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Economic Values and Implications of Innovation in the Korean Quarantine System on Plant Diseases and Pests*

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Abstract The increase of international trade across countries and borders results in increased risks associated with the inflow of new pests and diseases. These risks are likely to be increased more rapidly due to climate change. Some countries implement strict regulations on imports to prevent these risks and protect biosecurity, food safety, and public health. However, the problems arise when the diseases and pests are found in a country where their economic structure largely depends on agricultural exports and cause ripple effects on other industries and ecosystems. Therefore, establishing an effective quarantine system is essential to protect and recover from the damage caused by non-native diseases and pests. This study's objectives are 1) analyzing the agricultural policies relate to the quarantine system on diseases and pests in Korea, 2) evaluating the Korea plant quarantine system's value, and 3) simulating plant quarantine policy strategies. We estimated the Korean quarantine system's benefits on diseases and pests to reach these objectives. The benefits are measured with a willingness to pay from respondents surveyed by the contingent valuation method (CVM). The CVM approach directly asks people how much they would willingly pay for food security. Finally, the Korean quarantine system's values are simulated with several policy scenarios and different scales of infection at the regional level. The results of this study can deliver policy implications on the quarantine system innovation in developing countries including Asia.

Keywords Quarantine system, Risk analysis, Markov chain model, Contingent valuation method

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I. Introduction

An increase in international trade across countries and borders results in increased risks due to the inflow of new pests and diseases that have not been introduced in South Korea. The risks are likely to grow more rapidly when climate change exacerbates the spread of new diseases such as COVID-19 (Cho, 2014). Various countries implement strict regulations on imports to prevent these risks and protect biosecurity, food safety, and public health. However, this regulation policy was utilized to restrict imports of agricultural products by countries with relatively large agricultural agri-business exports. Hence, the World Trade Organization (WTO) imposed an agreement on applying Sanitary and Phytosanitary (SPS) measures to avoid any means of unjustifiable discrimination between WTO members or a disguised restriction on international trade.

For controlling new and critical diseases such as COVID-19, it is crucial to set up the appropriate point of entry screening and quarantine systems. Since South Korea has been carrying out quarantine management by designating countries with infectious diseases according to Article 5 of the Quarantine Law, South Korea is operating a flexible quarantine management system based on the results of epidemiological investigations of patients arriving from overseas with COVID-19 (Sanguansat, 2020; Quarantine Management Team, 2020).

Nevertheless, a serious issue arises when invasive diseases and pests are found in a country where their economic structure largely depends on agricultural exports and causes ripple effects on other industries and ecosystems. Therefore, establishing an effective quarantine system of risk assessment such as integrated pest management is essential to protect and recover from damages potentially caused by non-native diseases and pests.

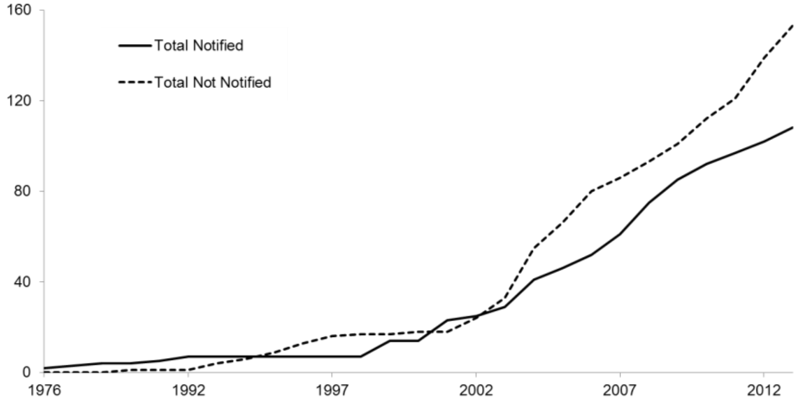

Figure 1 The cumulative numbers of free trade agreements (FTAs) by WTO Notification

Due to World trade among the free trade agreement (FTA) members increases, as demonstrated in Figure 1, the rapid growth of the influx of new diseases and insect pests overseas to South Korea is highly expected. Based on the WTO SPS measures, countries concentrating on agriculture industries actively utilize the regulation by measuring indirect ripple effects and direct losses stemming from the inflows of invasive diseases and pests.

Crop damages by foreign diseases and pests have significantly impacted food security and exports of domestic crops. Therefore, it is necessary to identify and estimate major domestic crops' economic damages to appropriately respond to agricultural environment change and improve the domestic agriculture industry's competitiveness in the global market. Additionally, the damages of invasive diseases and pests influence the real economy and non-market economies such as ecosystem, food safety, and food sovereignty.

In the current article, we analyzed how effective the Korean plant quarantine system is by considering the supply of agriculture products and simulated various strategic scenarios of phytosanitary policies. Our analyses and simulation can provide an essential basis for phytosanitary policies to prevent invasive diseases and pests. This study provides the estimate of the Korean plant quarantine system's intangible values needed to protect the ecosystem and food security and sovereignty.

In this paper, we estimated the values of the Korean plant quarantine system using: 1) Direct value: Losses in production, 2) Indirect value: Induced losses of the plant quarantine system (e.g., ecosystem protection, secure safe food, secure food sovereignty, costs and for the domestic industry protection).

II. Literature Review

The recent research trend in the WTO SPS is to seek more efficient policy instruments by measuring the indirect ripple effects and the direct effect according to the loss from occurrence and inflow of the diseases and pests. A decision on SPS measures primarily has been made based on the scientific judgment following a qualitative assessment of experts on pests and diseases. As the quantity and quality of available information associated with the improved analytical methods and techniques are becoming richer, statistical methods and quantitative evaluation are also being widely utilized.

It requires a comprehensive assessment considered in pathology, ecology, agriculture, economics, sociology, etc., for the systematic and efficient risk management of invasive diseases and pests. So, major international exporters of agricultural products try to apply various approaches to the economic analysis of SPS measures. In particular, several studies use bio-economics about the alien species rather than pests (Clark 1990).

Millennium Ecosystem Assessment (2005) mentioned that alien species are the prime cause of the destruction of biodiversity, disturbing the ecosystem, and affecting the economy, environment, and society. So, they are convinced that planning and management are required to protect and control alien species.

Several recent studies attempt to value the economic impact of invasive species on a national scale. Table 1 summarizes the findings of these studies for terrestrial invasive species. Each case study by countries, such as Australia, New Zealand, Canada, United States, has the range of damages from $ 1 million to $ 345 billion.

Table 1 Annual Economic Impacts of Terrestrial Invasive Species on a National Scale (adapted from Olson 2006)

Country	Type of Invasive	
	Plant	Microbial
Australia (in $AU)	4 billion[a]	
Canada (in $CAN)	38.21 million[b] (Leafy spurge and knapweed)	1.5 million[b] (Dutch elm disease) 73.34 million[c] (potato wart fungus) 1,000,000[c] (BSE)
Germany (in €)	103 million[d] (8 species)	5 million[d] (Dutch elm disease)
New Zealand (in $NZ)	100 million[e]	
United States (in $US)	34.5 billion[f]	39.7 billion[f]

BSE Bovine Spongiform Encephalitis

a Sinden et al. (2004)

b Colautti et al. (2006)

c One-time event, Colautti et al. (2006)

d Reinhardt et al. (2003)

e Williams and Timmins (2002)

f Pimentel et al. (2005)

Table 1 presents the sum of the costs calculated in part damage or individually, not considering all of the impacts and alien species. Although this result obtained by multiplying a constant marginal damage per pest by an estimate of the total pest population (or pest units if the population is not the measure) has a technical problem, it can provide appropriate and valuable information estimating the potential damages (Olson 2006).

Looking at the United States in Table 2, each plant pathogens and microbes has been introduced into the United States more than 20,000 species. And the economic loss of crops by alien species is $33 billion annually, and invasive pests cause 65% of this loss. Additionally, control costs of invasive pests reach $500 million annually (Pimental et al. 2005).

In Canada, the cumulative annual costs by 16 alien species are between $13.3 billion and $34.5 billion (Colautti et al. 2003). The Canadian Food Inspection Agency (CFIA) estimates that of the 485 invasive plant species in Canada, invasive plants in crops and pastures alone cost approximately $2.2 billion every year. The CFIA classifies 94 invasive species as agricultural or forest pests and estimates that these regulated species cost the Canadian economy $7.5 billion annually (ISC 2013).

Table 2 Estimated annual costs associated with some alien species introduction in the U.S. (Pimentel et al. 2005)

	Nonindigenous species	Losses and damages ($ million)	Control costs ($ million)	Total ($ million)
PLANTS	25,000			
Purple loosestrife		-	-	45
Aquatic weeds		10	100	110
Melaleuca tree		NA	3-6	3-6
Crop weeds		24,000	3,000	27,000
Weeds in pastures		1,000	5,000	6,000
Weeds in lawns, gardens, golf courses		Not Available	1,500	1,500
MICROBES	20,000			
Crop plant pathogens		21,000	500	21,500
Plant pathogens in lawns, gardens, golf courses		NA	2,000	2,000
Forest plant pathogens		2,100	NA	2,100
Dutch elm disease		NA	100	100

Olson and Roy (2005) maintained that invasive species introductions are a random variable but can be reduced through prevention. Even though prevention is an essential policy tool to mitigate the damage caused by invasive species, the best prevention strategy is associated with the social cost that invasive species occur in case (Pimental et al. 2005).

Quarantine policies such as border-control and eradication programs have the characteristics of a public good because it affects consumers and producers in that they are non-competitive and non-exclusion (Sumner, 2003; Sumner et al., 2005). In the real world, individual acts to reduce damages caused by invasive species, but external effects can occur if the government fails to recognize this situation properly (Horan et al. 2002; Finnoff and Shogren 2004; Finnoff et al. 2005a; Finnoff et al. 2005b; Thomas and Randall 2000; Shogren et al. 1993).

So, many countries used to apply most international trade regulations (e.g., SPS measures, IPM, etc.) to reduce the risks and damages caused by the influx of alien species. Roberts et al. (1999) and Roberts (1999) analyzed the effects of technical trade barriers that can be classified by policy instrument, scope, and regulatory goal. Beghin and Bureau (2001) investigated the methods to evaluate the impact of SPS and other non-tariff trade barriers on market equilibrium, trade flows, economic efficiency, and welfare. Smith (2003) provided the summary of the WTO-SPS compliance requirements and examined their role in several cases of Australia, Canada, Japan, foot-and-mouth disease, and exotic Newcastle disease. Mumford (2002) provided an overview of the economic issues between increased trade and quarantine. Lynch (2002) developed a model about import bans and subsidies for control in the exporting country and applied it to the international trade between the United States, Mexico, and Central America.

Besides, several types of research dealing with the trade, protectionism, evaluation of the relationship between the damage of alien species used the static model of the quarantine policies to reduce the impact of invasive species, where economic and political models are applied for the issue regarding the import restrictions. Below are various studies conducted for the topics.

Costello and McAusland (2003) analyzed the network between trade, protectionism, and invasive species damage. McAusland and Costello (2004) examined a static model of the use of tariffs and inspections to reduce trade-induced invasive species damages. Romano and Orden (1997) discussed the political economy of U.S. import restrictions on nursery stock and ornamental plants. Roberts and Krissoff (2004) investigated the status of 33 complaints related to SPS restrictions on horticultural products filed during 1995–2002.

Margolis et al. (2005) analyzed an invasive species externality with the Grossman and Helpman (1994) political economy model of trade, and Sumner and Lee (1997) suggested how the effects of SPS measures on export supply and import demand functions might be coupled with empirical trade models. Glauber and Narrod (2001, 2003) examined the quarantine programs designed to prevent karnal bunt spread. In the first paper of 2001, they mentioned that suboptimal regulations drive producers, consumers, and taxpayers to pay more than $350 million per year when losses due to seed development restrictions are included. James and Anderson (1998) analyzed the Australian quarantine policy to protect domestic banana production from pests and diseases using a partial equilibrium analysis.

Pak et al.(2020) demonstrated the innovation of assessment for the disease cases could better exploit the advantage of the existing method and improve the cluster detection due to the latent time component. The empirical results of this study are expected to provide more useful policy implications with agencies in charge of preventing and controlling the spread of epidemics in Asian countries.

III. Evaluating the Korean Plant Quarantine System

1. Direct Effects

As it is challenging to estimate supply (production) and demand functions of all crops when estimating direct values of KPQS, in this study, we used aggregated data from statistics annual reports by the Korean government. The pest damage to crops affects domestic production, and hence, affects agriculture-related exports. Considering domestic production of agriculture and the crop effect on imports and exports as shown in Table 3, the economic damages stemming from invasive diseases and pests were estimated. However, it should be noted that this study did not account for the substitutional and complementary effects associated with the damaged crops. As demonstrated in Figure 2, we only highlighted the supply side due to the limitation in using the aggregate data related to agricultural production.

Table 3 Framework for analysis

	Supply	Competition	Etc.
Export	○	-	○
Import	○	○	○
Domestic	○	-	-

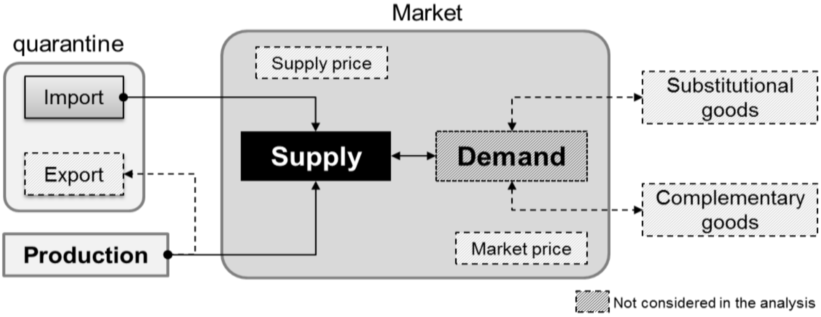

Figure 2 Scope of analysis

1.1 Agriculture and Forestry Production Trend in Korea

The total amount of agricultural and forestry production in Korea increased from KRW33.1 trillion in 2000 to KRW46.4 trillion in 2012 by 38.1% increase during the period. As referred to in Table 4, the portion of Rice production to GDP showed a declining pattern since 2005. However, the share of Livestock to GDP has shown a slight upward trend. And the percentage of horticulture is stagnant since 2005.

Table 4 Agriculture and Forestry Production and the ratio of value-added to GDP

Year	2005	2006	2007	2008	2009	2010	2011
Agriculture and Forestry	36,273	36,389	35,837	39,663	42,995	43,523	43,214
Portion of rice	23.5	23.1	21.9	23.6	20.2	15.6	18.5
Portion of flower	30.3	31	31.3	28	27.7	29.4	30.1
Portion of livestock	32.4	32.1	31.5	34.3	38.3	40.2	34.7
Value-added of agriculture and fishery	23,655	23,666	23,068	22,427	23,336	24,629	26,442
Portion of agriculture and fishery	3.0	2.9	2.6	2.4	2.4	2.3	2.4

1.2 Markov Chain Model

In general, for most diseases that will be included in the quarantine risk assessment, modeling is not possible due to the lack of data and uncertainty on all transmission mechanisms for the disease. In other words, it is important to look at the long-term risk of persisting disease effects, even if formal biological models of disease epidemiology are not available. This approach seems to be preferred over completely ignoring dynamic effects due to a lack of information. Therefore, this study uses the Markov chain model as a mathematical model instead of a biological model, in which the probability of events in the current period depends on the results of the previous period.

A Markov chain model (MCM) is a method to predict probabilities that would change at the next stage when a particular stage is given. This approach is practical when being applied for a study that examines the change and evolution progress of a specific system through recurring conditions. It is a probability theory with a stochastic process where only the previous events or states or results determine future events or results. MCM possesses the 'Markov property' that explains the probability distribution of the next stage only relies on the current stage without sequential events that would precede it.

The MCM consists of a sequence of random variables $X_1, X_2, X_3, \ldots, X_n$. Possible values of X_i form a countable set S called the stage space of the chain. If the conditional distribution X_{n+1} is defined as a function of only X_n in any previous stage, then the following equation should be met:

$$P(X_{n+1} = x \mid X_0, X_1, X_2, \ldots, X_n) = P(X_{n+1} = x \mid X_n) \qquad (1)$$

We assigned the stage space to the quarantine probabilities of invasive diseases and pests, followed by KPQS from 2000 to 2013 in this study.

In a transition matrix, probabilities start from one stage at time n to the other stage at time n+1, needs. We set the KPQS probability using asymmetrical game theory similar to Hinchy and Fisher (1991) and analyzed the effect of the KPQS as follows:

1) Without KPQS
 - The incidence probability in the next year without diseases and pests = 10%
 - The incidence probability in the next year with diseases and pests = 50%
2) With KPQS
 - The incidence probability in the without diseases and pests = 5%
 - The incidence probability in the with diseases and pests = 50%

Table 5 describes the transition matrix assumed.

Table 5 Transition matrix

	Without a Quarantine system [a]		With a Quarantine system	
	P(Inspection)	*P(Control)*	*P(Inspection)*	*P(Control)*
P(Inspection)	0.90	0.50	0.95	0.50
P(Control)	0.10	0.50	0.05	0.50

a. We referred to the study of Hinchy & Fisher (1991)

Therefore, Figure 3 elicits a dynamic stochastic process applied with the stochastic game of the KPQS probability related to invasive diseases and pests using MCM.

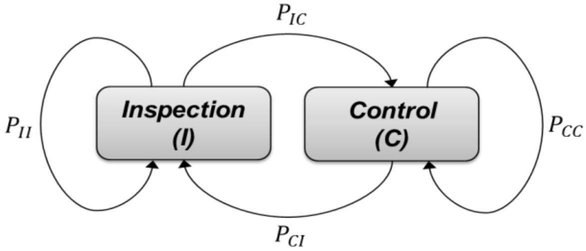

Figure 3 Probability transition diagram for plant diseases and pests using a Markov chain model

This diagram of the dynamic game process can be expressed as equation (2).

$$\textit{Effect of Plant Quarantine System} = (1-P')\cdot S(c)+P'\cdot S(d)-(1-P)\cdot S(a)-P\cdot S(b) \qquad (2)$$

Let P be the probability of the disease stage
Let P' be the corresponding probability when quarantine is introduced
Let S(i) be the total production where i corresponds to the particular case as following:
If i = a, (no quarantine, no disease); If i = b, (no quarantine, disease);
If i = c, (quarantine, no disease); and If i = d, (quarantine, disease)

1.3 Effect of the Korean Plant Quarantine System

Because the Korean Plant Quarantine System's effect is understood as the net loss rate of diseases and pests, the difference between the probability of the presence and the absence of the quarantine system needs to be measured as suggested transition matrix in Figure 3 and Eq. 2.

The direct value of KPQS was then transferred to a dollar value by multiplying the loss rate in Eq. 2 and the total amount of agricultural and forestry production in Korea. We assumed the following conditions : (1) fluctuations in exports associated with the inflow of invasive diseases and pests are considered insignificant to domestic supply because the exporting products have little relation with domestic consumption, (2) changes in supply are fixed without considering the price elasticity of supply because there is a difficulty to predict how imports associated with the inflow of invasive diseases and pests change, (3) each subsector or item itself of agricultural and forestry industry uses the same damage rate of diseases and pests despite the possible rate variation.

The direct loss results are presented in Table 6. The total impact on the fail of the KPQS was estimated as about 33 trillion KRW during the last 12 years (from 2000 to 2011), corresponding to approximately 2.7 trillion KRW on average.

Considering Korea’s annual GDP of 1,435 billion dollars in 2015, a large part of the agricultural and forestry industry loss stemmed from Vegetables, Fruit, and Floriculture sectors, taking 20%, 8%, and 2.3% of the total loss, respectively.

Table 6 Loss of Agriculture

	Without a Quarantine System (δ) (₩ B.)				With a Quarantine System (θ) (₩ B.)				Effect (δ-θ) (₩ B.)
year	Total	Veg.	Fruit	Flower	Total	Veg.	Fruit	Flower	
2000	3,314	674	258	66	1,657	337	129	33	1,657
2001	4,700	1,009	291	83	2,434	523	151	43	2,266
2002	5,217	1,056	403	122	2,763	559	213	65	2,454
2003	5,362	1,237	381	131	2,878	664	205	70	2,483
2004	6,151	1,265	485	151	3,327	684	262	82	2,824
2005	6,021	1,148	512	165	3,270	624	278	90	2,751
2006	6,055	1,224	494	157	3,296	666	269	85	2,759
2007	5,969	1,246	470	154	3,252	679	256	84	2,717
2008	6,609	1,202	500	151	3,603	655	272	82	3,006
2009	7,165	1,259	585	144	3,907	687	319	79	3,258
2010	7,254	1,392	597	142	3,956	759	326	77	3,298
2011	7,202	1,422	612	136	3,928	776	334	74	3,274
Sum	71,019	14,134	5,588	1,602	38,271	7,613	3,014	864	32,745
Avg.	5,918	1,178	466	133	3,189	634	251	72	2,729

₩ B. billion KRW
Veg. vegetables
Avg. average

1.4 Simulation Scenarios for Korean Plant Quarantine Policy Strategies

Scenarios on quarantine policies were developed and set to asymmetrical probabilistic games on the change to prevention and control of the probability of invasive diseases and pests. Table 7 and Figure 4 present the scenario-based game transition matrix and aversion probability, respectively.

Table 7 A transition matrix corresponding to scenarios

Scenario	Without a Quarantine system		With a Quarantine system		
	Baseline (A)	Worse (B)	Maintain (I)	Improvement (II)	Consolidation (III)
P(Inspection)	0.900	0.800	0.950	0.990	0.999
P(Control)	0.500	0.400	0.500	0.550	0.600

The scenarios were composed of climate change scenarios. We assumed that deterioration in the plant quarantine conditions occurs along with the global warming and policy scenarios that may improve or enhance the control performance of KPQS. Combining each scenario in Table 7, 6 scenarios were finalized (A-I; A-II; A-III; B-I; B-II; B-III).

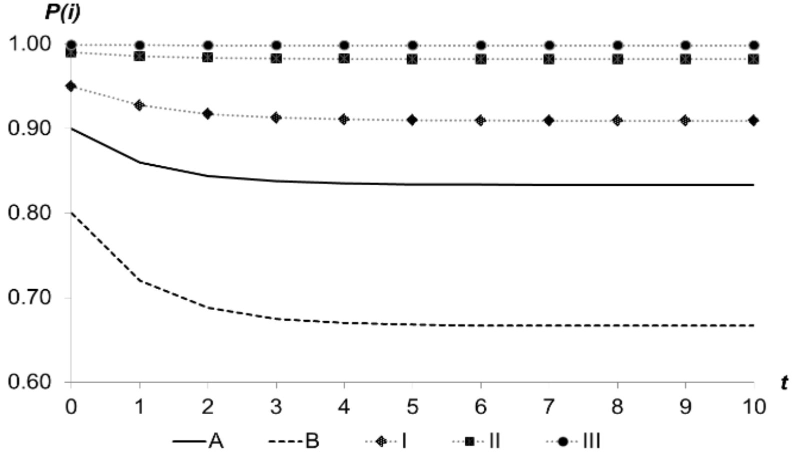

Figure 4 Aversion probability patterns of invasive damages by scenario

Table 8 summarizes the direct effect of the KPQS by each scenario. The annual direct benefit to agriculture and forestry measured from the scenarios ranged from about 2.7 trillion KRW to 17.7 trillion KRW. Among subsectors in Agriculture and Forestry, Vegetables' annual effect was between 0.5 trillion KRW and 3.5 trillion KRW benefit. In contrast, Fruits and Flowers' effects ranged from 0.2 trillion KRW to 1.4 trillion KRW and 0.06 trillion KRW to 0.4 trillion KRW, respectively.

Table 8 Annual effects by scenario

	A-I	A-II	A-III	B-I	B-II	B-III
Agriculture and Forestry	2,729	5,290	5,859	8,647	11,208	11,777
Vegetables	543	1,053	1,166	1,721	2,231	2,344
Fruit	215	416	461	680	882	927
Flowers	61	119	132	195	253	266

As increasing international trade and travelers, the plant quarantine is shifting from A-I scenario to B-III scenario. Thus, each country has strengthened the quarantine level for the protection of its environment and industry. It is necessary to set the actual scheme reflecting the change of crops, situations, and time for examining the more accurate and realistic effect of quarantine policy. This result showed that we should let the quarantine policy on the plant be reinforced and elaborated as soon as possible. Each scenario's damage is cumulative and increases over time.

2. Indirect Effects

In a previous paragraph, we put an induced effect of quarantine system on plants such as protecting the ecosystem and industry, ensuring food safety and sovereignty. In this paper, we used CVM to estimate the quarantine system's indirect benefits on the plant.

2.1Contingent Valuation Method

The contingent valuation method is the direct hypothetical method by using surveys to elicit willingness to pay. It is a survey methodology in which respondents are asked how much they would be willing to pay for specific environmental services (Tietenberg and Lewis 2008). The survey clearly defines the good/service and the (policy-induced) change in the good/service to be valued. CVM begins with setting a virtual marketplace for environmental services changes, and this marketplace should be realistic and neutral.

2.2 Design of survey

The indirect benefit of the quarantine system on the plant was evaluated using the Willingness-to-Pay (WTP) based on respondents' choice of the quarantine system's intention. A Goods of analysis is the Korean plant quarantine system, and the spatial scope is an entire household in Korea. A specific hypothetical scenario is about measures to strengthen the Korean plant quarantine system. The payment vehicle is an increase in income tax each year. We used the double bounded dichotomous choice (DBDC) format to obtain a WTP from the response. The survey population is households throughout Korea; the samples were designed as adults over 20 years old based on the ratio of age, gender, and region. The sample size is 2,000, randomly extracted depending on age, gender, and region ratio. We used the internet survey method to transfer more accurate and abundant information to respondents, and the professional survey agency conducted the pilot and complete surveys.

Population	Entire households in Korea (more than 20 years old)
Number of Sample	2,000 households
Sampling	Quota sampling-minimum quota
Sampling error	95-percent confidence level with plus or minus 3%
Survey method	Internet survey by the online questionnaire
Survey period	three weeks, November 2013

2.3 Hypothetical Scenario

The main contents of the virtual market scenario in the questionnaire are the same as in Table 9. To minimize the hypothetical bias, the survey was written that the respondents carefully answer the question of WTP because of the additional expenditure within a limited income. The amount of bid presented both the annual and monthly prices for reducing method of provision bias.

Table 9 Contents of survey questionnaire

Questionnaire	Contents
Awareness of the plant quarantine	• Awareness of the value of plant quarantine • Recognition of plant quarantine levels
Awareness of the environment	• Interest in the environment • Awareness of the value of plant quarantine • Awareness of the environmental issues • Recognition of invasive species
The economic value for the strengthened plant quarantine system	• The willingness to pay for the strengthened plant quarantine system

When setting up a virtual market scenario's payment vehicle, it is necessary to set it carefully because the respondents refuse to pay. In particular, if the payment vehicle is the tax, payment vehicle bias could be arising due to respondents' taxation reluctance. Thus we included the question of whether or not to pay the payment before providing the bidding question.

The WTP format used the DBDC recommended by the National Oceanic and Atmospheric Administration (NOAA) panel. A pilot survey was conducted to set the amount of first bidding. According to the distribution of the respondents' WTP, we set up five first-bidding prices: 2,000 KRW, 5,000 KRW, 10,000 KRW, 25,000 KRW, and 40,000 KRW. The first-bidding price was equally allocated for each price to respondents and randomly distributed.

2.4 Result

Table 10 presented the distribution of response for each first-bidding price. Here, Y means a "yes" for the willingness to pay a bidding price, and N means a "no." In the DBDC, respondents are asked a second question immediately after answering the first question. Usually, the bid included in the second question is twice of the first bid if the respondent answered "yes" to the first question and half if the respondent answered "no" to the first question. Thus the combination of responses can be presented in four as follows: [Y-Y], [Y-N], [N-Y], and [N-N].

Table 10 The result of response for each first bid

First bid	[Y-Y]	[Y-N]	[N-Y]	[N-N]	Sum
2,000 KRW	153	30	4	287	474
5,000 KRW	128	37	6	309	480
10,000 KRW	113	65	8	288	474
25,000 KRW	82	86	24	283	475
40,000 KRW	50	93	44	287	474
Sum	526	311	86	1454	2377

Table 11 lists the definition and summary statistics of variables expected to affect respondents' WTP to strengthen the quarantine system.

Table 11 Definition and summary statistics of variables

variables	Content	Definition	Mean	Std.
STRENGTH	In favor of the quarantine system strengthening	{agreement ↔ opposition (9～1)}	7.600	1.503
NGO	Social organization status	Join(1), Not join(0)	0.024	0.154
DONATION	Donation experience	Yes(1), No(0)	0.643	0.479
REGION	Living in location	Metropolitan area(0), The other area(1)	0.354	0.478
AGE	Age	*Ln*(20~59 years old)	3.616	0.304
JOB_1	White-collar	Officials, managers, professionals, researchers, etc.	0.471	0.499
JOB_2	Blue-collar	Self-employment, technical, functional / sales, daily, etc.	0.244	0.430

JOB_0	Unemployed	Reference group: unemployed	0.285	0.451
EDU	Education level of household	High school or less (1) College (2) College graduation (3) Graduate later (4)	2.585	0.983
INCOME	Income level	The total average monthly household income / household member	1.163	0.588
RELATED	Related with agriculture	Yes(1), No(0)	0.359	0.480
BID	First bid	2,000 KRW; 5,000 KRW; 10,000 KRW; 25,000 KRW; 40,000 KRW	-	-

Std. standard deviation

Based on these variables, a linear function of indirect benefit for quarantine system can be expressed as following equation (3):

$$\Delta V = f(REGION,\ AGE,\ STRENGTH,\ NGO,\ DONATION,\ EDU,\ JOB,\ INCOME,\ RELATED,\ BID) \tag{3}$$

Table 12 Result of DBDC

variables	*Coef.*	*Std. Err.*	z value	P>z	95% Conf. Interval	
constant	-0.218	0.045	-4.83	0	-0.307	-0.130
REGION	-0.005	0.003	-1.86	0.06	-0.010	0.000
AGE	-0.008	0.004	-1.71	0.09	-0.016	0.001
STRENGTH	0.003	0.001	3.09	0.00	0.001	0.005
NGO	0.022	0.005	4.62	0.00	0.013	0.031
DONATION	0.016	0.003	4.71	0.00	0.009	0.022
EDU	0.003	0.001	1.80	0.07	-0.000	0.005
JOB_1	0.005	0.003	1.39	0.16	-0.002	0.011
JOB_2	0.007	0.004	1.88	0.06	-0.000	0.014
INCOME	-0.005	0.002	-1.93	0.05	-0.010	0.000
RELATED	0.006	0.003	2.18	0.03	0.001	0.011
BID	-0.044	0.017	-2.59	0.01	-0.077	-0.011
L. L.	-2392.303					
WTP/HH,Year	13,424				7,138	59,231

Coef.: coefficient
Std. Err.: standard error
Conf. Interval: confidence interval
L.L.: log likelihood
HH: household

Table 12 shows estimates of the indirect benefits for the Korean plant quarantine system. BID's negative coefficient means that the higher the first bid's amount, the lower the probability of WTP. That is to say, the result of the survey is representing the reasonable payment behavior of respondents.

All variables were statistically at the significance level of 5% except JOB_1. NGO and DONATION were the following two most significant impact variables on pay responses beyond BID. Metropolitan area residents were more positive than the non-metropolitan residents on additional tax payments. The negative trend in WTP increased with age; this trend surfaces as younger were interested in ecosystem protection, food security, food sovereignty, and domestic industry protection. The higher income has a negative impact on WTP. The reason may be that they have already been paying for more safe food. And the higher education and vocational level showed a positive pay response. Finally, the WTP of the plant quarantine system reached about an annual 13,424 KRW per household.

Calculating the Korean plant quarantine system's indirect value, we multiplied the WTP per household by the national household (according to the Korea National Statistical Office, the number of national households is 18,206,328 households in 2013). As a result, the Korean plant quarantine system's indirect value was calculated at about 2,444 billion KRW. The range is from about 130 billion KRW to about 1.1 trillion KRW.

IV. Conclusion

This paper aims to evaluate the Korean plant quarantine system's value and simulate plant quarantine policy strategies. We analyzed the effect of plant quarantine in terms of the supply side to assess the plant quarantine system's value and the impact of plant quarantine policy.

In general, previous studies focused on the perspective of individual crop level rather than the national level. We considered only the agricultural market's supply-side using the aggregated data, Agricultural production amount instead of estimating supply and demand functions due to evaluating the national quarantine system's value. We assessed the effect of a national plant quarantine using the Markov Chain Model because it is difficult to calculate the impact of plant quarantine on all individual pests.

We estimated the Korean plant quarantine system's direct value by multiplying the loss rate derived from the previous paragraph and agricultural and forestry production. The base scenario showed that the estimated direct value is approximately 33 trillion KRW during 12 years (from 2000 to 2011) and an annual average of about 2.7 trillion KRW. A large part of the agricultural and forestry industry's damage was shown in the order of Vegetables, Fruit, and Floriculture. Vegetables, Fruit, and Floriculture hold 20%, 8%, and 2.3%, respectively.

The annual direct benefit of agriculture and forestry through six scenarios ranges from about 2.7 trillion KRW to 17.7 trillion KRW. Among agriculture and forestry, vegetables are from 0.5 trillion KRW to 3.5 trillion KRW, fruits are from 0.2 trillion KRW to 1.4 trillion KRW, and flowers are from 0.06 trillion KRW to 0.4 trillion KRW annually.

Then, we estimated the indirect benefit of the quarantine system on the plants using the WTP based on respondents' choice of the questionnaire about the quarantine system's intention. As a result of the analysis, the coefficient of BID is negative. This means that the higher the amount of the first bid, the lower the probability of WTP. That is to say, the result of the survey is representing the reasonable payment behavior of respondents. All variables showed a valid result at the significance level of 5% except JOB_1. NGO and DONATION were the following two most significant impact variables on pay responses' beyond BID.

The WTP of the plant quarantine system reached about an annual 13,424 KRW per household. If this is expanded to the national level, the value was calculated at about 2,444 billion KRW. The range is from about 130 billion KRW to about 1.1 trillion KRW.

Our approach has the limitations that it cannot be considered the effects of substitutional and complementary goods related to the damaged crops but only the supply side and the different ratio of damages by each crop. Therefore, it is necessary to set the actual scenario reflecting the change of crops, situations, and time for examining the more accurate and realistic effect of quarantine policy.

Even though this study used old data, the result showed that it is still important to promote and reinforce the quarantine policy of the plant. Each scenario's damage is cumulative and increases over time. The finding is especially meaningful because it could derive the benefits of the Korean plant quarantine system towards the stability of plant resources, ensuring food safety and sovereignty, etc., for the people. The results may provide valuable guidelines and an excellent example of the quarantine system innovation for the decision-makers and stakeholders in Asian and other developing countries.

Appendix

Table A.1 Plant Quarantine effects of the Scenario A-I

	Without quarantine system(δ)				With quarantine system(θ)				Effect (δ-θ)			
year	Agriculture	vegetable	Fruit	Flower	Agriculture	vegetable	Fruit	Flower	Agriculture	vegetable	Fruit	Flower
2000	3,314	674	258	66	1,657	337	129	33	1,657	337	129	33
2001	4,700	1,009	291	83	2,434	523	151	43	2,266	487	140	40
2002	5,217	1,056	403	122	2,763	559	213	65	2,454	497	190	58
2003	5,362	1,237	381	131	2,878	664	205	70	2,483	573	177	61
2004	6,151	1,265	485	151	3,327	684	262	82	2,824	581	223	69
2005	6,021	1,148	512	165	3,270	624	278	90	2,751	525	234	75
2006	6,055	1,224	494	157	3,296	666	269	85	2,759	558	225	71
2007	5,969	1,246	470	154	3,252	679	256	84	2,717	567	214	70
2008	6,609	1,202	500	151	3,603	655	272	82	3,006	547	227	69
2009	7,165	1,259	585	144	3,907	687	319	79	3,258	572	266	65
2010	7,254	1,392	597	142	3,956	759	326	77	3,298	633	272	64
2011	7,202	1,422	612	136	3,928	776	334	74	3,274	647	278	62
Sum	71,018	14,135	5,589	1,602	38,273	7,613	3,014	864	32,745	6,522	2,574	738
Avg.	**5,918**	**1,178**	**466**	**133**	**3,189**	**634**	**251**	**72**	**2,729**	**543**	**215**	**61**

Table A.2 Plant Quarantine effects of the Scenario A-II

	Without quarantine system(δ)				With quarantine system(θ)				Effect (δ-θ)			
year	Agriculture	vegetable	Fruit	Flower	Agriculture	vegetable	Fruit	Flower	Agriculture	vegetable	Fruit	Flower
2000	3,314	674	258	66	331	67	26	7	2,983	606	232	60
2001	4,700	1,009	291	83	483	104	30	9	4,216	905	261	74
2002	5,217	1,056	403	122	546	111	42	13	4,671	945	361	110
2003	5,362	1,237	381	131	567	131	40	14	4,794	1,106	341	117
2005	6,021	1,148	512	165	643	123	55	18	5,378	1,026	457	148
2006	6,055	1,224	494	157	648	131	53	17	5,407	1,093	441	140
2007	5,969	1,246	470	154	639	133	50	16	5,330	1,113	420	137
2008	6,609	1,202	500	151	708	129	54	16	5,901	1,073	446	135
2009	7,165	1,259	585	144	768	135	63	15	6,398	1,124	522	129
2010	7,254	1,392	597	142	777	149	64	15	6,476	1,243	533	127
2011	7,202	1,422	612	136	772	152	66	15	6,431	1,270	547	122
Sum	71,018	14,135	5,589	1,602	7,537	1,500	594	170	63,481	12,636	4,995	1,432
Avg.	**5,918**	**1,178**	**466**	**133**	**628**	**125**	**49**	**14**	**5,290**	**1,053**	**416**	**119**

Table A.3 Plant Quarantine effects of the Scenario A-III

	Without quarantine system(δ)				With quarantine system(θ)				Effect (δ-θ)			
year	Agriculture	vegetable	Fruit	Flower	Agriculture	vegetable	Fruit	Flower	Agriculture	vegetable	Fruit	Flower
2000	3,314	674	258	66	33	7	3	1	3,281	667	255	66
2001	4,700	1,009	291	83	47	10	3	1	4,653	999	288	82
2002	5,217	1,056	403	122	52	11	4	1	5,165	1,045	399	121
2003	5,362	1,237	381	131	54	12	4	1	5,308	1,225	378	130
2004	6,151	1,265	485	151	61	13	5	2	6,090	1,252	480	150
2005	6,021	1,148	512	165	60	11	5	2	5,961	1,137	506	163
2006	6,055	1,224	494	157	60	12	5	2	5,994	1,211	489	155
2007	5,969	1,246	470	154	60	12	5	2	5,909	1,234	465	152
2008	6,609	1,202	500	151	66	12	5	2	6,543	1,190	495	149
2009	7,165	1,259	585	144	72	13	6	1	7,094	1,246	579	143
2010	7,254	1,392	597	142	72	14	6	1	7,181	1,378	591	140
2011	7,202	1,422	612	136	72	14	6	1	7,130	1,408	606	135
Sum	71,018	14,135	5,589	1,602	709	141	56	16	70,309	13,994	5,533	1,586
Avg.	**5,918**	**1,178**	**466**	**133**	**59**	**12**	**5**	**1**	**5,859**	**1,166**	**461**	**132**

Table A.4 Plant Quarantine effects of the Scenario B-I

	Without quarantine system(δ)				With quarantine system(θ)				Effect (δ-θ)			
year	Agriculture	vegetable	Fruit	Flower	Agriculture	vegetable	Fruit	Flower	Agriculture	vegetable	Fruit	Flower
2000	6,628	1,348	516	133	1,657	337	129	33	4,971	1,011	387	100
2001	9,399	2,019	581	165	2,434	523	151	43	6,965	1,496	431	122
2002	10,435	2,112	806	245	2,763	559	213	65	7,671	1,553	592	180
2003	10,724	2,475	763	262	2,878	664	205	70	7,845	1,810	558	191
2004	12,302	2,530	970	303	3,327	684	262	82	8,975	1,846	708	221
2005	12,041	2,297	1,023	330	3,270	624	278	90	8,771	1,673	745	241
2006	12,110	2,447	989	313	3,296	666	269	85	8,814	1,781	720	228
2007	11,938	2,493	940	308	3,252	679	256	84	8,685	1,814	684	224
2008	13,217	2,404	999	301	3,603	655	272	82	9,614	1,749	727	219
2009	14,330	2,518	1,170	288	3,907	687	319	79	10,423	1,831	851	209
2010	14,507	2,784	1,195	284	3,956	759	326	77	10,551	2,025	869	206
2011	14,404	2,845	1,225	272	3,928	776	334	74	10,476	2,069	891	198
Sum	142,036	28,270	11,177	3,204	38,273	7,613	3,014	864	103,763	20,657	8,163	2,340
Avg.	**11,836**	**2,356**	**931**	**267**	**3,189**	**634**	**251**	**72**	**8,647**	**1,721**	**680**	**195**

Table A.5 Plant Quarantine effects of the Scenario B-II

	Without quarantine system(δ)				With quarantine system(θ)				Effect (δ-θ)			
year	Agriculture	vegetable	Fruit	Flower	Agriculture	vegetable	Fruit	Flower	Agriculture	vegetable	Fruit	Flower
2000	6,628	1,348	516	133	331	67	26	7	6,297	1,280	490	126
2001	9,399	2,019	581	165	483	104	30	9	8,916	1,915	552	157
2002	10,435	2,112	806	245	546	111	42	13	9,888	2,001	764	232
2003	10,724	2,475	763	262	567	131	40	14	10,156	2,344	722	248
2004	12,302	2,530	970	303	655	135	52	16	11,647	2,396	919	286
2005	12,041	2,297	1,023	330	643	123	55	18	11,398	2,174	968	313
2006	12,110	2,447	989	313	648	131	53	17	11,462	2,316	936	296
2007	11,938	2,493	940	308	639	133	50	16	11,299	2,359	890	291
2008	13,217	2,404	999	301	708	129	54	16	12,510	2,275	946	285
2009	14,330	2,518	1,170	288	768	135	63	15	13,563	2,383	1,107	273
2010	14,507	2,784	1,195	284	777	149	64	15	13,730	2,635	1,131	268
2011	14,404	2,845	1,225	272	772	152	66	15	13,633	2,692	1,159	258
Sum	142,036	28,270	11,177	3,204	7,537	1,500	594	170	134,499	26,771	10,584	3,033
Avg.	**11,836**	**2,356**	**931**	**267**	**628**	**125**	**49**	**14**	**11,208**	**2,231**	**882**	**253**

Table A.6 Plant Quarantine effects of the Scenario B-III

	Without quarantine system(δ)				With quarantine system(θ)				Effect (δ-θ)			
year	Agriculture	vegetable	Fruit	Flower	Agriculture	vegetable	Fruit	Flower	Agriculture	vegetable	Fruit	Flower
2000	6,628	1,348	516	133	33	7	3	1	6,595	1,341	514	132
2001	9,399	2,019	581	165	47	10	3	1	9,352	2,008	579	164
2002	10,435	2,112	806	245	52	11	4	1	10,383	2,102	802	244
2003	10,724	2,475	763	262	54	12	4	1	10,670	2,462	759	260
2004	12,302	2,530	970	303	61	13	5	2	12,241	2,518	966	301
2005	12,041	2,297	1,023	330	60	11	5	2	11,981	2,285	1,018	329
2006	12,110	2,447	989	313	60	12	5	2	12,049	2,435	984	312
2007	11,938	2,493	940	308	60	12	5	2	11,878	2,480	935	306
2008	13,217	2,404	999	301	66	12	5	2	13,151	2,392	994	300
2009	14,330	2,518	1,170	288	72	13	6	1	14,259	2,505	1,164	287
2010	14,507	2,784	1,195	284	72	14	6	1	14,435	2,770	1,189	282
2011	14,404	2,845	1,225	272	72	14	6	1	14,333	2,830	1,219	271
Sum	142,036	28,270	11,177	3,204	709	141	56	16	141,327	28,129	11,121	3,188
Avg.	**11,836**	**2,356**	**931**	**267**	**59**	**12**	**5**	**1**	**11,777**	**2,344**	**927**	**266**

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