	14.61	11.92	4.87	10.19	43.61
VC/acre	\$4,126	\$2,303	\$3,696	\$2,949	\$3,203	\$3,342

(Julian et al. 2011; “OAIN (Oregon Agricultural Information Network)” 2013)

TA= 8,137 acres

D = 0.58; ρ_{native} = 0.25; Q_Δ = 4,748,750 lbs

Consumer Welfare Calculations

(14)

$$CS_{native} = \left\{ \int_{p_e}^{p_a} ap^{\epsilon}\, dp + \int_{p_a}^{p_t} bp^{-e^{\frac{p}{v}}}\, dp - (p_t - p_e) \cdot Q_t \right\} \cdot (D \cdot \rho_{native})$$

(15)

$$CS_{\text{loss}} = \left\{ \int_{p_e}^{p_a} ap^{\epsilon}\, dp + \int_{p_a}^{p_\Delta} bp^{-e^{\frac{p}{v}}}\, dp \right\}$$

Fresh Market

a = 38,897,750; ϵ = -0.25; p_e = \$1.99; Q_t = 327,500; D = 0.58; ρ_{native} = 0.25

Table 2

		b (fresh market)	
	p_a=3.50	p_a=4.00	p_a=5.00
v=5	354,427,000	601,616,000	1,597,560,975
v=10	168,259,000	217,559,000	285,597,230
v=20	126,482,000	149,544,000	158,797,000

Table 3

		$\boldsymbol{p_t}$ (fresh market)	
	p_a=3.50	p_a=4.00	p_a=5.00
v=5	\$6.56	\$6.83	\$7.27
v=10	\$9.98	\$10.27	\$10.55
v=20	\$15.52	\$15.90	\$16.03

Table 4

		$\boldsymbol{p_\Delta}$ (fresh market)	
	p_a=3.50	p_a=4.00	p_a=5.00
v=5	\$3.52	\$3.73	\$3.73
v=10	\$3.53	\$3.73	\$3.73
v=20	\$3.54	\$3.73	\$3.73

Processed Market

a = 36,364,242; ϵ = -0.25; p_e = $1.52; Q_t = 327,500; D = 0.58; ρ_{native} = 0.25

Table 5

		b (processed market)	
	p_a=2.00	p_a=2.50	p_a=3.00
v=5	86,000,500	131,003,000	204,534,000
v=10	71,301,000	93,789,500	121,742,000
v=20	65,781,930	81,679,700	99,021,450

Table 6

		p_t (processed market)	
	p_a=2.00	p_a=2.50	p_a=3.00
v=5	$5.78	$6.03	$6.28
v=10	$8.98	$9.31	$9.62
v=20	$13.98	$14.50	$14.95

Table 7

		p_Δ (processed market)	
	p_a=2.00	p_a=2.50	p_a=3.00
v=5	$2.10	$2.54	$2.85
v=10	$2.13	$2.56	$2.85
v=20	$2.16	$2.57	$2.85

Appendix B

The study by Isaacs and Kirk (2010) calculated the following dependency ratios for Michigan blueberry farms.

Farms less than 5 hectares had D = 0.35

Farms greater than 5 hectares had D = 0.63334

The NASS statistics were in acres and grouped in such a way that the cutoff necessarily became 6 hectares as opposed to 5 hectares. The distribution within Oregon is as follows.

18.939% of Oregon Blueberry Farms are less than 6 hectares

81.04% of Oregon Blueberry Farms are greater than 6 hectares

The weighted average has D = 0.58.

Native pollinator contributions were calculated under the assumption that they are also a function of farm size. Isaacs and Kirk estimated the native pollinator contributions for both small and large farms.

Farms less than 5 hectares had ρ_{native} = 0.82

Farms greater than 5 hectares had ρ_{native} = 0.11

Weighted Average for Oregon had $\rho_{native} \approx 0.25$

Of course these calculations presume that the pollinator environments within Michigan and Oregon are fairly similar. While the regions have differing climates, most of the relevant pollinators in both states are found within the genuses of *Andrenids, Halictids,* and *Bombus.* Specifically, it is the bees in the genus of *Bombus* that are found to perform most of the native pollination for blueberries in both Michigan and Oregon (Rao et al. 2008; Isaacs and Kirk, 2010).

Appendix C

Another possible way to calculate producer welfare for Scenario II is to assume that only harvest costs are reduced proportionally with yield losses. All other per acre variable costs are assumed to say the same regardless of the status of native pollinators. Due to the fact that these variable costs do not change, they do not need to be included in the equation for changes in PS found below.

(12)

$$PS_{loss} = [(P_e \cdot Y) - (HC \cdot Y)] \cdot (D \cdot \rho_{native}) - (p_\Delta - p_e) \cdot Q_\Delta$$

Using the above equation, the results for both fresh and processed markets are found below.

Table 8

		PS_{loss} (fresh in 000s)	
	p_a=3.50	p_a=4.00	p_a=5.00
v=5	-36,439	-42,320	-42,410
v=10	-36,719	-42,320	-42,410
v=20	-37,542	-42,320	-42,410

Table 9

		PS_{loss} (processed in 000s)	
	p_a=2.00	p_a=2.50	p_a=3.00
v=5	-9,928	-22,249	-30,929
v=10	-10,768	-22,808	-30,929
v=20	-11,608	-23,089	-30,929

They differ slightly from the original results in that the producer surplus losses are greater due to higher variable costs. When totaled with the CS losses of Scenario II the total losses for pollinator absence range from $16.973 to $18.946 million. In comparison, the original range for Scenario II was $9.15 million to $11.124 million. The increase in losses was to be expected given that producer welfare gains were reduced due to higher variable costs. In the case of blueberry production, the method used in Appendix C may actually be more precise assuming that many of the other variable costs are expended before the grower could be aware of any pollination problems. However, the validity of this assumption must be assessed on a crop by crop by basis.