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An Empirical Assessment of the Economic Damage Caused by Apple Marssonina Blotch and Pear Scab Outbreaks in Korea

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Abstract: Marssonina blotch in apples and pear scab are diseases that may affect apple and pear production as well as related industries significantly. The range and scale of the economic influence of such outbreaks should be clarified to ensure the sustainable growth of these industries. This study evaluates the direct and indirect economic effects of outbreaks through a partial equilibrium approach and an input–output model; direct influences are measured on the basis of reduced production, and the estimated costs are 34,926 million Korean Won (mKRW) (US$ 29.79 million) and 11,767 mKRW (US$ 10.04 million) for apples and pears, respectively. The indirect effects are determined according to changes in the quantity of apples and pears supplied to the market; these effects can induce social welfare losses. These costs are estimated to be 305,065 mKRW (US$ 259.08 million) for apples infected with Marssonina blotch, which accounts for 186,628 mKRW (US$ 158.50 million) in producer surplus and 118,437 mKRW (US$ 100.58 million) in consumer surplus and 72,693 mKRW (US$ 61.74 million) for pears infected with scab, which accounts for 44,106 mKRW (US$ 37.46 million) in producer surplus and 28,587 mKRW (US$ 24.28 million) in consumer surplus. The findings from this study can be referenced by the Korean government in designing more effective control measures toward sustainable growth of related industry.

Keywords: economic assessment; fruit diseases; indirect effect; partial equilibrium model; risk analysis

1. Introduction

National quarantine measures are important because the risks of invasion by foreign pests and of diseases have increased with agricultural trade volume. This scenario is particularly true for industrialized countries including Korea, where markets for agricultural products have been established under numerous free trade agreements. Thus, the socio-economic and one-dimensional production effects of pests and diseases in industrialized countries have been under scrutiny [1]. Much effort has been exerted to investigate not only the direct effects of pests and diseases, such as yield reduction but also their indirect market influences. Previous research generally relied on economic methodologies to determine indirect effects empirically for the cases of United States of America (USA), Australia, and European Union (EU) [2–10]. Such effects must be evaluated to measure the economic damage caused by pests and diseases because an outbreak of these two factors often results in welfare losses for both producers and consumers. These losses can extend to the national scale involving both the upstream and downstream industries associated with the outbreak. In spite of these welfare and associated industry consequences of the outbreak, domestic research in Korea has focused only on the damage situations of the outbreak, the factors affecting this outbreak, and the associated adoption strategies [11–16]. This stresses a need to go beyond the direct production effects and to incorporate indirect market effects and associated welfare analysis of the outbreak in an empirical setting for Korea. Given this research gap, a comprehensive investigation should be conducted to evaluate the effect of the outbreak of pests and diseases from a socio-economic perspective; such a work ensures the sustainable growth of related industries. The empirical assessment of the economic damage associated with the outbreak of pests and diseases can provide a foundation to design better sustainable policies and management strategies.

This study explores the economic effect of the outbreak of pests and diseases by evaluating the associated welfare losses for consumers and producers in the process. The scope of this investigation extends beyond the direct production effect, which has been studied by domestic researchers in this field. Elucidating the full economic consequences of the outbreak is critical in designing a counter-measure to prevent the onset of pests and diseases. The partial equilibrium model (PEM) is widely used in economic studies to evaluate the market effect of policy and/or parameter changes in demand and supply; thus, this approach is employed in this research. In addition, a well-known input–output model approach is used to measure the industrial spillover effects associated with outbreaks.

Apples and pears, which are two widely consumed fruits in Korea, are selected for empirical illustration in this study. Pests and diseases can severely damage both fruits [17,18], and the price elasticities of demand tend to be high [19]. Such scenarios significantly affect the economy. Among the numerous pests and diseases that attack apples and pears, the current study focuses on the Marssonina blotch in apples and pear scab. The onset of the former has increased with climate change as a result of global warming and with altered cultivation methods; furthermore, previous studies indicate that Marssonina blotch causes more severe damage than pear scab [20–22]. A particular variety of pears called "Singo" is susceptible to pear scab, and this variety constitutes approximately 81.5% of the pears produced in cultivation areas [23]. Pear scab has also affected pears cultivated in China and in Japan [24,25].

2. Materials and Methods

2.1. Partial Equilibrium Model

The PEM is applied to measure the degree of economic damage to production and the resultant consumer/producer surplus caused by pests and diseases in Korea. This analytic tool is suitable for the economic evaluation of social welfare changes and facilitates the measurement of social welfare changes attributed to a "shock", such as supply reduction, by comparing market equilibrium conditions before and after this shock [26]. In the present study, a shock in PEM is equivalent to the reduced production caused by Marssonina blotch in apples and pear scab. Figure 1 depicts the market conditions before and after the reduced production caused by outbreaks. Social welfare loss is the sum of producer surplus (PS) and consumer surplus (CS) loss (= PS + CS − PS′ − CS′) caused by the inward shift in supply function as a result of outbreaks. The term "surplus" refers to the total net benefit or the value that is attributable to consumers and/or producers from selling and buying certain goods in the market at a given market price. This term is often used by economists in welfare analysis. In this study, we apply this economic concept to capture the welfare effects caused by the outbreaks of Marssonina blotch in apples and pear scab.

To render a PEM approach empirically tractable, we must obtain information on market equilibrium quantities, market equilibrium prices, and the demand/supply elasticities of apples and pears. To determine the market conditions before the "shock" (the outbreak of Marssonina blotch in apples and pear scab), necessary functions are estimated based on supply quantity, wholesale price, and demand/supply elasticities. Annual supply quantity and wholesale price are obtained at a market equilibrium point (E_0), and a new equilibrium point (E_1) based on estimated demand and supply functions is determined by reflecting the reduced production caused by outbreaks. In this study, market equilibrium is achieved when demand (Q_D) equals supply (Q_S). The price is determined for each equilibrium (see Figure 1); moreover, the demand and supply functions of apples and pears are estimated with Equations (1) and (2).

$$Q_D = \left[\frac{1}{\varepsilon_D}\right]\left[\frac{\partial Q_D}{\partial P}\right] P \quad (1)$$

$$Q_S = \left[\frac{1}{\varepsilon_S}\right]\left[\frac{\partial Q_S}{\partial P}\right] P \quad (2)$$

where ε_D and ε_S denote the price elasticities of demand and supply, respectively.

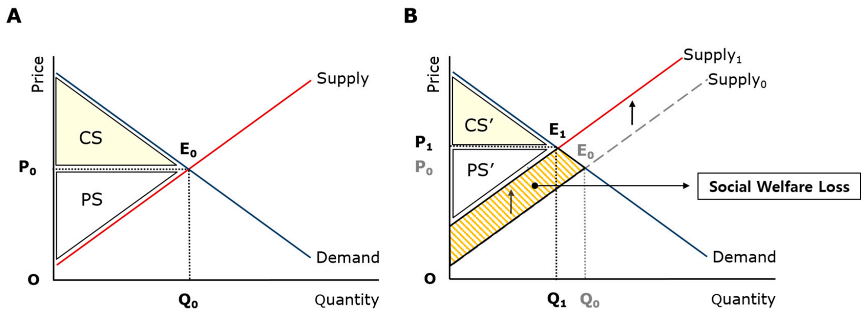

Figure 1. The social welfare effect of disease outbreak: market equilibrium before the disease outbreak (**A**) and after the disease breaks out (**B**).

The extent of social welfare loss related to apples and pears can be evaluated by comparing the market equilibrium points before and after the shock. The shaded areas in panel B of Figure 1 indicate this extent.

2.2. Input–Output Model

The input–output (IO) model is utilized to investigate the indirect effects of pest and disease outbreak from the perspectives of upstream and downstream industries. An IO model approach is often used by economists because it measures the spillover effects of changes in the final demand of a given sector on the production and employment status of the related sectors in an economy [27]. To determine these effects, this approach relies heavily on an IO table that characterizes inter-industry linkage within an economy for a given year. Equations (3) and (4) describe this process; specifically, Equation (3) indicates the process of estimating demand-driven spillover effects.

$$(\mathrm{I} - \mathrm{A})^{-1}\, dY = dX \quad (3)$$

where A denotes technical coefficients; dY captures final demand changes; and dX describes the total output changes. Reduced production due to outbreaks is represented as changes in final demand (dY), and these changes exert demand-driven spillover effects on downstream industries (dX). Equation (4) expresses the process of estimating supply-driven spillover effects.

$$\Delta \mathrm{X}'_{\mathrm{en}} = \left(\Delta \mathrm{X}'_{\mathrm{ex}} \mathrm{B}_{\mathrm{ex}}\right)\left(\mathrm{I} - \mathrm{B}_{\mathrm{en}}\right)^{-1} \quad (4)$$

where B_{ex} and B_{en} are technical coefficients in a supply-driven IO model; the subscript ex denotes a sector in "shock" (e.g., outbreaks of pests and diseases); and subscript "en" represents the remaining sectors. Output changes in the remaining sectors ($\Delta X'_{en}$) can be affected by supply reduction in a given sector (e.g., the fruit sector) as a result of an outbreak ($\Delta X'_{ex} B_{ex}$). These changes ($\Delta X'_{en}$) can in turn be applied to measure the supply-driven spillover effects on upstream industries.

2.3. Data

To estimate the economic damage caused by the outbreak of Marssonina blotch in apples and pear scab, we must estimate the derange functions for each disease. We collected data on the amount of apples and pears as well as the proportions of cultivation areas affected by such outbreaks from previous damage reports regarding each disease. The damage function parameters for each disease were identified by using regional data derived from the Rural Development Administration (RDA) for the period of 2010 to 2012. Marssonina blotch causes early defoliation in apple trees; thus, the resultant damages to the fruit are associated with quality and weight reduction [28–30]. By contrast, pear scab not only affects the leaves and flowers of pear trees but also damages the fruit [31,32]. Therefore, we focus on the ratio of infected apple tree leaves (*i.e.*, the rate of disease occurrence in the leaves) and on the ratio of infected fruits (*i.e.*, the rate of disease occurrence in fruits) to assess the damage caused by Marssonina blotch and pear scab, respectively. Table 1 shows these ratios by region for the period of 2010 to 2012.

Table 1. Rates of leaves infected with Marssonina blotch in apple trees and of pears infected with pear scab by region [33]. (unit: %).

Region	Apple Marssonina Blotch		Pear Scab	
	Average	Total	Average	Total
Gyeonggi	-	-	0.11	1.28
N. Chungcheong	0.52	7.78	-	-
S. Chungcheong	0.27	3.59	0.15	2.16
N. Jeolla	0.52	6.46	0.27	3.74
S. Jeolla	-	-	0.20	2.89
N. Gyeongsang	1.16	16.36	0.05	0.61
S. Gyeongsang	1.11	16.28	0.60	3.99
Ulsan	-	-	0.31	4.53
Mean	0.79	11.24	0.24	3.38

"Average" refers to average rates of infected leaves for survey trials (12 times a year) during 2010–2012. "Total" represents the average of cumulative rates of infected leaves for a year during 2010–2012.

In addition, we obtain the production amount, cultivation area, yield, average wholesale price, average producer price from 2010 to 2012 (derived from "Income data from Agriculture and Livestock Activities" as reported by RDA), and the demand/supply elasticities of apples and pears. Table 2 lists the description and sources of the parameters used for empirical analysis.

Table 2. Description of parameters (three-year average value for 2010–2012).

Parameters	Apple	Pear	Sources
Production Amount (ton)	411,474	256,971	KOSIS [34]
Cultivation Area (ha)	21,202	13,983	KOSIS [34]
Producer Price per Unit (KRW/kg)	2470	2141	RDA [35]
Wholesale Price (KRW/kg)	4282	2779	KAMIS [36]
Yield (kg/ha)	19,449	18,258	KOSIS [34]
Demand elasticity	−0.52	−0.54	KREI [37]
Supply elasticity	0.33	0.35	KREI [37]

Finally, this study used the year 2012 national IO table (*i.e.*, technical coefficients) constructed by the Bank of Korea to conduct an analysis of IO model. The IO table consists of 138 industrial sectors including 24 agricultural sectors. Apples and pears belong to the fruit production industry. This study estimates the ripple effects in upstream industries such as the food processing industry induced by the supply shortage of fruit industry (*i.e.*, the production reduction in apple and pear industry) by using the supply-driven input-output model.

2.4. Estimation of the Damage Caused by Disease Outbreak

To estimate the damage caused by disease outbreaks, data must be collected on the ratio of infections per year, production amount, cultivation area, and yield. First, the amounts of apples and pears produced must be determined with Equation (5) as follows:

$$Q_{P,\,i} = A_i \times m \tag{5}$$

where $Q_{P,\,i}$ denotes the production amount (Qp) in the i-th region, A_i is the cultivation area of region i, and m denotes the yield of the study subject.

Early defoliation limits production effects on fruit weight in the case of apples infected with Marssonina blotch [38]. Therefore, the following damage function uses the weight loss attributed to this defoliation to estimate the damage caused by the outbreak. Equation (6) describes the relationship between weight loss and this damage.

$$Q_{ad,i} = W_{d,i} \times n_i \tag{6}$$

where the damage caused by Marssonina blotch in apples to region i ($Q_{ad,\,i}$) is equal to the weight loss rate ($W_{d,i}$) multiplied by the quantity of fruits harvested (n_i). In Equation (7), weight loss rate is calculated by subtracting the weight with defoliation (W_r) from the weight without defoliation (W_0). In accordance with Sagong *et al.* [38], the weight without defoliation is assumed to be 291 g:

$$W_{d,i} = W_0 - W_r \tag{7}$$

In Equation (8), the quantity of fruits harvested can be computed by dividing the produced amount by the weight without defoliation. This quantity is used for calculating damaged quantity by multiplying a weight loss parameter.

$$n_i = \frac{Q_{AP,i}}{W_0} \tag{8}$$

where $Q_{AP,i}$ is production amount of apples in region i.

Table 3 presents the effect of Marssonina blotch on the defoliation of apple trees and on fruit weight as per the study conducted by Sagong *et al.* [38]. In addition to the parameters adopted from this research, we must implement the following assumptions: first, all leaves infected with Marssonina blotch are defoliated and the damage caused by the disease is reflected by weight loss alone. This assumption is necessary given the limited data on the relationship among the ratio of infected leaves, the ratio of production amount to sales amount, and defoliation rate. Second, the sum of the ratio of infected leaves in a given region is the same as the defoliation rate because early defoliation is difficult to detect. Third, the defoliation rate is equal to the minimum defoliation rate when data on such rates are unavailable for a given region.

Pear scab affects the fruit [31]; therefore, the associated damage is calculated by multiplying the ratio of infected fruits with the production amount (see Equation [9]).

$$Q_{pd,i} = Q_{PP,i} \times r_i \tag{9}$$

where $Q_{pd,i}$ denotes the damage caused by pear scab in region i and $Q_{PP,i}$ is the production amount of pear in this region i. r_i indicates the ratio of infected fruits in region i.

Table 3. Effect of Marssonina blotch on defoliation in apple trees and fruit weight [38].

2009		2010	
Defoliation (%)	**Fruit Weight (g)**	**Defoliation (%)**	**Fruit Weight (g)**
0.0 ~ 9.9	330	0.0	291
10.0 ~ 19.9	310	0.1 ~ 29.9	281
20.0 ~ 29.9	309	30.0 ~ 49.9	266
30.0 ~ 39.9	298	50.0 ~ 69.9	262
40.0 ~ 49.9	291	70.0 ~ 99.9	259
50.0 ~ 59.9	286	100.0	245
Over 60.0	282	-	-

To estimate the damage attributed to pear scab, the following assumptions are held: first, all pears affected by the disease are discarded because of limited information regarding the potential for damaged pears to be sold in the market. Second, the sum of the ratio of infected fruits for all survey trials in a year is equal to the ratio of infected fruits in a given region. Third, the ratio of infected fruits is equal to the minimum fruit infection rate when data on this ratio are unavailable for a given region.

3. Results and Discussion

3.1. Economic Evaluation of Direct Damages Caused by the Outbreak

Tables 4 and 5 present the data on regional economic damages caused by Marssonina blotch in apples and pear scab outbreaks based on the three-year average ratios of infected leaves and fruits, respectively. In Table 4, the direct effects of damaged apples are estimated to cost 34,926 million Korean Won (mKRW) (US$ 29.79 million) on the basis of 14,140 tons of reduced production. N. Gyeongsang Province is estimated to have the most significant economic cost at 22,217 mKRW (US$ 18.95 million), followed by N. Chungcheong Province and S. Gyeongsang Province. These findings are consistent with the high ratio of infected leaves in these regions. Approximately 74% of economic damage is associated with the infection in the Gyeongsang provinces (both N. Gyeongsang and S. Gyeongsang), which are major apple production regions in Korea.

Table 4. Regional damages caused by the outbreak of Marssonina blotch in apples

Region	Production Amount (A) (kg)	Harvested Number of Fruit	Weight Loss (kg/Fruit)	Damaged Quantity of Fruit (B) (kg)	Damage Rate (B/A) (%)	Economic Cost of Damage (mKRW)
Gyeonggi	2,299,667	7,902,635	0.01	79,026	3.44	195.20
Gwangwon	1,323,667	4,548,683	0.01	45,487	3.44	112.35
N. Chungcheong	53,667,000	184,422,680	0.01	1,844,227	3.44	4,555.24
S. Chungcheong	20,290,333	69,726,231	0.01	697,262	3.44	1,722.24
N. Jeolla	27,617,000	94,903,780	0.01	949,038	3.44	2,344.12
S. Jeolla	2,089,333	7,179,840	0.01	71,798	3.44	177.34
N. Gyeongsang	261,744,333	899,465,063	0.01	8,994,651	3.44	22,216.79
S. Gyeongsang	41,177,667	141,504,009	0.01	1,415,040	3.44	3,495.15
Busan	19,333	66,438	0.01	664	3.44	1.64
Daegu	1,138,667	3,912,944	0.01	39,129	3.44	96.65
Daejeon	93,667	321,879	0.01	3219	3.44	7.95
Ulsan	13,333	45,819	0.01	458	3.44	1.13
Total	411,474,000	1,414,000,000	-	14,140,000	-	34,925.80

"Economic Damage" is calculated by multiplying the quantity of damaged fruit (kg) with the producer price per unit (2470 KRW/kg). "mKRW" represents million Korean won.

The direct effects of diseased pears are estimated to cost 11,767 mKRW (US$ 10.04 million) on the basis of 5497 tons of reduced production (see Table 5). The economic damage caused by pear scab is estimated to be most significant in S. Jeolla Province, followed by S. Chungcheong Province and S. Gyeongsang Province.

Table 5. Regional damage caused by pear scab outbreaks.

Region	Production Amount (A) (kg)	Diseased Fruits (%)	Damaged Quantity of Fruit (B) (kg)	Damage Rate (B/A) (%)	Economic Cost of Damage (mKRW)
Gyeonggi	50,186,333	1.28	642,385	1.28	1375.13
Gwangwon	1,923,667	0.61	11,734	0.61	25.12
N. Chungcheong	14,629,667	0.61	89,241	0.61	191.04
S. Chungcheong	48,043,333	2.16	1,037,736	2.16	2221.45
N. Jeolla	12,228,000	3.74	457,327	3.74	978.99
S. Jeolla	62,708,000	2.89	1,812,261	2.89	3879.45
N. Gyeongsang	35,341,333	0.61	215,582	0.61	461.49
S. Gyeongsang	17,778,333	3.99	709,948	3.99	1519.76
Jeju	125,333	0.61	765	0.61	1.64
Seoul	125,000	0.61	763	0.61	1.63
Busan	268,667	0.61	1639	0.61	3.51
Daegu	103,333	0.61	630	0.61	1.35
Incheon	892,667	0.61	5445	0.61	11.66
Gwangju	395,667	0.61	2414	0.61	5.17
Daejeon	1,144,000	0.61	6978	0.61	14.94
Ulsan	11,077,667	4.53	502,188	4.53	1075.02
Total	256,971,000	-	5,497,036	-	11,767.32

"Economic Damage" is calculated by multiplying the quantity of damaged fruit (kg) with producer price per unit (2141 KRW/kg).

3.2. Economic Evaluation of Indirect Damage Caused by the Outbreak

Table 6 shows the social welfare changes; that is, the indirect effects caused by the outbreaks of Marssonina blotch in apples and pear scab. These effects are measured based on changes in quantity of apples and pears supplied to the market, which can induce social welfare losses. The cost of apples infected with Marssonina blotch is estimated to be 305,065 mKRW (US$ 259.08 million) (186,628 mKRW (US$ 158.50 million) and 118,437 mKRW (US$ 100.58 million) in producer and consumer surplus, respectively); this cost accounts for 6.53% of the total surplus. The social welfare losses for pears are estimated to be 72,693 mKRW (US$ 61.74 million) (44,106 mKRW (US$ 37.46 million) and 28,587 mKRW (US$ 24.28 million) in producer and consumer surplus, respectively); this cost constitutes 4.14% of the total surplus. Approximately 60% of welfare loss is associated with producer surplus, thus implying that (i) the economic damages caused by the outbreak of these diseases are mainly observed on the producer side and (ii) the surplus loss on the consumer side is not negligible. The second point suggests that the outbreak of such diseases must be understood in terms of their considerable effect on consumer welfare; this understanding provides a rationale for public intervention in the design of effective counter-measures for both producers and consumers (e.g., public control measures for pests and diseases). While this stresses the benefit side of public control measures, it should be noted that a full cost-benefit analysis is called for introducing such measures.

Table 7 shows the social welfare changes in individual farms and general households as a result of disease outbreaks. By considering the number of households on the producer and consumer sides, we can evaluate the indirect economic damages of disease outbreaks on a household. Our results show that the indirect household effects on apple producers and consumers in terms of welfare loss cost approximately 4.81 mKRW (US$ 4085) and 6739 KRW (US$ 5.72), respectively. The indirect effects on pear producers and consumers amounted to costs of 1.95 mKRW (US$ 1656) and 1627 KRW (US$ 1.38), respectively. These findings suggest that indirect household effects of Marssonina blotch in apples are stronger than those of pear scab.

Table 6. Social welfare changes caused by outbreaks of Marssonina blotch in apples and pear scab.

Specification	Diseases	
	Apple Marssonina Blotch	**Pear Scab**
Q_0 (ton)	425,614	262,468
P_0 (KRW/kg)	3999	2668
Q_1 (ton)	411,474	256,971
P_1 (KRW/kg)	4282	2779
Social Welfare Loss (mKRW)	305,065	72,693
- Production	186,628	44,106
- Consumer	118,437	28,587
Loss rate (%)	6.53	4.14

Q_1 is the actual amount of production (*i.e.*, status quo production level). And Q_0 is the counterfactual production level "without damage of diseases". This amount is used as a baseline of production to evaluate associated social welfare loss.

Table 7. Social welfare changes caused by disease outbreaks for individual farms and general households.

Specification	Diseases	
	Apple Marssonina Blotch	**Pear Scab**
Number of farm households [39]	38,765	22,589
Number of general households [40]	17,574,067	
Welfare loss for each households (KRW)		
- Farm households	4,814,338	1,952,539
- General households	6739	1627

"KRW" represents Korean won, "General households".

3.3. Economic Evaluation of Industry Spillover Effects Caused by the Outbreaks

Table 8 presents the demand- and supply-driven industry spillover effects of outbreaks. First, the demand-driven industry spillover effects in the case of Marssonina blotch in apples are estimated to cost 86,466 mKRW (US$ 73.74 million) in terms of output, including 60,547 mKRW (US$ 51.64 million) worth of reduced production. The spillover effects on the fertilizer and pesticide sectors cost approximately 8106 mKRW (US$ 6.91 million) and corresponds to the highest indirect effect among related industry sectors. The demand-driven industry spillover effects in terms of value added and number of jobs are estimated to cost 52,470 mKRW (US$ 44.76 million) and 2517 jobs, respectively. The supply-driven industry spillover effects are estimated to cost 39,162 mKRW (US$ 33.40 million) in terms of output. That is, the output cost of related industry sectors, which use apples as intermediate inputs, decreases by 39,162 mKRW (US$ 33.40 million). Moreover, the supply-driven industry spillover effects on the food and restaurant sectors are the highest among the related industry sectors.

Second, the demand-driven industry spillover effects in the case of pear scab are estimated to cost 21,812 mKRW (US$ 18.60 million) in terms of output, including 15,274 mKRW (US$ 13.03 million) worth of reduced production. Similar to the previous case, the fertilizer and pesticide sectors experience the highest indirect effect among the related industry sectors. The demand-driven industry spillover effects of pear scab in terms of value added and number of jobs are estimated to cost 13,236 mKRW (US$ 11.29 million) and 635 jobs, respectively. The supply shortage effects in terms of output cost 9879 mKRW (US$ 8.43 million). As in the case of Marssonina blotch, the food and restaurant sectors are subject to the strongest shortage effects among the related industry sectors.

Table 8. Industry spillover effects of the outbreaks of Marssonina blotch in apples and pear scab.

Disease	Apple Marssonina Blotch		Pear Scab	
	Demand-Driven	Supply-Driven	Demand-Driven	Supply-Driven
Total Effects (mKRW)	−86,466	−39,162	−21,812	−9879
- Direct Effects	−60,547	−18,710	−15,274	−4720
- Indirect Effects	−25,919	−20,452	−6538	−5159
Value-added (mKRW)	−52,470	-	−13,236	-
No. of Jobs (head)	−2517	-	−635	-
No. of Employment (head)	−265	-	−67	-

4. Conclusions

This study presents an economic methodology to investigate both the direct effect associated with reduced production and the indirect effect related to welfare changes caused by this reduction. This methodology is applied to outbreak cases of Marssonina blotch in apples and pear scab. The direct and indirect economic effects of these events are identified by a partial equilibrium approach and an IO model. The direct effects are measured on the basis of reduced production; the estimated costs are 34,926 mKRW (US$ 29.79 million) and 11,767 mKRW (US$ 10.04 million) for apples and pears, respectively. The indirect effects are determined based on changes in the quantity of apples and pears supplied to the market; these effects can cause social welfare losses. These costs are estimated to be 305,065 mKRW (US$ 259.08 million) for apples infected with Marssonina blotch, which accounts 186,628 mKRW (US$ 158.50 million) in producer surplus and 118,437 mKRW (US$ 100.58 million) in consumer surplus and 72,693 mKRW (US$ 61.74 million) for pears infected with Scab, which accounts 44,106 mKRW (US$ 37.46 million) in producer surplus and 28,587 mKRW (US$ 24.28 million) in consumer surplus. Our estimation results also indicate that the Gyeongsang provinces (N. Gyeongsang and S. Gyeongsang) comprise approximately 74% of the total direct economic damage caused by Marssonina blotch in apples. Meanwhile, S. Jeolla Province accounts for roughly 33% of the total direct economic damage attributed to pear scab. With respect to indirect welfare effects, producer surplus losses are estimated to be considerably greater than consumer surplus losses.

These findings can be utilized to perform a comprehensive benefit-cost analysis for public management policies for invasive insects and diseases. A rationale to introduce public management policies needs relevant and appropriate measures of costs and benefits they involve to control the outbreak of invasive species. An empirical assessment can provide conceivable outcomes in benefits of such policies in favor of both producers and consumers and enable comparison with private control measures of such pest and insects. This practice will contribute in achieving sustainable management of agricultural resources from a socio-economic viewpoint and stable agricultural prices and production.

The current work can be differentiated from previous studies in this line of research in that the former applies PEM and IO approaches to explicitly consider the direct and indirect welfare effects caused by disease outbreaks as well as the associated industry spillover effects. The findings of this study are expected to be referenced as basic information in developing public control measures for such diseases toward sustainable growth of related industry. The analysis presented in this article can be extended in several directions. First, the single-sector approach followed in our research can be extended to a multiple-sector model that directly incorporates the export and import sectors. Second, a dynamic model that captures the inter-temporal effects of damage can be incorporated into the conceptual framework given the perennial characteristics of specific fruit trees and data availability on the dynamics of disease outbreaks in a single tree (or farm). Thus, analysis processes can be refined to evaluate the economic damage caused by outbreaks of such diseases. Third, more refined production decisions can be addressed to consider endogenous changes in production and input use decisions under uncertainty. Being away from risk neutrality and considering risk-averse risk preferences will provide a better framework to evaluate economic costs of the outbreak and make associated discussion more realistic. Finally, future studies can empirically estimate the effects of the ratio of infected leaves (or fruits) on production to sales in consideration of data availability.

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