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Valuation of Pollinators:
With Individual Crops' Demand

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Abstract

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Pollinators play a vital role in agricultural production. Without proper pollination, crops may lack in quality and quantity which can affect both production and consumption of agricultural goods. Pollinator density decline has long been a topic of study, as with economic development, many wild pollinators lost their habitat. To make things worse, due to climate change, managed pollinators are also experiencing colony disappearance and collapse.

Korean farmers have been dealing with annual bee colony loss occurrences for the past few of years. Bee colonies are perishing due to many reasons mostly caused by climate change. As many Korean farmers rely on honeybees and bumblebees for the pollination of various fruits and vegetables, such occurrences result in decreased

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production and increased expenditures to replace the lost pollinators. In response, the Korean government is actively implementing pollinator-related policies.

Many studies have estimated the value of pollinators through various methods. Based on studies that estimate individual crops' pollinator dependency ratio, most pollinator valuation studies either use production revenue data for the production value approach or the cost of pollinator replacements for the replacement value method. Others combined previous methods to reflect the changes in the environment and market.

In this study, the economic value of pollinators in Korea is estimated by evaluating the changes in social welfare loss caused by pollinator decline. Building on the short term model of Lippert et al.(2021), the social welfare loss for each crop is estimated. This study analyzes the demand and demand elasticity of individual crops necessary for the final model rather than referencing estimation results of existing studies. National data such as the Crop Production Survey and the Household Income and Expenditure Survey were mostly used, but past research and data such as Klein et al.(2007) were also used for each crops' dependency ratio.

The estimated results contain both national and regional estimates, and the results reveal that, pollinators are valued at around 7.6 trillion won in Korea. This result is higher than that of other previous literature and it can be seen that methods that focus more on the production aspect have a tendency to underestimate the value of pollinators. The results also show that, despite Korea's relatively

small geographical area, it was found that regional differences do exist. Additionally, applications of the model to estimate losses caused by pollinator loss was attempted by implementing specific scenarios. Policy implications are drawn from such findings, particularly in light of recent pollinator-related policy decisions taken by the Korean government.

Keyword : pollinator valuation, welfare effect, productivity, demand elasticity
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Chapter 1. Introduction

1.1. Background

Many environmental aspects influence agricultural productivity. Most often, direct climate-related factors such as climatic conditions and extreme weather events are thought of, and with the rising attention to climate change and its influence, such relationship is emphasized more than ever. However, in addition to the direct impact of climate change, indirect impacts also cause threats to the agriculture industry. Of them all, pollinator density decline is becoming more prevalent as a major threat.

Pollinators, despite their small physical appearance, play a vital role in agricultural production. According to Food and Agriculture Organization of the United Nations (FAO), pollinators are defined as "… animals that carry pollen from the male to the female parts of plants and thus ensure that fruit or seeds are formed,"[1] Pollinators include various animals such as bees, wasps, moths, butterflies, birds

[1] Other organizations and countries use similar definitions and the term "animal" in the definition includes insects as well.
Definition comes from: FAO, 2007. "Item 8 of the Draft Provisional Agenda COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE Eleventh Regular Session Rome, 11-15 June 2007 POLLINATORS: NEGLECTED BIODIVERSITY OF IMPORTANCE TO FOOD AND AGRICULTURE" Pg. 1 (https://www.fao.org/3/k0113e/k0113e.pdf)

etc. Most significant are bees where species such as the honeybee and bumblebee are often used for pollination (Yoon et al., 2021).

Plants, including crops, heavily rely on pollinators for the formation of fruit and seeds. Around 65 percent of plants worldwide and 75 percent of crops are dependent on pollinators (Barth, 1985; Klein et al., 2007). Simply put, a majority of crops and their production are influenced by fluctuations in pollinator density. While it is intuitive that a crop's production quantity takes a hit from a declining pollinator density, quality is also affected. Without animal pollinators, flowers turn to other methods such as wind and self-pollination which leads to the production of lower-quality crops. Klatt et al. (2014) discovered that a lack of sufficient pollination from pollinators caused production of strawberries lacking in marketable quality, and a similar result was shown in the research of Vaissière, Freitas and Gemmill-Herren (2011) with kidney beans. Thus, pollinator density is highly influential to agricultural production and consumption.

Due to its close connection to overall vegetation, pollinator density decline has long been a topic of study, as with economic development, many wild pollinators lost their habitat. Studies such as Brittain et al. (2013) and Winfree et al. (2007) claim that diversification of pollinators, including both managed and wild species lead to improvements in overall productivity. However, more recently, due to continuing climate change, managed pollinators are also experiencing density decline with cases of colony disappearance and collapse. Many Korean farmers depend on honeybees and bumblebees for the pollination of various fruits and vegetables. With the continuous increase of greenhouse cultivation and decrease in wild pollinator density, managed species are vital for production. According to Yoon et al. (2021), in Korean agriculture, honeybees were the most used managed pollinator with 69.8 percent, followed by bumblebee (22.7 percent), mix of the two (7.4 percent) and flies (0.1 percent).

Despite such reliance, Korean farmers have been dealing with annual bee colony loss occurrences for the past few of years. Significant losses were observed starting from 2020 with a large loss in honey production and actual honeybee loss in southern regions of Korea in 2021. Around 17% of bee colonies perished in early 2022 as a result of abnormal weather, mite infestations, and wasp attacks, all caused by climate change (Ministry of Agriculture, Food and Rural Affairs (MAFR), 2022). For the entirety of 2022, a total of 57.1 percent out of 1.54million of honeybee colonies were lost (Korea Beekeeping Association, 2023).[2] Since members of the Korea Beekeeping Association are farmers with more than thirty beehives, the loss is expected to be higher when including non-member farmers. There have been multiple reports of farmers wasting pollinating season due to the lack of bees, resulting in the decrease of production and increase of expenditures to replace the lost pollinators. Human pollination has long become a common sight in fields and orchards, implying a dramatic increase in the cost of production.

Regarding the annual bee colony collapse and death and the continuous decline in wild pollinator density, the Korean government has been actively implementing pollinator-related policies. Prior to the

[2] The statistics are as of Nov. 30th 2022.

public's current increased attention regarding pollinators, government departments related to agriculture such as the Rural Development Administration (RDA) have already been providing guidelines and education to farmers for the optimal use and promotion of managed pollinators. Classifying pollinators as an environmentally friendly farming method RDA provides guidelines on the definition, types, use, and breeding methods. Additionally, data for pesticide and insecticides that are harmful to pollinators are made available so that farmers can readily check and limit their use to prevent the harming of pollinators.[3] With the increase in occurrence if bee colony death during the winter of recent years, more announcements are made every winter, where farmers are reminded to prepare for honeybee hibernation.[4]

In addition to the above efforts, MAFR has announced in June 2022 the "Five-Year Comprehensive Plan for the Beekeeping Industry."[5] Although it is mainly focused on the beekeeping industry in Korea, the plan also has a wider perspective: creating a more honeybee-friendly environment. The plan includes the creation of forests consisting of honeybee plants, technology to prevent disease, R&D, and support for beekeeping farms. Of the abovementioned plans, honeybee plant forests are one of the widely used methods to both protect and boost honeybee population and productivity.

MAFR has also included the value of pollination as one of the factors that support such plans. Accounting 2.5 percent of the beekeeping industry revenue as pollinator service, MAFR

[3] Rural Development Administration, 2023. Policy Brief.
[4] Ministry of Culture, Sports and Tourism, 2023. Policy Brief.
[5] Ministry of Culture, Sports and Tourism, 2022. Policy Brief.

approximates 40 billion won as the value of pollination. The aim is to increase the value to 70 billion won until 2026 and R&D is listed as one of the methods. Such consideration of pollinator service as an aspect of the beekeeping industry is different from former policies as previously, pollination was not as emphasized (Lee et al. 2019).

Thus, with heightened interest towards pollinators and their service, it is vital to understand the economic value of pollinators. As more public attention is given to pollinators and their role in the environment and further, in agriculture along with government’s response with new policies, an overall calculation of the value of pollinators is necessary to prevent further cost incurred by trial and error. Thus, in consideration of current policy climate in Korea and the overall threat pollinators face with climate change, economic valuation of pollinators is necessary.

1.2. Research Purpose and Method

This study aims to estimate the economic value of pollinators through recent data and to derive policy implications with the consideration of current situation of Korea.

It is without a doubt that pollinators play a major role in agriculture and that many researchers have strived to convert this service of pollinators into monetary value. However, as many studies are focused mostly on the production aspect of pollination service, valuation in a wholistic sense seems to be lacking.

Figure 1. Flow of Research

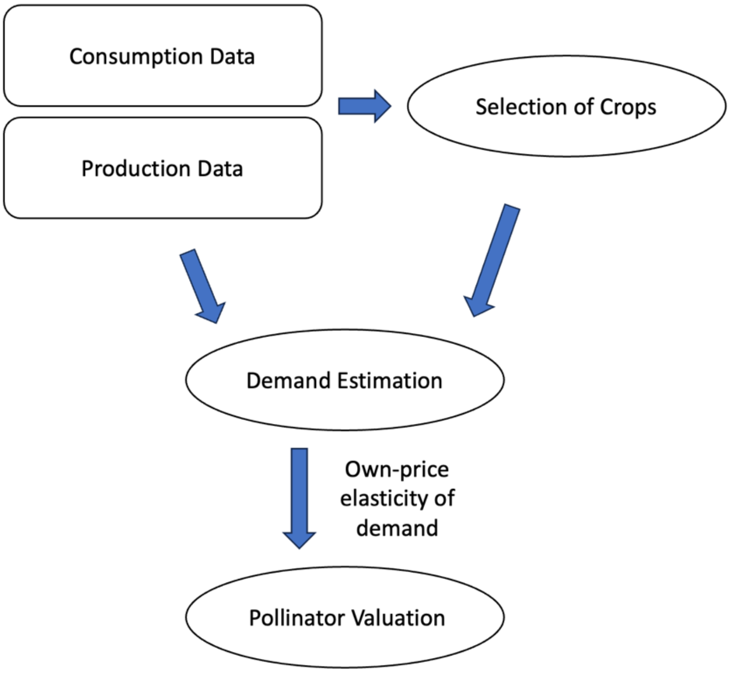


Figure 1 depicts the analysis process for this research. Based on available data, crops are selected for analysis. The demand is estimated and the value of pollinators are calculated. Rather than to rely on previous literature and information for necessary demand estimates, this study aims to estimate demand for pollinator-dependent crops in Korea and with the estimation results, calculates the value of pollinators in Korea. In addition to the demand estimation, a confidence interval is constructed for the own-price elasticity of demand to provide a more reliable estimation of pollinator value in terms of ranges.

The research is conducted as follows: after identifying the necessary estimate from the final model (own-price demand elasticity), a panel data of household consumption for the period of 2004-2014 was constructed. Then, own-price elasticity was obtained through Tobit regression and a Krinsky and Robb confidence interval for the elasticity was constructed. This is to account for the time gap between consumption and production data and since it is more reliable to present pollination value as a range rather than as a single value. The range of own-price elasticity is then used for pollinator valuation. Like many other research, value of pollinators is expressed as changes in social welfare in this research. Since the valuation model also requires production data, a cross-sectional data of pollinator-dependent crops were constructed. Finally, the calculated social welfare change, along with producer surplus and consumer surplus are suggested.

1.3. Literature Review

With the importance of pollinators and their pollination activities, pollinator valuation has long been a topic of study (Robinson et al., 1989; Southwick and Southwick, 1992; Morse and Calderone, 2000; Allsopp et al., 2008; Gallai et al., 2009; Suh et al., 2011; Winfree et al., 2011; Lippert et al., 2021; Jung and Shin, 2022).

Allsopp et al. (2008) calculates the value of managed honeybees and wild pollinators in South Africa through two commonly used valuation methods: production value approach and the replacement value method.[6] By using two different methods that calculate the same thing, Allsopp et al. (2008) highlights the discrepancies between the methods. Since the two methods both estimate the value of pollinators, it is intuitive that the results would be at the very least be similar. However, the research shows that the replacement values varied from that of proportional total production estimates and thus provided the grounds for further research.

Gallai et al. (2009) aimed to assess the vulnerability of food production in the context of pollinator decline. Using an approach similar to the production value approach, the contribution of pollinators in the production of crops was €153 billion, 9.5 percent of the worldwide crop production. Furthermore, regional discrepancies were found where regions such as the Middle East Asia and Central Asia were more vulnerable than other areas. As a global-scale analysis,

[6] More details about the methods will be given in Chapter 3.

although this study lacks in detail regarding the price elasticity of demand, it provides insight into models that are not solely dependent on production data.

Suh et al. (2011) uses the replacement value method based on farm household survey data. Focused on crops that are dependent on pollinators, such as apples, pears, peaches, and so on, it is estimated that around 760 billion won is affected by the pollinators. When compared to the production value of beekeeping, it is six times larger and accounts for 25.7 percent of fruits produced. The study concludes that the results can support subsidies to beekeeping households for income preservation and for the promotion of the positive externality of bees.

Jung and Shin (2022) is the most recent research concerning pollinator valuation in Korea. Using the production value approach, the research used 2015 agricultural census data for the production value of 71 crops. It was found that across the crops, the average dependence ratio was 29.2 percent.

Lippert et al. (2021) calculates both the short-term and long-term social welfare effects of pollinator collapse based on the model developed by Southwick and Southwick (1992) and Gallai et al. (2009) Based on the production value approach, Lippert et al. (2021) incorporates the consumption aspect into the model through the utilization of own-price elasticity of demand. With the developed model, the research analyses the potential loss of social welfare for a sudden pollinator collapse in the case of Germany and worldwide. Here, Lippert et al. (2021) concludes that in cases of pollinator collapse, a short-term analysis is more adequate as the long-term model requires tighter restrictions. It was found that the short-term welfare effects of a total pollinator loss are between 1 and 2 % of global GDP, depending on the assumed price elasticity.

Of the above and many other studies, this research builds upon Lippert et al. (2021) and attempts to estimate the value of pollinators in Korea. As the short-term welfare effect model reflects the production value approach and the consumption elasticity used in Gallai et al. (2009), this study attempts a wholistic analysis, estimating the own-price elasticity of demand and to derive policy implications from the estimation results.

1.4. Organization of Research

The structure of this research is as follows:

In chapter 1. Introduction, the main topic and purpose of this research is presented, along with its background and related literature review.

Chapter 2 discusses the methodologies used in this study: the short-term welfare effect model and Tobit demand estimation.

Chapter 3 describes the data used for analysis and the final form used for analysis.

In chapter 4, the analysis results and its significance are presented.

Finally, in chapter 5, analysis results are recapped and policy implications, research limitations, and possible improvements are suggested.

Chapter 2. Methodology

2.1. Existing Literature

Valuation of pollinators have long been a topic of research, dating back to Meade (1952) where bees were used as an example of externalities. Abundant amount of literature exists in the 2000s and 2010s when the importance of pollination was emphasized. Since pollinators, with the exception of managed pollinators such as honeybees and bumblebees, do not have an established market, their value is often calculated in terms of welfare change. Most often the welfare change is caused by pollinator collapse. The methodologies used by these existing studies can be largely divided into two: replacement value method and production value approach.

2.1.1. Replacement Value Method

As the name suggests, the replacement value method calculates the value of pollinators from the costs incurred from using alternative pollination methods such as human labour for manual pollination. Focusing on the producer's additional cost caused by pollinator decline, data is often collected from surveys conducted to farmers centering on other pollination technology and the purchase of managed pollinator species.

Groot et al. (2002) evaluates domestic ("wild") pollinator value by the cost of its replacement through the purchase of managed species which include honeybees and bumblebees. Allsopp et al. (2008) also used this method by calculating the cost of replacing honeybees with other technology such as human pollination and revealed that different methods of valuation led to different results. In Korea, Suh et al. (2011) estimated the value of pollination through a household survey of pollinator replacement costs, which, in comparison to income from beekeeping, was much higher.

However, there are also disadvantages to this method as since it relies mainly on producer's response and data to replacement cost, it is limited to the producer's side to the market and to certain farms and their crops that respond to the survey or have existing data.

2.1.2. Production Value Approach

The production value approach calculates the value of pollinators by using the crop production value and the dependency ratio of crops on pollinators. This method focuses on the production value lost due to the decline in pollinators and requires the dependency ratio data for calculation.

$$(1) \qquad \sum_{i=1}^{N} P_i \times Q_i \times D_i$$

Above is the basic form of production value approach. The model largely consists of produce price (P), quantity (Q), and dependency ratio (D). Due to the relative accessibility of production data, production value approach is widely used in many countries and organizations. Studies using this method include Allsopp et al. (2008), Gallai et al. (2009), Lippert et al. (2021), and Jung and Shin (2022).

The dependency ratio represents the proportion that a certain crop relies on pollinators for pollination and ranges from 0 to 1.0. The ratio is measured as below (Klein et al., 2007):

$$(2) \qquad D_i = 1 - \left(\frac{f_{i,pe}}{f_{i,p}}\right)$$

$f_{i,wp}$ denotes fruit set without pollinator for crop i and $f_{i,p}$ denotes fruit set with pollinator for crop i. Thus, crops with less fruit set due to lack of pollinators will have a higher dependence. Crops with a dependence ratio of 0, such as rice and barley, do not rely on pollination for produce. On the other hand, for crops with a 0.95 ratio, including melons, pollinators are essential. A higher ratio indicates a higher dependence on pollinators, hence the name “dependence ratio.” Studies often refer to Robinson et al. (1989), Southwick and Southwick (1992), Morse and Calderone (2002), and Klein et al. (2007). Appendix 1 of Klein et al. (2007) is also used by the FAO, which presents the production value approach as a guideline to pollinator valuation.[7]

As briefly mentioned above, the main advantage of the production value approach is the relatively accessible data for analysis. Dependency ratio is usually referred from ecological studies of which there are staple studies often referred to.

Production value or production quantity and price data are one of

[7] The FAO provides a pollinator valuation “tool” in which the average value of Klein et al. (2007)’s findings are included to be used as the dependence ratio. The data will later be introduced in chapter 4.

the more common data as it is collected by most countries. Additionally, these data are low in variability, usually only differing in unit of measurement (i.e. monetary value, weight, time period etc.) and fundamentally represent the same information. Due to this availability across many countries and regions, the production value approach is frequently used for large-scale analysis such as global pollinator valuation and country comparisons (Gallai et al., 2009). However, this method also has drawbacks since it is limited to the producer's side and lacks mobility to adjust to market changes.

Despite the above methods representing the producers' cost and revenue loss respectively, the two methods lack in consistency. Based on the theory that since the two methods essentially calculate the same pollinator value, the results should match. However, it was shown in Allsopp et al. (2008), that despite analyzing the same pollinators in South Africa, the two methods obtained different results. Due to such discrepancy between the two methods, Winfree et al. (2011) developed the attributable net income method, which combines the two methods to consider the changes in the environment and market caused by pollinator collapse. Lippert et al. (2021) developed on the production value approach used in Gallai et al. (2009), presenting a short-term and long-term model which includes own-price demand elasticity.

2.1.3. Attributable Net Income

Initially, the attributable net income method was considered to be the main model for this research. This method combines the production value approach and the replacement value method. Through this, the model accounts for a two-step effect on the market caused by pollinator collapse. The first effect is the impact on the producers' surplus due to the decline in productivity and increase in cost. Following the first effect, a second effect influences both the producers and consumers as the price of crops increase and thus producers have an increase in profit while consumer welfare decreases. The model is as below:[8]

$$(3) \qquad SW = \pi_a + \pi_{\neq a} + CS$$

SW: Social Welfare, π: Producer Surplus,

a: Area with pollinator loss, CS: Consumer Surplus

Each term in the social welfare equation is defined with terms of price(P), total yield(Y), and cost(C).

$$(4) \qquad \pi_a = P(Y_a + Y_{\neq a})Y_a - C(Y_a, q_a)$$ [9]

$$(5) \qquad \pi_{\neq a} = P(Y_a + Y_{\neq a})Y_{\neq a} - C(Y_{\neq a}, q_{\neq a})$$

$$(6) \qquad CS(P) = \int_{P}^{\bar{P}} Q(P)dP$$

In detail, the price (P) is a function of the sum of income in both regions with and without pollinator loss, thus the total market production. Although omitted in the above expression, total yield (Y) depends on the variable q which denotes pollination service and so,

8 The model below comes from Appendix A of Winfree et al. (2011)
9 This producer surplus which includes pollinator service is based on McConnell and Bockstael (2005).

could be expressed as $Y(q)$. Such form is intuitive in the sense that the yield of a crop is directly reliant on pollination and through this, the production value approach is included in the model. The cost (C) is also a function of yield, but differs in that it is only affected by the yield produced within the region and the direct effect of pollination service. A marginal change in pollination service, such as a loss, can affect production cost as producers may have to seek out alternative methods to replace the original pollination service and thus incur replacement cost. Thus, the replacement value method is included in the cost section.

The consumer surplus is calculated as the area below the demand curve and above the price and hence the integral form. $Q(P)$ is the market demand and $\bar{P}$ is the upper price limit where there is no demand.

Deriving the change in social welfare caused by a change (decline) in pollination service, the original equation (1) changes into the form below:

$$(7) \qquad \Delta SW = \left[\frac{\Delta\pi_a}{\Delta q_a} + \frac{\Delta\pi_{\neq a}}{\Delta q_{\neq a}} + \frac{\Delta CS}{\Delta q_a}\right]\Delta q_a$$

Ultimately, the change in social welfare can be expressed as below:

$$(8) \qquad \Delta SW = \left[-\left(1 + \frac{1}{\epsilon_a}\right)PY_aD_\rho + (VC)D_\rho\right] + \left[-\left(\frac{1}{\epsilon_a}\right)\frac{Y_{\neq a}}{Y_a}PY_aD_\rho\right] + \left[-\left(\frac{1}{\epsilon_a}\right)\frac{(Y_a + Y_{\neq a})}{Y_a}PY_aD_\rho\right]$$

Social welfare can now be derived from pollinator dependency (D), price elasticity of supply (ϵ_a), pollinator loss scenario (ρ), and variable cost (VC), which, according to Winfree et al. (2011), can all be estimated through available data and existing research. It was based on this that the attributable net income method was originally selected. Problems arising from the price elasticity of supply ultimately led to the selection of a different model: the short-term welfare effect model.

2.2. Short-term Welfare Effect[10]

Considering the weakness of the replace value method and the production value approach, this study's model is built on Lippert et al. (2021)'s short-term welfare effect model.

Only the short-term model was selected, as based on the findings of Lippert et al. (2021), the long-term model requires more speculation and thus tends to deviate from the actual agricultural sector. In addition, from the previous estimation results for the attributable net income method, it was revealed that producers tend to have inelastic supply, and hence more apt for a short-run assumption.

Unlike the long-term model of Southwick and Southwick (1992) and Gallai et al. (2009) the short-run model of Lippert et al. (2021) is limited to a single year or a cropping season between pollinator

[10] Model used in this study is based on the model developed in Lippert et al. (2021). The original title of the section is "3.1. Short-term welfare effects of a sudden pollinator collapse." (pp. 4)

collapse and adaptation. The model is built on Gallai et al. (2009).

For all crops, isoelastic demand function is assumed for simplicity and is shaped as below:[11]

$$(9) \qquad P(Y) = P_0 \left(\frac{Y}{Y_0}\right)^{\frac{1}{\varepsilon}}$$

P: price, Y: yield, P_0: price at equilibrium, Y_o: yield at equilibrium, ε: own-price elasticity of demand

Another assumption introduced by Lippert et al. (2021) is that at the equilibrium, the agroecological conditions are at the optimum, meaning that the environment has the "full potential to sustain pollinating insects."

As this model assumes perfect competition, the long-term equilibrium price (P_0) is horizontal, and producers have zero profit. In the short-run, crop supply is assumed to be perfectly inelastic, indicating that producers cannot adapt quickly to sudden changes such as pollinator collapse.

In the case of pollinator collapse, yield would decrease to Y_1 ($Y_0 \rightarrow Y_1$) which leads to an increase in price ($P_0 \rightarrow P_1$). Then, producer surplus can be expressed as below:

$$(10) \qquad \Delta PS = P_1 Y_1 - P_0 Y_0 = P_1 Y_0 (1 - D) - P_0 Y_0$$

Where $Y_1 = Y_0 - Y_0 D = Y_0(1 - D)$ as D is pollinator dependency. Thus, the right most expression calculates the change in producer

[11] Variable expressions were changed from the original to lessen confusion from using multiple expressions for the same variable.

surplus by including the impact of pollinator collapse. Here, pollinator collapse indicates a complete disappearance of pollinators in order to fully evaluate their pollination activities.

$$(11) \qquad P_1 = P_0 \left(\frac{Y_0(1-D)}{Y_0}\right)^{\frac{1}{\varepsilon}}$$

From the above demand function, P_1 can be expressed in term of $P_0, Y_0, D,$ and ε and can be substituted in the producer surplus equation.

$$(12) \qquad \Delta PS = P_0 \left(\frac{Y_0(1-D)}{Y_0}\right)^{\frac{1}{\varepsilon}} Y_0(1-D) - P_0 Y_0$$

$$= P_0 Y_0 \left\{(1-D)^{1+\frac{1}{\varepsilon}} - 1\right\}$$

Due to this form, the producers' surplus is affected mainly the own-price elasticity of demand where if $|\varepsilon| > 1$ (elastic demand), change in producer welfare is negative and if $|\varepsilon| < 1$ (inelastic demand), it is positive.

Under the same conditions of change, consumer surplus can be calculated as below:[12]

$$(13) \qquad \Delta CS = -(P_1 - P_0)Y_1 - \int_{Y_1}^{Y_0} P(Y)dY + P_0(Y_0 - Y_1)$$

$$= -\frac{P_0 Y_0}{1+\varepsilon}\left\{(1-D)^{\frac{1}{\varepsilon}+1} - 1\right\}$$

---

[12] The derivation of the final expression can be found in Appendix A1 of Lippert et al. (2021).

Thus, the short-term change in social welfare can be expressed as below:

$$(14) \qquad \Delta SW = \Delta PS + \Delta CS = P_0 Y_0 \left[(1-D)^{\frac{1}{\varepsilon}+1} - 1\right] - \frac{P_0 Y_0}{1+\varepsilon}\left[(1-D)^{\frac{1}{\varepsilon}+1} - 1\right]$$
$$= \frac{\varepsilon}{1+\varepsilon} P_0 Y_0 \left[(1-D)^{\frac{1}{\varepsilon}+1} - 1\right]$$

This the final form that is used for the valuation of pollinators, and consists of: own-price elasticity of demand, equilibrium price and yield, and the dependence ratio, all of which can be obtained through market data and previous studies.

2.3. Own-Price Demand Elasticity

One major difference between the production value approach is that the short-run welfare effect model requires additional data: own-price elasticity of demand. Previous research such as that of Gallai et al. (2009) and Lippert et al. (2021) refer to other demand studies as reference for each crop. In the case of Lippert et al. (2021), numerous studies are referred to for the own-price elasticity of demand for crops pollination-dependent crops in Germany such as apples, cherries, and beans. In this study, however, for a more comprehensive analysis of Korea's agriculture, a simple demand analysis was conducted to obtain demand elasticities.

Since the short-run welfare effect model only requires own-price elasticity of demand, Tobit regression was used. The Tobit model was used mainly due to the fact that the available consumer data was censored at zero, as households responded “0” for items they did not consume.[13]

$$(15) \qquad y_i = X_i\beta + u_i \quad if\ RHS > 0$$
$$y_i = 0 \qquad if\ RHS < 0$$
$$i = 1, \ldots, 9$$

For the demand analysis, the quantity consumed for each crop was set as the dependent variable and the independent variables included price of individual crop and household characteristics (household income, size of household, gender of household head).

Considering the limitations in data and to provide a more reasonable estimate, Krinsky and Robb confidence interval (Krinsky and Robb, 1986; 1990) was used to obtain a range of the own-price elasticity of demand at the 95 percent confidence level. The Krinsky and Robb method assumes consistency and asymptotically normal multivariate distribution of the estimator (Dowd, Greene, and Norton, 2014).

[13] Further explanation of the data will be provided in the next chapter, “Chapter 4. Data.”

Chapter 3. Data

3.1. Data for Demand Estimation

For consumption data, the Household Income and Expenditure Survey was used. A panel data from 2004 to 2014 was created from this data and the monetary values were adjusted using the Consumer Price Index (2020=100) provided by Statistics Korea.[14]

The consumption data was limited to past data, at the very latest up to 2014, due to changes in the commodity grouping for the Household Income and Expenditure Survey. In addition, the latest data of the survey available no longer include lower groupings and individual commodities and thus was not adequate to be used for crop-specific demand estimation. Ten crops: beans, apples, pears, peaches, persimmons, watermelons, Korean melons, strawberries, cucumbers, and sesame were selected for this research.

Table 1. Basic Statistics (Consumption Data)

Variable		Obs	Mean	Std. dev.	Min	Max
	Beans	117,685	1982.33	5952.51	0	517,000
	Apple	117,685	5832.037	8512.95	0	626,500

[14] Data accessed Feb 9th, 2023.

Household Counsump-tion (Won)	Pear	117,685	2420.76	5195.08	0	501,794
	Peaches	117,685	1442.32	2931.77	0	175,000
	Korean Melon	117,685	1726.11	2735.81	0	90,307
	Watermelon	117,685	2623.67	3732.38	0	90,000
	Strawberries	117,685	2751.96	4582.47	0	127,400
	Cucumber	117,685	1126.25	1314.13	0	38,109
	Sesame seeds	117,685	1094.73	4096.18	0	286,752
Crop Price (Consumer Price Index, 2020=100)	Beans	117,685	72.26	13.50	55.68	96.01
	Apple	117,685	86.87	12.94	71.49	108.43
	Pear	117,685	79.21	17.22	58.11	117.52
	Peaches	117,685	100.09	15.54	80.38	124.34
	Korean Melon	117,685	109.72	16.07	90.03	141.31
	Watermelon	117,685	90.39	18.63	67.81	121.16
	Strawberries	117,685	93.98	12.85	73.91	121.08
	Cucumber	117,685	64.99	13.05	44.44	83.79
	Sesame seeds	117,685	79.04	9.96	65.81	91.09
Household Character-istics	Household Size	117,685	2.92	1.23	1	10
	Household Head Gender	117,685	1.26	0.44	1	2

	Income (1,000 won)	117,685	3,091.68	2,234.27	0	75,400

Although the Household Income and Expenditure survey is not limited to the ten crops above, the crops were selected due to two reasons. First, since this research aims for pollinator valuation, crops that are not dependent on pollinators were excluded. In other words, crops with a dependence ratio of zero are not included in the final data and analysis as, when put into the short-term welfare effect model, the crop would only give a zero value. Such crops include mostly food crops such as rice and wheat. Another reason for the selection of the ten crops is the consistency between the expenditure data and the production data. Without data in either of the datasets, it is impossible to conduct analysis in this research. Thus, the household expenditure data and crop production data were compared at the very beginning to determine common crops between the two.

3.2. Data for Pollinator Valuation

Since the valuation model is for short-term analysis, only cross-sectional data for a single year or a cropping season can be used. Data of 2021 was used for analysis.[15]

For crop yield, the Crop Production Survey provided by Statistics Korea was used. This data provides yield and area for around 53 crops

[15] Data for 2022 was not yet fully released. 2021 was used for maximum data availability.

for each province, which includes subdivisions within each crop such as autumn cabbage and spring cabbage. However, as mentioned previously, only ten crops were used for analysis as only some overlapped across all the demand and production data.

The Crop Production Survey also separates data for crops that are cultivated in both open field and greenhouse, which is useful in cases of analysis where wild and managed pollinators are separated. However, for the overall analysis of social welfare loss in this research, open field and greenhouse crops were not separately analyzed. According to Garibaldi et al. (2013), for open field crops, the current ratio of wild pollinator visits worldwide averages around 0.5. Based on this, it can be assumed that open field crops have a ratio of wild pollinator to managed pollinator as 50:50, and 0:100 for greenhouse crops. However, theoretically, pollinator valuation assumes the scenario of general pollinator collapse, where pollinators suddenly disappear, both open field and greenhouse crops will be affected. Thus, open field and greenhouse was not taken into account.[16]

In the case of crop price, the total product value of the crops in the Statistical Yearbook of Agriculture, Food and Rural Affairs released by the Ministry of Agriculture, Food and Rural Affairs was used. The product value was divided by the total product yield in the Crop Production Survey to keep the price same across all regions under the assumption that prices do not differ between provinces.

The dependency ratio comes from FAO's resource, which is based

[16] In the case of wild pollinator valuation, open field crop data can be used.

on Klein et al. (2007) data.[17] FAO provides this specific data to be utilized for valuation of pollination services at the national level, and thus was considered as apt for this research.

Table 2. Basic Statistics (Production Data)

Crop		Mean	Std. Dev.	Min.	Max.
Beans	Price (index)	117.87	2.92	114.10	122.19
	Quantity produced (ton)	25,409.3	36,688.29	5,737.68	128,066
	Dependency ratio	0.25	0	0.25	0.25
Apples	Price (index)	120.5	7.49	113.31	135.64
	Quantity produced (ton)	103,062	171,613.7	0	515,931
	Dependency ratio	0.65	0	0.65	0.65
Pears	Price (index)	134.63	6.38	125.01	144.37
	Quantity produced (ton)	40,839.3	63,659.67	0	210,293
	Dependency ratio	0.65	0	0.65	0.65
Peaches	Price (index)	123.18	5.92	117.4	137.36
	Quantity produced (ton)	37,743.7	62,699.8	1	192,094
	Dependency ratio	0.65	0	0.65	0.65
Water-melons	Price (index)	120.8	6.62	109.28	132.26
	Quantity produced (ton)	96,096.3	144,635.5	3,579	489,029
	Dependency ratio	0.95	0	0.95	0.95
Korean	Price (index)	111.59	4.81	105.6	120.07

[17] FAO, "Tool for Valuation of Pollination Services at a National Level" (https://www.fao.org/pollination/resources/pollination-assessment/economic-value/en/) (sources: Klein et al., 2007; FAO, 2008)

Melons	Quantity produced (ton)	39,394.6	81,134.54	228	198,598
	Dependency ratio	0.95	0	0.95	0.95
Straw-berries	Price (index)	102.94	4.42	98.68	112.69
	Quantity produced (ton)	35,309.2	54,124.08	627	177,480
	Dependency ratio	0.25	0	0.25	0.25
Cucum-bers	Price (index)	111.92	4.85	102.78	116.90
	Quantity produced (ton)	54,786.2	82,785.39	2,696	283,933
	Dependency ratio	0.65	0	0.65	0.65
Sesame seed	Price (index)	101.57	1.1	100.55	104
	Quantity produced (ton)	1,987.80	2,920.08	252.28	10,090.14
	Dependency ratio	0.25	0	0.25	0.25

Chapter 4. Analysis Results

4.1. Demand Elasticity

The estimated own-price elasticity of demand is presented in the table 3. Based on the Tobit regression, the elasticities mostly lie between -1.2 to -0.5, showing a range of elasticity but overall, the usual negative price and demand relationship. This estimation result lies between the elasticities used in both Lippert et al. (2021) and Gallai et al. (2009) where the elasticities were -1.0 to -0.5 and -0.8 to -1.5, respectively.

It can be seen that of the crops, beans have the most elastic demand, followed by sesame seed. Since both crops exceed -1, it can be expected that the producers of the two crops will face negative surplus, as mentioned in Chapter 3. For other crops, they all have elasticities that have absolute value under 1, and thus, producers will have a positive surplus.

Table 3. Own-price Elasticity of Demand[18]

Crops	Price Coefficient	Elasticity
Beans	-1.466***	-1.17
Apple	-0.900***	-0.71
Pear	-0.700***	-0.77

[18] ***: indicates significance at 1%.

Peaches	−0.228***	−0.67
Watermelon	−0.481***	−0.85
Korean Melon	−0.197***	−0.73
Strawberries	−0.506***	−0.88
Cucumber	−0.266***	−0.69
Sesame seeds	−0.847***	−1.13

From the demand elasticity estimates, Krinsky and Robb confidence interval was constructed.[19] A sample of 5000 observations from a normal distribution for the own-price elasticity of demand was drawn. The intervals are as in Table 4 and can be shown as in Figure 2.

Table 4. Confidence Interval of Elasticity

Crops	Elasticity	Lower	Upper
Beans	−1.172	−1.223	−1.120
Apple	−0.713	−0.753	−0.672
Pear	−0.766	−0.804	−0.729
Peaches	−0.673	−0.729	−0.617
Watermelon	−0.850	−0.887	−0.814
Korean Melon	−0.730	−0.780	−0.680
Strawberries	−0.878	−0.931	−0.825
Cucumber	−0.694	−0.723	−0.664
Sesame seeds	−1.126	−1.211	−1.041

[19] Statistical software Stata was used.

Figure 2. Confidence Interval of Elasticity

It can be seen that even with the lower and upper limits in consideration, the crops have a strong divide between beans and sesame seeds and others. With the exception of the two, the own-price elasticity tends to lie between −1.0 to −0.5, a result that is closer to that of Lippert et al. (2021). Considering the short-term and wide-impact aspect of pollinator collapse, a relatively less elastic demand compared to that of the long run is more reasonable. Prior to the actual valuation, it can be noted that with mostly inelastic demand, producers will mostly have positive producer surplus.

4.2. Value of Pollinators

Using the estimated demand elasticity, the short-term welfare effect of sudden pollinator collapse in Korea was calculated. Since crop production data was available to the province level, the short-term effect on the nation and on each province could be calculated.

Although Korea has a relatively small territory, provinces differ in their main crop choice. For example, fruits tend to be cultivated in the Chungchung province and Gyeonsang province, while the Jeolla region produces mostly food crops such as rice. Since crops differ in how much they are affected by pollinator loss (dependency ratio), it is evident that regional differences will exist.

At the national level, it can be seen in table 11 that with sudden pollinator disappearance, social welfare loss occurs for all crops. Looking at the individual components of the social welfare, it can be seen that with the exception on beans and sesame seeds, producers experience welfare gains. This, as mentioned above, can be attributed to the relatively inelastic demand.

The social welfare change is depicted as a box graph in Figure 3.[20] It is very clear that watermelons and Korean melons face the most severe social welfare loss with a sudden pollinator collapse. Such finding cannot be solely explained by demand elasticity as both crops

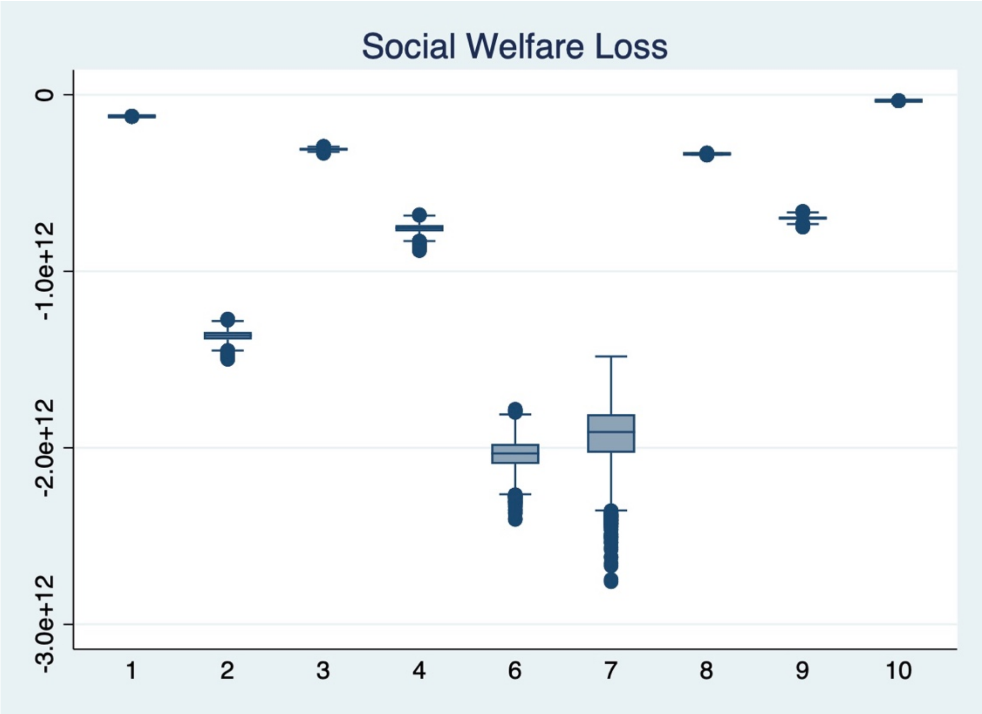
[20] Due to spatial problems, crops names are substituted with numbers. The numbers correspond to the order of the crops in table 5. For example, 1 in Figure 3 is beans, 2 is apple, and so on.
Crop 5, persimmon, is excluded from the final valuation due to issues in data.

do not exhibit more inelastic demand compared to other crops with -0.85 for watermelon and -0.73 for Korean melon. Instead, it can be explained by the high dependence ratio of the two crops. Compared to other crops that have dependence ratio ranging from 0.05 to 0.65, melons are highly dependent on pollinators with a dependence ratio of 0.95. Within the FAO data used for this analysis, 0.95 is the highest value, and it implies that with the disappearance of animal pollinators, only five percent of the current melon yield will be produced. Thus, it can be seen that the dependence ratios' impact on the crops' productivity is more significant.

Table 5. Changes in Social Welfare (National) (Trillion won)

Crops	Producer Surplus	Consumer Surplus	Social Welfare
Beans	−0.018	−0.104	−0.122
Apple	0.55	−1.91	−1.36
Pear	0.094	−0.403	−0.309
Peaches	0.367	−1.12	−0.755
Watermelon	0.358	−2.39	−2.03
Korean melon	0.707	−2.62	−1.91
Strawberries	0.047	−0.382	−0.335
Cucumber	0.309	−1.01	−0.699
Sesame seeds	−0.004	−0.03	−0.034
Total	2.41	−9.969	−7.554

Figure 3. Social Welfare Loss (National)



Despite the original assumption of sudden pollinator collapse in the short-term welfare effect model, it is without a doubt that such a scenario is highly unlikely. As the dependence ratio relies on the probability of fruit set with or without pollinators, it seems possible to replace the value with different scenarios.

For example, in the case of apples, it has a dependency ratio of 0.65 which signifies that with pollinator disappearance, 65 percent of apples are lost. Then, what happens when only a certain percentage of pollinators are lost? Assuming that the probability of fruition remains constant for all scenarios of pollinator loss, if there were to be a pollinator loss of 50 percent, then 32.5 percent of apples are lost. Accordingly, the modified model is as below:

$$(16) \qquad \Delta SW = \Delta PS + \Delta CS = \frac{\varepsilon}{1+\varepsilon} P_0 Y_0 \left[(1 - D * \rho)^{\frac{1}{\varepsilon}+1} - 1 \right]$$

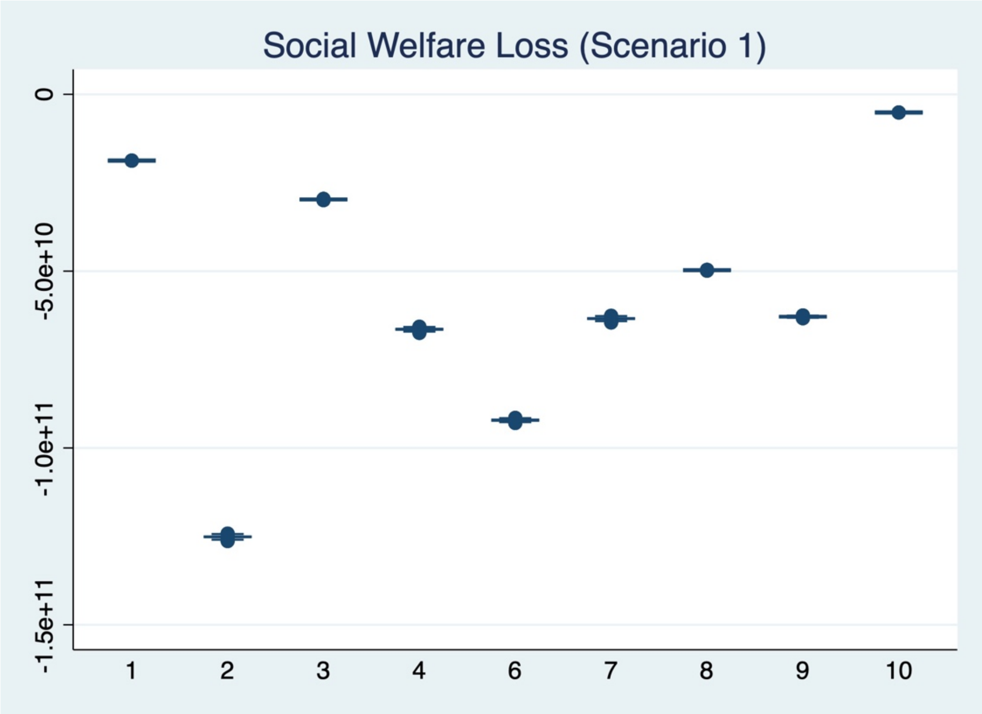
ρ: pollinator loss scenario.

Using this theory, the short-term welfare effect model can be further used to assess prior to and after pollinator loss, like in the case of Korea in the winter of 2021-2022 when around 17 percent of bees were lost. Naming this scenario as Scenario 1, the short-term welfare effect caused by pollinator loss in Korea was analyzed. The results are displayed in table 6 and Figure 4.

Table 6. Changes in Social Welfare (National, Scenario 1) (Trillion won)

Crops	Producer Surplus	Consumer Surplus	Social Welfare
Beans	−0.003	−0.016	−0.019
Apple	0.051	−0.176	−0.125
Pear	0.009	−0.039	−0.03
Peaches	0.032	−0.099	−0.066
Watermelon	0.016	−0.108	−0.092
Korean melon	0.024	−0.087	−0.063
Strawberries	0.007	−0.057	−0.05
Cucumber	0.028	−0.091	−0.063
Sesame seeds	−0.001	−0.005	−0.005
Total	0.163	−0.676	−0.513

Figure 4. Social Welfare Loss (Scenario 1)



Compared to the original assumption of complete pollinator disappearance, the amount of social welfare loss is smaller. However, the social welfare loss for the Korean Melon has significantly decreased while that of the apple has increased. This may be due to the fact that with the decreased impact of pollinator loss, demand elasticity may be playing a bigger role in determining the size of welfare loss with apple having a more inelastic demand compared to the Korean Melon.

In the case of scenario 1, it assumes that the size of pollinators correlates to the size of honeybees, as its 17 percent loss is directly reflected into the pollinator value. For a more specific analysis, data of Korea's pollinator population and its composition should be reflected. As mentioned briefly in this research, honeybees take up the majority with 69.8 percent of managed pollinators and is widely used for the pollination of various crops unlike others such as bumblebees which are limited to crops such as tomatoes (Yoon et al., 2021; Lee et al., 2022). According to Lee et al. (2022), in 2020, of 125,929ha of cultivated land, around 28 percent (35,213ha) relied on managed pollinators for production. Assuming that the area relying on managed pollinators remain mostly the same for 2021 and for all crops, scenario 2 can be introduced, in which the ratio of area/yield reliant on managed pollinators, the ratio of honeybees, and the 17 percent loss that occurred in the winter of 2021-2022 are all reflected. The results are shown below in Table 7. Like this, the valuation model can be adjusted in many ways to better reflect the current situation and the possible loss caused by pollinator loss.

Table 7. Changes in Social Welfare (National, Scenario 2) (Million won)

Crops	Producer Surplus	Consumer Surplus	Social Welfare
Beans	−0.095	−0.552	−0.647
Apple	2.956	−10.300	−7.328
Pear	1.026	−4.394	−3.368
Peaches	1.390	−4.247	−2.857
Watermelon	1.870	−12.500	−10.600
Korean melon	1.500	−5.556	−4.055
Strawberries	0.108	−0.883	−0.775
Cucumber	1.705	−5.564	−3.859
Sesame seeds	−0.005	−0.039	−0.044
Total	10.455	−44.034	-33.533

Additionally, in-depth analysis was conducted for each crop and province. Due to the number of crops and provinces, two crops, beans and strawberry is selected as an example to represent food crops and crops that are often used in pollinator-related studies, respectively.

4.2.1. Crop case: Beans

In the case of beans, as mentioned previously, it has a high own-price elasticity of demand, leading to a negative producer surplus. Due to the negative surplus for both producers and consumers, the social welfare loss is an addition of the two. Although it can be classified as a food crop, in Korea where rice is the staple food crop, beans are less preferred and can be easily substituted. In addition, rice and maize tend to have near to or zero dependency ratio on pollinators whilst beans have a 25 percent reliance. Thus, if pollinator collapse were to occur and with it the decline in bean production, it is likely that consumers will be less affected by such event and also simply swap beans to other food crops during the season.

Although there lacks drastic difference of loss between the provinces, of the nine, Jeollabuk-do and Gyeongsangbuk-do have higher losses in comparison to other regions. This can be mainly attributed to the fact that these two provinces are the largest producers of beans. As the short-term welfare model relies on yield value, welfare loss occurs proportionately. If demand elasticity for each province was available, then there may be less proportionality and may depict a more region-specific welfare effect.

Table 8. Change in Social Welfare: Beans (Regional)

Province	Change in Social Welfare (Billion won)		
	lower	mean	upper
Gyeonggi-do	-9.322	-9.37	-9.422
Gangwon-do	-12.099	-12.161	-12.23
Chungcheongbuk-do	-16.783	-16.869	-16.963
Chungcheongnam-do	-11.974	-12.035	-12.103
Jeollabuk-do	-20.403	-20.508	-20.623
Jeollanam-do	-16.727	-16.813	-16.908
Gyeongsangbuk-do	-22.114	-22.227	-22.352
Gyeongsangnam-do	-6.646	-6.68	-6.717
Jejudo	-5.261	-5.288	-5.318
National	-121.329	-121.951	-122.636

Figure 5. Change in Social Welfare: Beans (National)

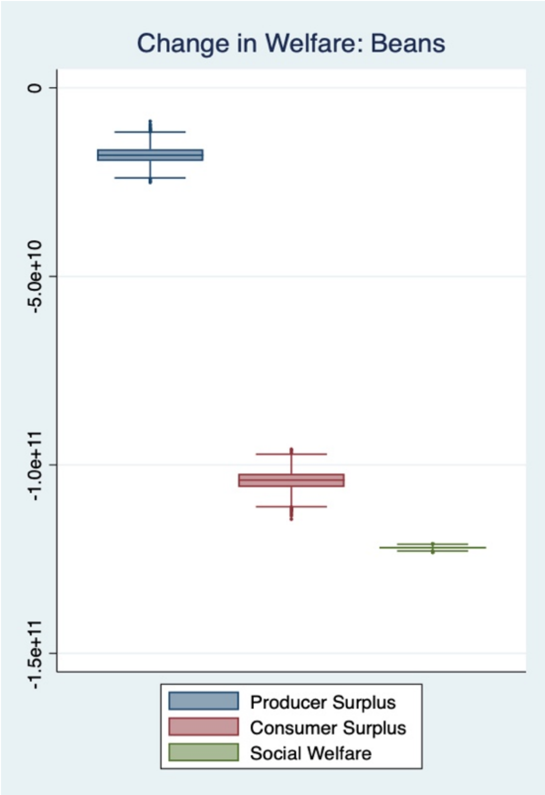
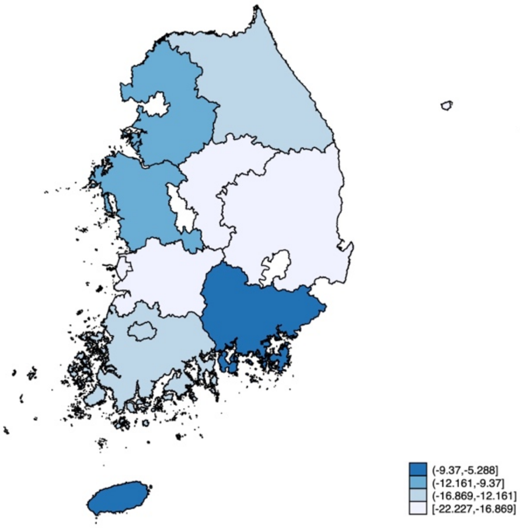


Figure 6. Change in Social Welfare: Beans (Map)



4.2.2. Crop case: Strawberry

For strawberry, producer welfare effect is positive. As a consequence, the social welfare loss is smaller than the consumer loss, as depicted in Figure 7. This is in direct contrast to Figure 5 where the social welfare loss is bigger than consumer welfare loss for beans.

Another difference strawberry has in contrast to beans is the drastic difference between provinces in production scale. While provinces did not differ much with bean production, in the case of strawberry, Gyeongsangnam-do, depicted in the lower right area in light grey (Figure 8) is the most prominent producer. Compared to the smallest producer, Jeju, Gyeongsangnam-do produces 100 times as much, and with the second highest producer, Chungcheongnam-do, nearly twice as much. At the national scale, Gyeongsangnam-do is accountable for 40% of strawberry produces and over 90% of exported strawberries. The national total for strawberry is 1.476 trillion won and its export value is 647million dollars (approximately 4,900tonnes).[21] Recently, there was a decline in cultivation area of strawberry while production remains the same, indicating increase in productivity, and the cultivation area is expected to be on the rise.

[21] For consistency, the data is from 2021. Data accessed at KATI, 2023.

Table 9. Change in Social Welfare: Strawberry (Regional)

Province	Change in Social Welfare (Billion won)		
	lower	mean	upper
Gyeonggi-do	-6.419	-6.479	-6.549
Gangwon-do	-3.066	-3.095	-3.129
Chungcheongbuk-do	-9.262	-9.349	-9.45
Chungcheongnam-do	-76.181	-76.901	-77.726
Jeollabuk-do	-38.566	-38.931	-39.348
Jeollanam-do	-38.654	-39.019	-39.438
Gyeongsangbuk-do	-28.964	-29.238	-29.552
Gyeongsangnam-do	-129.474	-130.699	-132.1
Jejudo	-1.377	-1.39	-1.405
National	-331.963	-335.101	-338.697

Figure 7. Change in Social Welfare: Strawberry (National)

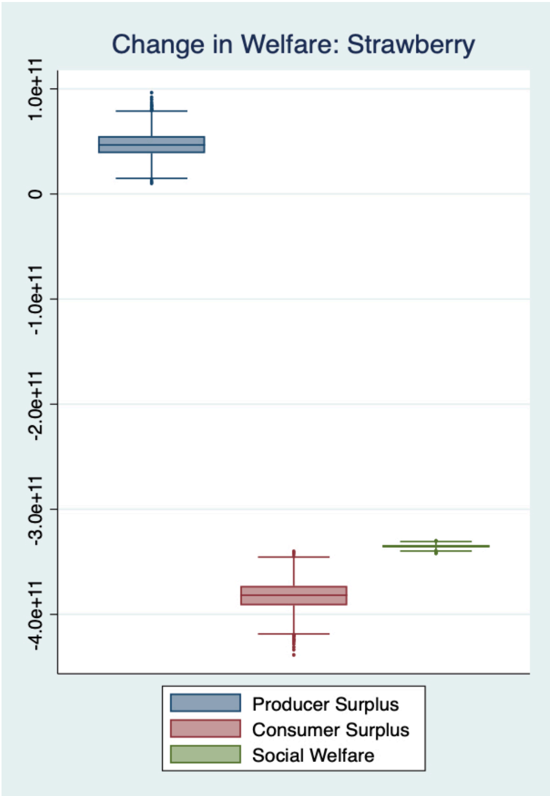
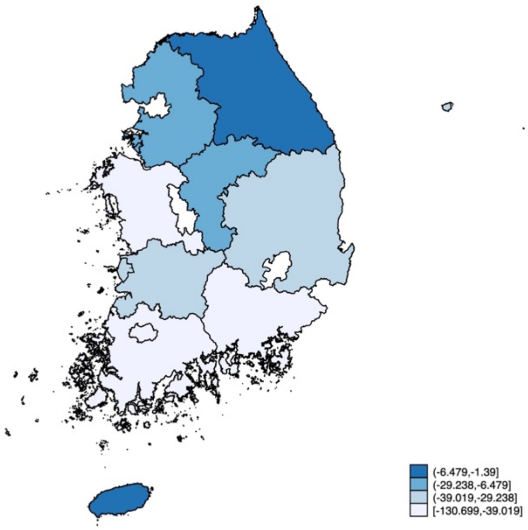


Figure 8. Change in Social Welfare (Strawberries)



Of the various kinds, Seolhyang dominates production where it was 86.6 percent of total strawberries produced in 2020. This specific kind is reliant on bees for pollination. Although honeybees have higher fruit set rate, due to Korean strawberries being produced in greenhouses during winter, honeybees hibernate during the production period and thus farmers mostly use bumblebees. Bumblebees are a common managed species of pollinators as farmers buy them for pollination purposes, with a single colony price being around 70,000 won.[22] Considering the dominance of Seolhyang and its reliance on bumblebees, producer's reliance on a single cultivar and species may lead to sudden production decline when bumblebees are affected by sudden weather events, disease, and many more environmental factors.

Thus, it can be seen that pollinator loss has many implications ranging from the overall loss in national social welfare, to specific damages to crops and regions dependent on the production of the said crops, all of which vary significantly.

[22] For the most recent market data, prices of bumblebees were referred from released prices at Korea's most often used search engine (Naver). (Accessed Feb 10th, 2023)

Chapter 5. Conclusion

Pollination is without a doubt a crucial production step in agriculture. The current continuance of pollinator density decline poses as a threat to agricultural productivity which not only affects the farmer's welfare but also that of the consumer. Because of this, pollination service valuation studies have long been in place with a variety of estimation methods. However, in the case of Korea, there is still a lack of research that takes into account aspects other than production. As the most commonly used pollinator valuation methods are biased to the producer's welfare, research utilizing those methods tend to omit the market reactions of the consumer.

This is understandable since the value of pollination has recently gained more attention. With annual events of managed bee colony collapse and continuous decline of wild pollinators, human pollination has become a common sight in Korean agriculture. As previous studies in Korea have claimed, the value of pollination service should rightfully be acknowledged and reflected into policies, of which the Korean government is recently introducing more of. In this context, it is critical that a comprehensive estimation of pollinator service value in the Korean agricultural market takes place.

Thus, this study has aimed to estimate the economic value of pollinators by using recent consumption and production data and to derive policy implications with the consideration of current situation of Korea. The short-term welfare effect model from Lippert et al.

(2021) was used as the short-term period allowed for less assumptions on supply and demand, and also due to the fact that it reflects the consumers' welfare change in the social welfare. Unlike previous studies, such as Gallai et al. (2009) and Lippert et al. (2021), as this study is limited to Korea, demand elasticity was also estimated.

With an average dependence ratio of 0.58 and own-price elasticity of -0.85, for the nine crops in this research, pollinator's value in Korea is 7.6 trillion won. Since this is the result for only nine crops, it can be inferred that the total valuation of pollinators can be much larger. In comparison to other studies such as that of Lee et al. (2022) and Jung and Shin (2022), the result of this study is much larger. Such result can be attributed to the consideration of consumption aspect through demand elasticity, and thus, proves that popular methods that mostly focus on the production aspect somewhat underestimate the value of pollinators.

Analysis shows that with the exception of two crops out of the nine, producers experience an increase in their welfare due to the inelastic own-price elasticity of demand. Contrary to this, the consumer surplus for all crops were negative indicating that regardless of crop, consumers were worse off due to pollinator collapse. Such results are obtained as by including the demand elasticity, model accounts for the two effect of productivity loss: producers' profit loss due to less yield and higher production costs, and the producers' gain through higher prices and the consumers' loss. Based on this, most fruit crops had social welfare loss that was smaller than consumer welfare loss, and in the case of beans and sesame social welfare loss was much bigger.

Since sudden pollinator disappearance is highly unlikely, the model was modified to estimate loss of welfare in various scenarios. The recent event of bee colony loss in Korea was reflected, where 17 percent of pollinators disappeared. This result led to differences in the relative scale of loss for crops. Additionally, more specific situations were introduced. Such modification of the short-term model can be used not as a pollinator value, but rather the damage caused by the scenario, indicating the model's use for damage estimation as well.

Regional analysis was also conducted for individual crops. Though intuitive, the regions with high production level of a specific crop had the high welfare losses. The proportionate behavior stems from the production value included in the model. In order to lessen such relationship, separate demand elasticity can be used for each province.

There are limitations to this study. The limitations include: lack of recent data for demand elasticity estimation, uniform elasticity for all provinces, and the limited number of crops, all of which are due to lack of consistency between data. For the demand estimation, this study had limited data as the household consumption survey rearranged the categories and only provided data for aggregated commodities. Thus, demand had to be estimated using past data, although it was attempted to be offset through constructing a Krinsky and Robb confidence interval. In addition, as the data was on a national scale, demand elasticity for individual provinces could not be obtain, leading to the proportionate social welfare loss in the results. Finally, in order to use the demand estimate, crops in the consumption data and production data had to correspond, and thus greatly reduced the number of crops in the research.

Based on this, this study can be extended in many ways. First, for a detailed comparisons between regions, demand elasticities estimated at the province level is necessary. In addition, the modified model for pollinator loss scenarios can be used for damage calculation. Like in the case of bee colony collapse in the winter of 2021-2022, the model can be used to assess the severity of the situation. Lastly, this study is based only on the quantitative aspects of pollination. It is well known that without proper pollination, crops lack in quality and so, a sudden pollinator loss can cause social welfare loss much larger than the value estimated in this study. Though data would have to be available, incorporating qualitative aspects in the estimation model will extend this research.

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국문초록

개별 작물 수요 추정을 통한 화분매개곤충의 경제적 가치평가

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우리나라의 지속적 생태계 파괴, 기후변화 등으로 인해 국내 곤충 밀도가 감소하고 있으며 큰 문제로 대두되고 있다. 특히 꿀벌과 같은 화분매개 곤충의 밀도감소는 생태계 뿐만 아니라 작물 생산에도 큰 영향을 미치기 때문에 이와 관련된 다양한 경제적 가치 평가 분석이 진행되어 왔다. 그러나 주로 사용된 분석 방법들은 생산자를 중심으로 생산량 또는 생산비용에 초점이 맞추어져 있어 사회 전체에서의 화분매개 곤충의 가치를 분석했다고 보기엔 한계가 있다. 따라서, 본 연구에서는 화분매개 곤충이 작물 생산에서 차지하는 비중을 반영하되, 이러한 곤충의 감소로 인한 생산자와 소비자의 후생 변화를 추정해 경제적 가치를 평가하고자 하였다.

본 연구에서는 국내 주요 생산 작물들 중 화분매개 곤충의 수분활동에 의존하는 작물들을 선정한 후 이들의 수요함수를 Tobit 모형으로 추정해 개별 작물의 자기가격 수요탄력성을 구하였다. 이후 단기 사회후생 효과 모형에 수요탄력성을 반영해 생산자와 소비자의 사회 후생을 도출하였다.

연구 결과, 추정된 화분매개곤충의 가치는 7.6조로, 기존 방법론을 사용한 선행연구들에 비해서는 높게 추정되었다. 이를 통해 생산자 중심의 분석인 기존 방법론들은 화분매개곤충의 가치를 일부 저평가하는 경향도 있다는 것을 확인할 수 있었다. 또한 지역별 생산 작물에 따라 생산액이 달라지는 만큼 화분매개곤충의 가치 및 감소로 인한 피해 또한 지역별 차이가 있음을 확인하였다. 더 나아가, 본 연구에서 사용한 방법론을 활용하여 가치평가 뿐만 아니라 화분매개곤충의 밀도감소 시나리오를 설정해 그로 인해 발생하는 피해 산정을 추정함으로써 본 연구에서 사용한 모형의 응용도 시도하였다.

주요어 : 화분매개곤충, 가치평가, 후생효과, 수요탄력성, 생산성

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