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Conceptualising the Economics of Plant Health Protection Against Invasive Pests: A Deterministic Approach

Jaakko Heikkilä
Jukka Peltola

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Jaakko Heikkilä and Jukka Peltola

MTT Economic Research
Agrifood Research Finland
Luutnantintie 13, FIN-00411, Helsinki, Finland
jaakko.heikkila@mtt.fi
jukka.peltola@mtt.fi

Abstract. Threats to animal and plant health by invading organisms are increasing due to trade liberalisation and increased movement of goods and people. This paper conceptualises an economic approach to protecting plant health against invasive organisms, specifically addressing a multidisciplinary audience involved in plant health research and in governmental policy-making process. We discuss the analytical framework and present some generally available management options. We also build a basic deterministic model dealing with prevention and reactive treatment, followed by a numerical application to the case of Colorado Potato Beetle in Finland.

The analysis undertaken supports the notion that prevention is a viable strategy. Treatment should be considered only if low invasion probability combines with a low level of damage. However, the strategy choice implies also distributional impacts that warrant attention. Furthermore, as uncertainty plays a major part with invasive species, deterministic analysis may not provide entirely reliable results. The approach presented demonstrates the basic economic thinking behind the issue, and the concepts described allow further development of more sophisticated forms of analysis.

Index words: invasive pest, plant health, control policy, Colorado Potato Beetle

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1. INTRODUCTION

Invasions by exotic organisms are on the increase due to trade liberalisation and increased movement of goods and people. The topic is not trivial. Globally, 480 000 non-native species have been introduced to various ecosystems, and the annual losses due to non-native organisms in just six countries (the US, the UK, Australia, South Africa, India and Brazil) are estimated to be a minimum of US$ 314 billion (Pimentel et al. 2001). Global losses in agriculture to introduced species are estimated at US$ 55-248 billion annually (Bright 1999).

Besides the sizeable economic losses, the public good nature of invasive species management calls for a social role in managing the problem. The problem arises as protection, once provided, is available for all parties and any one party's consumption does not reduce the amount of protection enjoyed by other parties. Such goods are typically under-provided by the free market.

In strict economic terms, a system aiming to prevent the invasion (henceforth called 'prevention' or 'protection system') is appropriate only if protection is achieved in a cost-minimising manner. The other available option is reactive control once the invasion has taken place (henceforth called 'treatment').

The goal in our study is to conceptualise an economic approach to protecting plant health against invasive organisms, specifically addressing a multidisciplinary audience involved in plant health research and in governmental policy-making process. The outline of the paper is as follows. Section 2 discusses the analytical framework and presents some general management options. Section 3 builds a basic deterministic model dealing with two alternative strategies and Section 4 illustrates an application to the case of Colorado Potato Beetle in Finland. Finally, Section 5 concludes.

2. THE ANALYTICAL FRAMEWORK

2.1 Prevention vs. treatment

A pest invasion is analogous to a case in which input productivity suddenly declines: less output is produced per each unit of input. To maintain production at a given level more inputs per unit of output need to be used, and since the input has a positive cost, the costs of production increase. Invasion events can be thought of as systems: the event of no invasion corresponds to a system that prevents the pest from invading, and the event of increased input use to a system that controls the pest if it invades.

The broadest division of invasive species management is thus between what we call prevention and treatment. This is in essence a proactive versus reactive division. In other words, whether there should be a system (institution or instrument) that controls the entry of the invasive organism or whether resources should be devoted to controlling it if and when it invades. Dalmazzone et al. (2000) and Perrings et al. (2002) discuss loosely the same issue and point out that whereas prevention (their mitigation) aims to reduce the likelihood of invasion, treatment (their adaptation) aims to reduce the impact of an invasion. However, their adaptation concept is also proactive, and as such broader than what we mean by treatment in this paper.

The division we have made is however just one of many possible categorisations. ELI (2002) divides US state-level legislative tools to five categories: i) prevention; ii) regulation; iii) control and management; iv) enforcement and implementation; and v) co-ordination. Our 'prevention' corresponds to theirs, whereas our 'treatment' is in their 'control and management' category.

An example of the prevention approach is the European Union system of protected zones (ZP, zone protégée) which aims to prevent the introduction and spread of organisms harmful to agricultural production. Under the system it is permissible to import agricultural products into a protected zone only from another protected zone or from a designated buffer zone.

Actions involved in preventing a pest from invading are nonetheless costly (surveillance, labelling, import restrictions, disinfection, post-monitoring). Often the benefits of not having the pest around outweigh these costs, but this is by no means inevitable (Mumford 2002, Lichtenberg and Penn 2001). Several countries have voluntarily renounced their EU protected zone. For instance, the UK recently gave up (except for Northern Ireland) its ZP for beet necrotic yellow vein virus, France its for maritime pine bast scale (*Matsucoccus feytaudi*) and Denmark its for tomato spotted wilt tospovirus and tobacco whitefly (*Bemisia tabaci*) (European Commission 2000, EU 2002). Economic factors are likely to have influenced these decisions.

Further, besides giving protection against invasive organisms, protection systems may also act as technical barriers to trade and as such potentially give the areas concerned a trade advantage. Recently, concern was voiced regarding this issue by Australia in the COP-6 meeting of the parties to the Biodiversity Convention (ICTSD 2002). In addition to protection being costly, treatment is enhanced by improving control practices.

We agree that in many occasions preventative actions are a good strategy, given the difficulties in eradicating some invasive species reactively. However, it should be noted that what we mean by reactive treatment does not imply eradication. Further, we argue that we should not take for granted that one of the strategies is by necessity superior. International agreements (such as the SPS agreement of the World Trade Organisation) often require an analysis of the problem at hand to justify any trade restrictive practices. Thus, if it turns out that a protection system is economically superior, then that result can be used should the protection system be criticised on trade grounds. This type of a study helps identifying the factors that are important in determining the strategy.

2.2 Costs, benefits and distribution

Even in prevention versus treatment framework there are various options available to control the invasion. Our framework consists of three possible actions (prevention, treatment and passive) leading to five potential outcomes and thus five cost and benefit structures. The potential paths are presented in Figure 1. When the prevention strategy is successful, the area remains non-invaded (State P1). If prevention fails, the society can choose either to support treatment or to remain passive (States P2 and P3). These two strategies are also available without preventative action (States T1 and T2). The difference between treatment and passive role is the effectiveness of control: the producer control is assumed to be more effective when supported by the society.

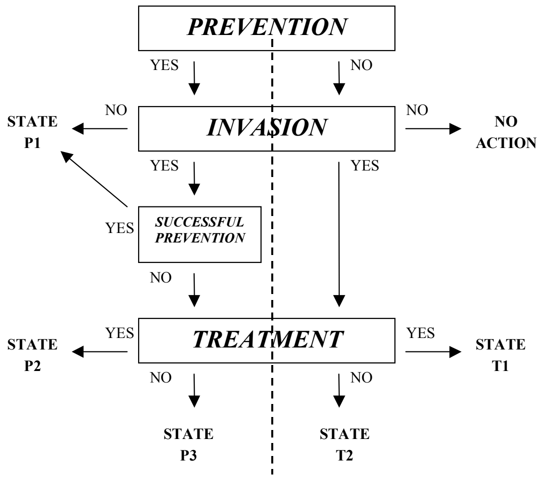

Figure 1. The different paths available for the society.

The output price may differ depending on whether there is an invasion or not, and thus the strategy choice also has distributional effects. Prices depend on the total quantity produced and on the price elasticity of domestic supply, which measures the extent to which the price responds to changes in the total quantity produced. For instance, if the price elasticity of supply is –2, a 10% decrease in total yield increases the price by 20%. Price changes are likely if the aggregate output changes sufficiently and price transfers are imperfect. Hence, despite increased production costs, aggregate profit in the invaded state may turn out to be higher than in the non-invaded state.

However, the possible price increase results in changes regarding the division of income. First, some producers may lose their entire crop, whereas others escape unharmed. In such a case, the division of profits between the producers ends up being very unequal. Second, the price increases may increase producer profits, while at the same time they reduce consumers' surplus[1]. This is illustrated in a standard supply and demand framework in Figure 2.

[1] Consumer surplus is the additional satisfaction on top of the price gained from consuming the good. If you were willing to pay 10€ for a good that only costs 7€, you gain an extra 3€ of satisfaction. Consumer surplus measures these net benefits of consumption. The idea of producer surplus is similar: it is the extra benefit between the price received and the price at which the producer would have been willing to sell the good.

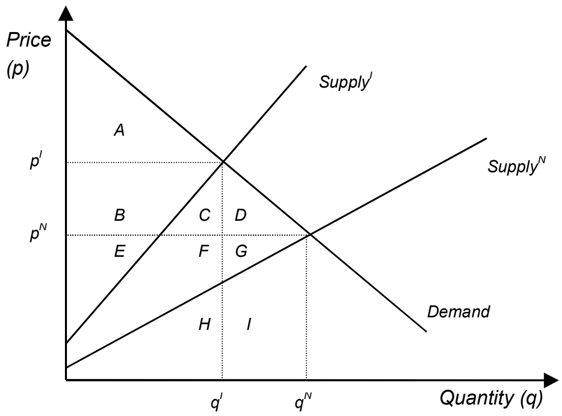

Figure 2. Demand and supply with (*Supply*^{I}) and without (*Supply*^{N}) the pest invasion. The original pre-invasion equilibrium is at p^N, q^N and the post-invasion equilibrium at p^I, q^I.

Originally, consumer surplus is the area $A + B + C + D$ but following an invasion it will be just A. Supply change (from 'normal' to 'invasion' state) thus results in the consumers losing $B + C + D$ in consumer surplus. The effect on producers is ambiguous, as they lose $F + G$, but gain B in producer surplus. Hence, whereas the consumers unambiguously lose in the case of an invasion, for the producers the sign of the change depends on the damage magnitude and the price elasticity of supply. Further, there is an additional social loss presented by the triangle $D + G$. If we were able to prevent the pest from establishing, we would also avoid this social loss, as well as the loss associated with higher costs of production.

The policy choice thus has economic and distributional implications. For the purposes of the present paper, we consider only two simplistic strategies: invest resources to successfully prevent a pest from invading in the first place (State P1) or allow invasion if it so happens and invest in reactive treatment (State T1).

In the case of successful prevention, the cost is simply the cost of the protection system. We assume that there is a given level of prevention, a given cost and a given (100%) probability of success. In the case of treatment there are three types of costs. First, the direct cost of treatment consists of resources devoted to controlling the pest, including for instance pesticide and labour costs. Second cost is the value of lost production due to treatment not being perfectly effective and/or interim damage occurring before treatment is applied. Third cost incurs as consumers lose some of their consumer surplus if product prices increase.

3. MODELLING THE PROBLEM

3.1 The model

Studies of pest control strategies do not necessarily include economic considerations and those that do, often lack either the theoretical or the policy component. In our opinion all three are necessary: the economic component to be able to compare costs and benefits; the theoretical component to formalise the ideas and perhaps allow application to other cases; and the policy component to be able to analyse the decision making process between various alternatives. A suitable model could thus consist of pest invasion dynamics and ecophysiology of crop production, which together produce a yield-loss model. This can be incorporated as a damage function to a production function. Finally, the farm level profit function should allow aggregation to social level and thus policy analysis. In this paper, we illustrate a first step towards such a model.

Our model is based on a pollution model by Barrett and Segerson (1997), supplemented by a profit function with an incorporated damage function. Furthermore, as the invasion primarily imposes costs on the society, we deal only with costs and think of benefits as negative costs.

The model is static: at the beginning of a year a decision is made as to how to control the invasion. We feel the approach is appropriate *provided* that the invasive pest is not able to establish a permanent population. For instance, in the case of Colorado Potato Beetle in Finland, as long as the harsh Finnish winter exterminates all the beetles, the approach is appropriate. Once this is no longer the case, a dynamic approach taking into account the winter survival and development of resistance to chemical control becomes necessary. This will be explored in future work.

The assumptions of the model are as follows: only two alternative strategies are available; the prevention strategy is 100% effective; control is only damage reducing, not production enhancing; neither strategy has any external costs or benefits; the producers are profit maximisers; the society is a risk neutral cost minimiser; the producers take the price as given, but the price can differ in the two states; any price change is fully transferred to consumers; and the pest is host-specific and causes no ecological damage other than that to its host.

To manage the problem, the society has to make a choice between two alternative strategies leading to the following states:

State P1: $TC_{P1} = A$

Total costs (TC) consist simply of the fixed costs of prevention (A), as with 100% effectiveness there are no production losses or control costs.

State T1: $E(TC_{T1}) = P_E\left[\sum_{i=1}^{N}(d\pi_i) + T + dCS\right]$

The pest invades with a given probability (P_E), i.e. it is appropriate to talk about expected total costs (E(TC)). These consist of the expected change in aggregate producer profit (sum of $d\pi_i$ over N producers), plus the expected cost of treatment (P_E T), plus the expected change in consumer surplus (P_E dCS).

The change in profit from the 'no invasion' to the 'invasion' state for a representative producer i is

$$d\pi_i = \pi_i^{NOINV} - \pi_i^{INV}$$

where

$$\pi_i^{NOINV} = m_i\{p_{P1}q_i(x_i) - p_x x_i\}$$

$$\pi_i^{INV} = m_i\{p_{T1}q_i(x_i)[1 - D_i(N_i(A) - \eta z_i)] - [p_x x_i + p_z(T)z_i]\}$$

The quantities are in per hectare terms and the per hectare profit is multiplied by the producer's total production area m_i to give total profit π_i. The above functions can be broken down as follows.

Production revenue is represented by $p_S q_i(x_i)$, i.e. the state-dependent producer price of the product p_S (where S = P1 or T1) multiplied by the quantity produced q_i which depends on inputs x_i. In other words, the price depends on whether an invasion has occurred or not.

The pest damage function is $D_i(N_i(A)-\eta z_i)$. The magnitude of damage D_i is increasing in a larger density of pest individuals in the production area N_i, which is dependent on the magnitude of prevention undertaken by the society A. From this, the number eradicated by the producer ηz_i is subtracted. This number is increasing in increased use of control z_i. The damage is a figure between 0 and 1, i.e. proportional to the quantity produced in the absence of the pest. In the 'no invasion' –case, the damage function is naturally zero.

Production costs are represented by $p_x x_i + p_z(T)z_i$. The first term denotes the production costs without the pest, i.e. the unit price of inputs p_x multiplied by their quantity x_i. The second term is the magnitude of treatment z_i multiplied by its unit price p_z, which depends on the social level of support T. If the society chooses to invest in treatment, the price of treatment to producers is lowered. In the 'no invasion' –case the second term is zero.

3.2 Choice criteria

The society invests funds (A or T) to manage the problem. As we concentrate on comparing the two states, there is no need to carry out optimisation procedures. Instead, four possible social objectives and their choice criteria are:

i) Minimise unconstrained total costs: choose min $\{TC_{P1}, E(TC_{T1})\}$.

ii) Minimise expenditure subject to a given level of damages ($\overline{D}$): If $\sum_{i=1}^{N}(m_i q_i D_i) > \overline{D}$, choose P1; otherwise choose P1 or T1, depending on which one imposes smaller total costs. If the damages in the case of an invasion are greater than the maximum allowable level, then prevention should be undertaken, no matter what the cost. If this is not the case, the more economical of the two options should be chosen. If the acceptable level of damage is defined in terms of expected damage, also the choice criteria should be in terms of expected damage.

iii) Minimise damage subject to available funds ($\overline{R}$): If $\overline{R} \geq A$, choose P1; otherwise choose T1. If the maximum level of funds is enough to undertake 100% effective prevention, then naturally that should be chosen. If there are no sufficient funds, clearly the other objective should be chosen. So, under our assumptions this objective is a non-problem. If we assumed that prevention is not 100% efficient, this would be a fairly good criterion to choose.

iv) Minimise the difference between periods, i.e. reduce variability in the economy: If the potential difference in total costs between the periods is greater than some maximum allowable level, choose the option of no variation (P1). Also a more complex criterion could be used, for instance that the maximum level should not be violated more than 1% of the time.

Hence, it is not always pure cost minimisation that should be the economic criterion for policies. However, at this stage we find it unprofitable to artificially define a maximum level of damage and thus the second criterion is ruled out. On a similar argument we rule out the fourth criterion. Further, as we assume a perfectly effective protection system, the third criterion is not sensible. Thus, at this point, the criterion of unconstrained cost minimisation is a reasonable one to use, but it is worth pointing out that even this basic framework allows consideration of various objectives.

Adopting the first objective, the problem of the risk neutral and welfare maximising society is to choose min $\{TC_{P1}, E(TC_{T1})\}$. The variables on which the choice depends are:

i) the damage done by the pest (D);
ii) the probability of invasion (P_E);
iii) the relative cost of prevention (A);
iv) the relative cost of treatment (T); and
v) the price elasticity of domestic supply.

4. A NUMERICAL ILLUSTRATION

4.1 The empirical case

We now illustrate an analysis of the two policies described above. The case we discuss is that of Colorado Potato Beetle (*Leptinotarsa decemlineata*) (CPB) and food potato production in Finland. The beetle has made two larger invasions to Finland, in the summers of 1998 and 2002. More details on the CPB and Finland can be found in Tomminen (1999) or Koukkunen (1999).

The CPB is the most destructive insect defoliator of potato. It is an oligophagous species that feeds exclusively on Solanaceae, primarily on *Solanum* species (Raman and Radcliffe 1992). The beetle originates from North America and is nowadays common in Europe except for Scandinavia, Britain and Ireland. The species has become more destructive in Europe than it is in North America due to most of its predators, parasites and diseases remaining in America (Sandhall and Lindroth 1976).

The case is appropriate because ecosystem damage of invasion would probably be fairly limited. Moreover, as long as the winter exterminates all the beetles, the static approach is justifiable. Finland also has a protection system in force: certain areas have the European Union ZP –status regarding the beetle (EU 2002). These areas include Satakunta, Varsinais-Suomi, Uusimaa, Pirkanmaa, Häme, South-Eastern Finland and the Åland Islands and they represent 30-40% of total potato production in Finland. Economic evaluations have not been conducted in Finland, but in England Mumford et al. (2000) estimated the costs of treatment to be 7.5 times those of prevention.

4.2 Application

We assume a scenario in which there is a given probability of an invasion that affects the whole area, and each producer faces similar conditions. Alternative scenarios are left for future work. Table 1 presents indicative variable values to apply the model. Given these data, it is a straightforward task to calculate the costs for the two states. Consumer loss shall be presented by $B + C + D$ in terms of Figure 2, but due to lack of data regarding the supply curve producer gains have to be approximated by area $B + C – (G + I)$, i.e. additional sells at the new price less the lost sales at the old price, from which the additional production costs are subtracted.

Variable	*Symbol*	*Value*	*Source*
Cost of prevention (€/year)	A	1,000,000 €	Estimate, no data for Finland available.
Probability of invasion (%)	P_E	0.10	Estimate.
Crop damage by the pest (%)	D_i	0.15	Based on Grafius 1997 in N. America and Parkkonen 2002 in Russia.
Treatment costs (€/ha)	$p_z z_i$	200 €/ha	Grafius 1997, Raman and Radcliffe 1992. No data for Finland available.
Production costs (€/ha)	$p_x x_i$	3,000 €/ha	Based on MKL 1999.
Product producer price (€/kg)	p_S $(S=P1,T1)$	p_{P1} = 0.20 €/kg p_{T1} = 0.30 €/kg	Based on MAF 2001. Values are within recent price fluctuations.
Total production area (ha)		13,100 ha	MAF 1998.
Total production (kg/year)		288,500,000 kg	MAF 1998.

Table 1. The illustrative baseline variable values.

We also have to make some additional assumptions: i) the past figures on total production as well as on production and control costs are the profit maximising solutions; ii) the demand curve is linear over the price range considered; iii) the resulting price and quantity combination is the new market clearing equilibrium; and iv) prevention and treatment costs can be fully transferred to consumers.

Computing the costs for the two states results in the outcome presented in Table 2. In State P1 the total costs are 1,000,000 € (i.e. the cost of the protection system), whereas in State T1 the expected total costs appear to be 1,343,875 €. With these indicative figures, and under our assumptions, it would thus be reasonable to maintain the protected zone.

	PRODUCERS		*CONSUMERS*		*TOTAL*	
	Absolute	*Weighted*	*Absolute*	*Weighted*	*Absolute*	*Weighted*
State P1 costs €	0	0	1,000,000	1,000,000	1,000,000	1,000,000
State T1 costs €	-15,867,500	-1,586,750	29,306,250	2,930,625	13,438,750	1,343,875
CHOICE	*Treatment*	*Treatment*	*Protection*	*Protection*	*Protection*	*Protection*

Table 2. Strategy choice by sector. Shows both absolute (unweighted) and invasion probability weighted costs.

However, the decision depends on the sector we are dealing with. Consumers would be in favour of the protection system, as they would be imposed significant costs in the case of treatment. Producers, however, on aggregate could be better off under treatment, as they would possibly see negative costs (gains) through rising prices. In absolute terms the consumer losses are greater than the producer gains, and if both are given equal weight by the society, the protection system is the cost-minimising strategy.

4.3 Sensitivity analysis

Naturally, these total costs should be thought of merely as a starting point for sensitivity analysis. In this scenario, treatment becomes attractive if, other things equal, one of the following happens:

i) the damage done by the pest decreases to 10.2% (32% decrease);
ii) the invasion probability decreases to 7.4% (26% decrease);
iii) the cost of the protection system increases to 1,343,875 € (34% increase);
iv) the cost of treatment decreases to –60 €/ha (i.e. negative) (132% decrease); or
v) the producer price in State T1 decreases to 0.14 €/kg (53% decrease).

The last two events are unlikely, but any of the other events are fairly plausible. Let us, therefore, explore how isolated deviations in the variables affect the chosen strategy.

4.3.1 Damage and invasion probability

The effect of changes in the proportional damage done and the probability of invasion are presented in Figure 3. The diagrams present the strategy chosen at different values of damage and invasion probability, i.e. events i) and ii) above. All other values are as given in Table 1.

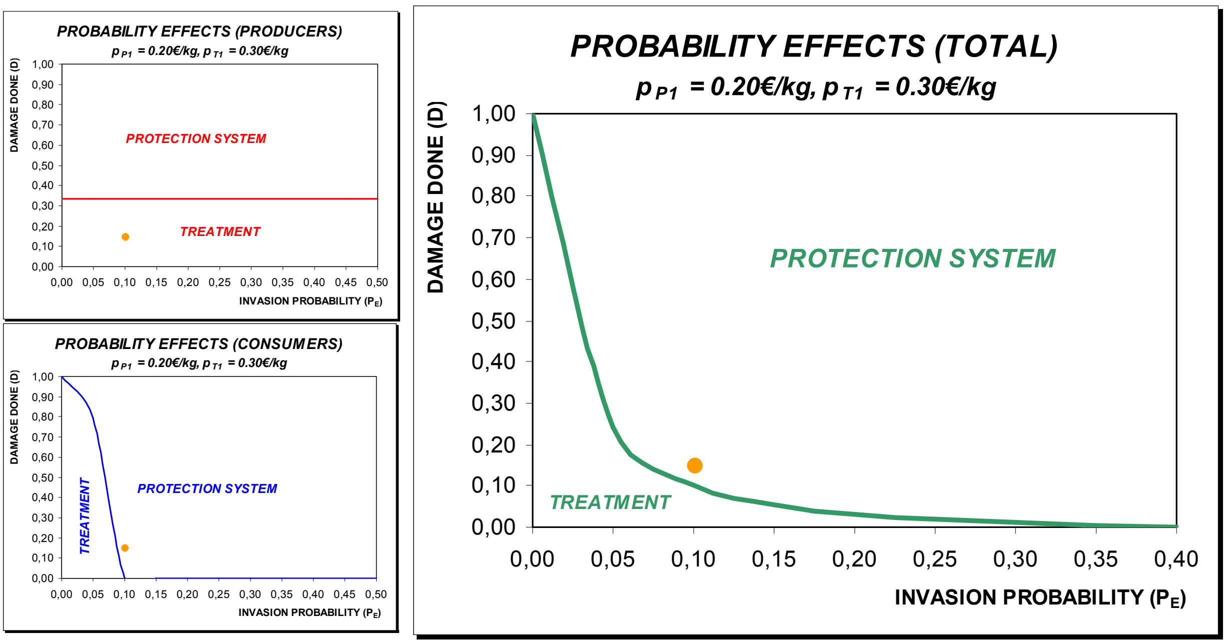

Figure 3. The choice of strategy depending on damage and invasion probability for producers and consumers and on aggregate when both groups are given equal weight. The line is the strategy boundary, i.e. it depicts the points at which both strategies impose the same total costs. Outside this line, one of the strategies (indicated) is preferred. The dot represents the baseline values.

Producers will always prefer the protection system if the damage done is over 33%, no matter what the invasion probability. On the contrary, for consumers the choice depends more on the invasion probability, and basically if it is less than 10% the consumers would prefer treatment no matter what the damage. The preferences of both groups are fairly compatible, and only combinations of high damage and low probability (or vice versa) result in conflicting preferences.

As for the aggregate choice, the right hand side of Figure 3 shows that if the damage done by the pest is high the invasion probability has to be very low to justify treatment. Further, treatment is not justified if the invasion probability is 38% or higher even if the pest can be perfectly controlled (0% damage). This is due to the resulting consumer welfare losses as well as control having a positive cost even if it is perfectly effective. Thus, only a limited range of low damage and low invasion probability justifies adopting the treatment strategy.

4.3.2 Price response

Price changes affect the distribution of costs and benefits substantially, although they do not seem to have major overall effects. It is fairly evident that producers like price increases (prefer treatment) whereas consumers dislike them (prefer prevention). On aggregate, if the post-invasion price is above about 0.35 €/kg, prevention is preferred regardless of the pre-invasion price, since at this level consumer and producer losses become large relative to the cost of the protection system.

The percentage change in price was also checked against the invasion probability and the magnitude of damage done. On aggregate, the effect is close to negligible, i.e. no matter what the price increase, the optimal strategy is little affected. However, when looked from the point of view of either of the two groups, the price increase does have a significant effect: quite intuitively the producers like and consumers dislike it.

We use an elasticity figure of –3.3, but the qualitative conclusions would have been the same if a value of –2 was used, a figure forwarded by Jalonoja and Pietola (2001) when studying the actual price behaviour of food potato markets in Finland. Furthermore, the authors found that in case of a shock, the prices are likely to remain at the new level for the duration of that storage period. Currently, prices are located fairly close to the strategy boundary and any price increases seem to favour the protection system.

If following the invasion the price remains unchanged at 0.20 €/kg, the prevention strategy is still the cost minimising choice. In such a case, treatment becomes attractive if, other things equal:

i) the damage done decreases to 12.7% (15% decrease);
ii) the probability of invasion decreases to 8.8% (12% decrease);
iii) the cost of the protection system increases to 1,128,000 € (13% increase);
iv) the cost of treatment decreases to 102 €/ha (49% decrease); or
v) the prices at both states decrease to 0.17 €/kg (15% decrease).

4.3.3 Costs of the protection system and treatment

The costs of prevention and treatment become important when the price in the invaded state remains the same as in the non-invaded state. Even fairly low changes (13% and 49%, respectively) may cause a switch in the strategy. However, if the price increases as assumed in the baseline scenario, the cost of treatment has to decrease such that it becomes negative to change the strategy, whereas the cost of the protection system would have to increase by 34%. Thus, the cost of treatment does not seem critical, but the cost of the protection system may trigger a strategy switch. This naturally depends on the baseline values, i.e. how close to the boundary we are. Unfortunately, the cost data is presently unavailable from the plant protection authorities.

5. DISCUSSION

Generally, it seems that only when a low invasion probability combines with a low level of damage is the treatment strategy more attractive than prevention. All the variables contribute somewhat to this choice, but the cost of treatment is the least critical of the five variables considered. This is because it is relatively small in absolute terms, the expected value being only 262,000 euro in the baseline scenario, compared to e.g. expected consumer losses of 2.9 million euro.

The implication is that the strategy choice cannot be impacted through actions that lower treatment costs. However, for reasons of effectiveness and cost-efficiency these costs do matter, and should naturally be minimised. This should preferably be done in such a way that all costs of control, including the environmental impacts of chemical control substances, are included in the assessment. Further, if the efficiency of control methods is increased such that damage can be reduced, and at the same time the probability of invasion is reduced through for instance regional co-operation, the case may turn out to be favourable for the treatment strategy.

The cost of prevention on the other hand influences the choice more, but at this point it is difficult to say anything precise, as no data are currently available. Furthermore, the assumption of 100% effectiveness that we made in this paper is naturally very restrictive. In reality, no system is perfectly efficient, and there will be a trade-off situation in two respects: first, more resources spent on protection means on one hand that protection becomes more preferable (as it reduces the expected probability of invasion), but on the other hand it becomes less preferable (as it gets more expensive).

The second trade-off is that the more protection there is, the more better-off the society is in the sense that the invasion is less likely, but the less well-off it is in the sense that international commerce is restricted to a greater degree. Such trade-off problems cannot be readily solved by the current approach. More accurate data on the various costs and benefits would allow also such considerations to be taken into account and a more policy-orientated report to be drafted. Actual policies dealing with such a public good problem should also take the various incentives and disincentives of the policies into account.

Let us yet emphasise that in many occasions preventative actions are a good choice of strategy. This approach is forwarded by e.g. the intergovernmental scientific advisory body established by the UN Biodiversity Convention (Perrault and Muffett 2001). Further, even if the protection system might not succeed in keeping the pest out of the country, it could still reduce the impact of the invasion. However, we argue that no strategy is automatically preferred in all circumstances. Prevention may not be optimal in cases where there are high costs of prevention compared to its benefits, or an exogenous factor (such as temperature) automatically eradicating the population at regular intervals. As has been demonstrated, it is not impossible to find plausible variable values that favour treatment in the case of CPB in Finland.

It is also possible that a protection system exists even when treatment appears to be the cost-minimising strategy. This may be due to additional benefits of protection (or additional costs of treatment) that have not been considered here. The benefits of the protection system could be for instance enhanced protection of domestic production from imports, and the costs of treatment could be environmental costs of control. The observed events of countries renouncing their protection systems suggest that either the criterion used or the relative costs and benefits of the strategies have changed.

The strategy choice also has distributional effects. Possible invasion induced price increases unambiguously lead to losses in consumer surplus, and an invasion would in reality affect the distribution of profits within the producers. Hence in the case of treatment, the distributional effects depend on whether there is an invasion or not, and on how the price responds to the invasion. The prevention strategy thus does not imply as great distributional impacts, but it too has to be funded by some means. If it is the consumers (taxpayers) that end up paying the bill, they in essence are subsidising the producers.

The overall strategy choice then depends on the relative magnitudes of the consumer and producer effects, and how these are weighted. We have assumed similar weights for both groups, but in reality the case may be that one of the groups might have a stronger lobby and thus be given more weight in decision making. A clear conclusion nonetheless is that whether there is an invasion or not is not the only issue to take into account. It is also important to consider how the market environment responds to the shock and how any counter-measures are to be financed.

Our case is presented in a static one-period framework, in which only pair-wise changes in the variables are analysed. The effect of several variables moving simultaneously is not discussed. Further, deterministic analysis results in a solution only for a given set of numbers, and as such does not provide entirely reliable results in a case where uncertainty plays a major role. Thus in later work a stochastic simulation analysis with more accurate data and more general assumptions will be conducted.

Even with the above restrictions the current approach has demonstrated the economic thinking behind the issue and highlighted various factors that should be accounted for. The basic concepts described here allow the development of more sophisticated forms of analysis.

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