CHAPTER 10

PHYTOSANITARY MEASURES UNDER UNCERTAINTY

A cost-benefit analysis of the Colorado potato beetle in Finland

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Abstract. We have undertaken a temporal cost–benefit simulation of two policies for controlling an invasive pest – the Colorado potato beetle – in the agricultural network of Finland. The policies assessed are the current policy based on a European Union (EU) protected zone (pre-emptive control) and an alternative policy of giving up the protected zone (reactive control). Besides the natural stochasticity related to agricultural production, we assume that the environmental change affects the dynamics of the problem. This change is included by means of three linear trends: i) local climatic change, ii) regional climatic and production change, and iii) biological change in the pest population. Uncertainty is incorporated through stochastic variables and a sensitivity analysis. The main result is that protection is economically viable, provided that there is some future change and a non-insignificant level of winter survival of the pest population.
Keywords: Colorado beetle; protected zone; invasive alien species; simulation analysis

INTRODUCTION

The environment, natural resources and resource-based production are all affected by invasive alien species. Changes in local climatic conditions and abrupt modifications in agricultural policies together with uncertainty related to stochastic environmental fluctuations make invasive-species policies challenging to design and implement. These changes are often exacerbated by changes in the species' characteristics. It is therefore not surprising that invasive species pose an increasing threat to animal and plant health.

Within the European Union's plant health legislation, protected zones are a regional tool available to account for differences in ecological conditions. The aim of the protected-zone policy is to eradicate and prevent the spread of quarantine organisms if encountered in the zone. Member countries can use this voluntary black-list instrument to protect their production environment against specified invasive plant pests. Related national legislation in Finland obliges individual

A.G.J.M. Oude Lansink (ed.), New Approaches to the Economics of Plant Health, 147-161

farmers to inform the authorities of any quarantine pest observations and to follow orders from the plant protection authorities regarding eradication of those pests. It also specifies penalties for not following orders and obligations and sets out the rights of producers to compensation for eradication costs as well as for the value of the lost crop.

This protection naturally comes at a cost, including the costs of surveillance, labelling, import restrictions, eradication and post-monitoring. The benefits of not having the pest may outweigh these costs, but this is not inevitable as pointed out, for instance, by Mumford (2002) and MacLeod et al. (2005). The aim of this paper is to evaluate the current policy in Finland on the Colorado potato beetle.

COLORADO POTATO BEETLE

The Colorado potato beetle, *Leptinotarsa decemlineata*, (CPB) is the most destructive insect defoliator of the potato. It is oligophagous, feeding exclusively on Solanaceae and primarily on potato. Although the beetle targets other species such as tomato, egg plant, pepper and tobacco, potato is the main host plant in Finland.

The CPB is established in North America, some Central-American countries, many Asian countries and most European countries (except for Britain, Ireland, Norway, Sweden, Finland and some Spanish and Portuguese islands) (EPPO; European Commission 2000). Its presence in Europe dates back some 80 years. It was introduced from the USA to Bordeaux in France in 1922, from where it rapidly spread throughout Europe, reaching Spain and Germany in the 1930s, Portugal and Poland in the 1940s, Bulgaria in the 1950s and Greece in the 1960s (EPPO).

The first invasion in Finland took place in 1983, but was localized and short-lived. The two main invasions were in 1998 and 2002, with the first confirmed case of winter survival observed in 2004. The time-span of the invasion data is not long, but given this dataset, it seems that the invasion pressure is increasing in both the invasion years (2002 vs. 1998) as well as in the interim years (2003-2005 vs. 1999-2001).

Most of the plots affected in both 1998 and 2002 were situated in south-eastern Finland, suggesting that the beetles had spread from either Russia or Estonia, as depicted in Figure 1. The beetle flies only short distances, but can disperse by means of wind-borne long-distance migration, which seems to be its primary mode of transport to Finland. It can also be carried over large distances in sea water, and in addition, transportation of its host plants in, for instance, trucks and trains provides a third method of dispersal (EPPO).

The CPB protected-zone area represents roughly 30 to 40 % of the total potato production in Finland, and includes Satakunta, Turku, Pirkanmaa, Uusimaa, Häme, Kymi and the Åland Islands. The actions within the protected zone and the eradication measures to be undertaken are specified in Council Directive 2000/29/EC and in Regulation 38/04 of the Finnish Ministry of Agriculture and Forestry. Although the protected zone is only for the given areas, national legislation is applied to the entire country and hence the beetle has to be eradicated wherever encountered.

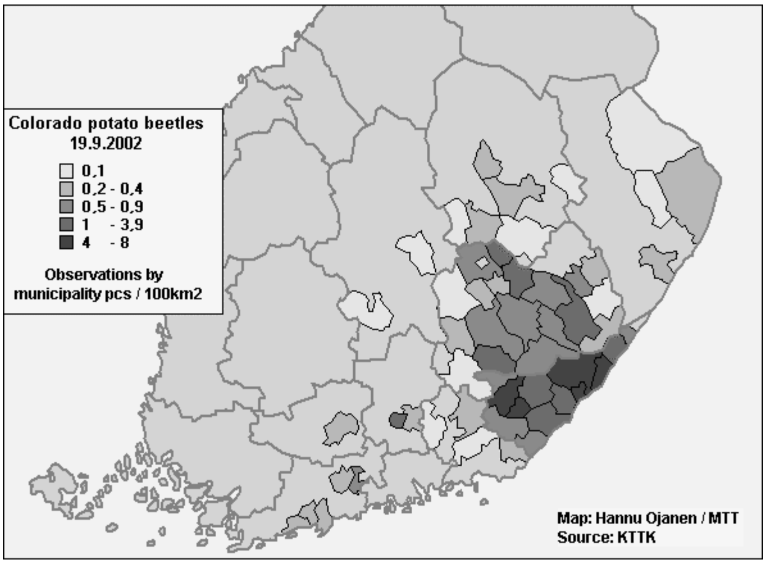

Figure 1*. The density of beetle observations in Finland in 2002.*

POLICY COSTS

Cost structure

Costs caused by invasive species may be divided into five categories. In the quantitative analysis carried out in this paper, we include potato production losses, beetle control costs and domestic market effects. In contrast, foreign-trade impacts and environmental, health and cultural costs are excluded from the analysis.

The estimation of costs is affected by natural stochasticities as well as uncertain human behaviour. The physical state of nature itself does not have the main importance in this study. The focus is rather on the economic outcome of that state of nature. Due to the economic focus, also the main uncertainty issues arise from human preferences and decision-making or from the functioning of the society and its institutions. In natural sciences *scientific, stochastic and parametric uncertainties* are important. Related to the CPB, these would translate to uncertainties and natural variation in the invasion process and parameters of the process respectively. These effects are included through stochastic simulation and sensitivity analysis. Given our focus, the main emphasis is on factors affecting human wellbeing such as *impact, policy and value uncertainties*, which here translate to uncertainties in how invasions and policies affect production, and how some unknown economic values affect the process.

The two policies analysed are the current pre-emptive control based on the European Union protected zone and an alternative policy of reactive control by individual producers. In the case of pre-emptive control, the economic cost includes the fixed and variable costs of the protection system. The fixed costs consist of maintaining the appropriate infrastructure and undertaking regular checks to monitor the pest status. The variable costs depend on the invasion magnitude and consist of authority-driven eradication of the pest and financial compensation for the producers.

In the case of a reactive control, two types of costs ensue. First, there are changes in producer surplus due to price changes, pest control costs and the value of lost production, caused by imperfect control or interim damage occurring before control application. Secondly, there may be changes in consumer surplus if the product prices increase due to reduced supply. The costs included in the quantitative analysis of the policies are summarized in Table 1 and discussed in more detail below.

***Table 1**. Costs of pre-emptive and reactive control.*

PROTECTED ZONE (PRE-EMPTIVE CONTROL)		NO PROTECTED ZONE (REACTIVE CONTROL)	
Fixed	**Variable**	**Fixed**	**Variable**
Authority fixed costs - fixed inspection points, advertising, telephone, postage, etc.	Authority variable costs: - inspection visits - area controlled and eradicated - compensation payments	No expenses	Changes in surpluses - production losses - control costs - invasion-induced price changes

Costs of pre-emptive control

The actual costs incurred in maintaining the CPB protected zone in Finland, as well as the invasion magnitudes (farms inspected, inspection visits and the number of infestations discovered) in the years 1998–2004 are reported in Table 2.

***Table 2**. Incurred costs and invasions in Finland in 1998-2004. Note:'a' denotes a partial estimate*

Year	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Total cost (€)	N/A	78,712	19,005	45,747	576,371[a]	279,181	29,659
Compensation (cases)	38	11	8	2	85	130	N/A
Compensation (€)	9,340	3,110	3,100	1,850	25,264	31,090	N/A
Farms	400	140	200	200	800	500	238
Visits	500	270	200	240	1,485	773	309
Infestations	149	1	0	2	324	6	29

The fixed costs of the protected zone used in the assessment are estimated from costs incurred in the years 1999-2001. The compensation payments (a variable cost) are subtracted from these costs. The fixed cost thus derived amounts to €37,827/year, which is assumed to include 200 inspection visits per year.

As for the variable costs of protection, a simple model was built to estimate the related variables using the data in Table 2. The estimated costs are as follows: i) inspection cost € 256/visit; ii) control substance cost € 20/ha infested; and iii) eradication cost (including compensation) € 610/ha infested. The model results were then compared with the historical realizations and the model seemed to produce reasonable estimates. As we have no direct data on the hectares invaded, an assumption had to be made that an infested plot is the size of one hectare. Discussions with experts confirm that an average potato plot size of one hectare is not an unreasonable assumption.

In addition, we include the possibility that the protection system may fail in any particular year. In this case, the failed area will be added to the invasion area in the next year. In practice, this is modelled as a product of two variables. The first is the event of protection failure, which is either true or untrue – it either happens or does not happen. If it happens, it will happen in a given percentage of the area invaded in that year. In the present analysis, the failure probability that we use is 0.30, meaning that in every year there is a 30% chance that some beetles will be left unobserved. If there is a failure, then we assume that it will be on 20 % of the invaded area. Thus, protection fails annually on average on 6 % of the invaded area.

In addition, a trend which will increase both of these parameters over time is included in the analysis. This is not a separate trend as such, but is included in all other trends. This is because increasing winter survival, increasing invasion pressure and increasing pesticide resistance (the three trends analysed) all imply that maintaining the protection system will become more difficult, which is then captured in our analysis through increasing failure probability and area.

Costs of reactive control

If the beetle is not eradicated as a part of the protection policy and the producers have to apply control, there will be reactive control costs. These consist of both the cost of the chemical control substances as well as the cost of applying them. The CPB is known not only for its powers of destruction, but also for its ability to rapidly develop resistance to insecticides. For instance, in Russia, Poland and Estonia, the CPB seems to be highly resistant to common pesticides.

The estimates of US chemical-control costs vary widely and have been reported to be US$ 40-$410/ha in Michigan in 1991 (Grafius 1997) and about US$ 300-$700/ha on Long Island due to higher resistance (Raman and Radcliffe 1992). There are no cost estimates available for Europe and, thus, in this analysis, we have applied a non-stochastic figure of € 100/ha for the current analysis. The figure is lower than the costs in the US due to, for instance, a lower level of pesticide resistance in northern Europe. On the other hand, the figure is higher than the cost of € 20/ha used in estimating the costs of the protection system. This is for two reasons. First, the protection system cost does not include work input (which is included in eradication cost category), and secondly, the government agency may have a better knowledge and bargaining power and thus lower-priced control substances than private producers.

Beetle-related variables

Crop damages
The CPB reduces tuber yield of potatoes indirectly by reducing the leaf area, hence decreasing the area available for photosynthesis. The relationship between photosynthetic leaf area reduction and yield loss is not straightforward, but in general reduced leaf area leads to a decreased yield. The relationship is affected, for instance, by how much the leaf area is reduced and at what stage of plant development that is done. The temperature affects the feeding rate of the CPB positively, and also potato types differ in the degree of resistance and damage suffered.

Detailed quantitative descriptions of the beetle's destructiveness in Europe are lacking. EPPO states that in some EPPO countries the yield losses are up to 50 % of the yield. In badly infested areas of Russia, the losses have been reported to be 20 to 70 % of the yield (Parkkonen 2002). The state-wide yield losses in Michigan, USA, are on average 12 % of the yield, although they could be up to 21 % in seriously affected areas (Grafius 1997). These figures may be slightly higher in Europe because most of the beetle's predators, parasites and diseases have remained in America.

Crop damages are modelled as a simple percentage reduction in the yield. Thus, within the area invaded the statistical mean yield is reduced by a given percentage. The estimate should be based on the damages that incur when we have adapted (in the short term) to the presence of the beetle. In a cost–benefit analysis carried out in England (Mumford et al. 2000), it was assumed that when controlled the beetle would impose no damage whatsoever, which we do not find likely. We therefore use a mean of 10 % of the crop for damages by the beetle, and allow this to vary stochastically. The maximum damage is 0.40 and the minimum is zero. In at least 5 % of the iterations the crop damage is zero, and in 5 % of the iterations it is greater than 0.22. The distribution is truncated so that values less than zero are assigned the value zero.

Invasion probability and magnitude
Invasions are modelled as a product of two variables. The first is the invasion event which is either true or untrue with a given probability. We use the figure 0.33, i.e., there will be an invasion on average every three years. If the invasion is true, i.e., if it happens, it will be of a given size. We use a mean of 400 ha, roughly based on the estimated invasion magnitude in the year 2002. The maximum is 935 ha and the minimum is zero. In 5 % of the iterations, the size is below 170 ha and in 5 % it is above 630 ha.

This magnitude is important in two respects. First, in calculating the cost of the protection system, it is the area in which the authorities need to undertake eradication and pay compensation. Secondly, in calculating the costs of reactive control, it is the area on which the beetle produces crop losses, has to be controlled and begins its spread from. Additionally, the invasion magnitude determines the number of inspection visits, so that their number is four times the invasion magnitude, based on past data on the number of infestations and the number of inspection visits. This relationship does not imply causality either way.

Winter survival

The CPB avoids freezing temperatures by digging into the soil to hibernate and by entering a period of diapause, both of which increase its cold tolerance. Its ability for winter survival in Finland is not certain. In the Ukraine, mortality during hibernation has averaged 30 %, but could be up to 83 % (EPPO). In addition to winter temperature, if the summer is too cold, there is no opportunity for proper development. Even a mild winter can then exterminate the population. In Russia, it has been estimated that the requirement for a full generation developing (required for establishment) is at least 60 days of temperature being over +15ºC and winter temperature not falling below –8ºC (Vlasova, cited in EPPO). Given the recent experiences in Estonia, Russia and Finland, these conclusions may need to be reviewed.

Winter survival in the model affects the spread of the beetle in reactive control, where the protection system is abandoned and coexistence with the beetle becomes reality. It also affects the survival of the population under the protection system when protection has failed in some area. The analysis assumes that in these instances some proportion of the beetle population (or rather, of the area invaded) survives the winter and adds to the invasion area in the following year. The analysis uses a value of 30 % for winter survival. The maximum value is 0.87 and the minimum is zero. In 5 % of the iterations the value is below 0.07 and in 5 % of the iterations it is above 0.53. To anticipate the results, it turns out that this variable is extremely important, and perhaps one for which reducing the uncertainty regarding its true value would be valuable.

Spread variables

In addition to new invasions and the winter survival of the existing populations, the spread of the beetle determines the extent to which the beetle will be present in the country in the event of giving up the protection system. If not controlled, the offspring population of a single CPB pair may become very large. If authority-driven protection is not undertaken (i.e. in reactive control), we assume that there will be some spread already in the first summer. In the case of pre-emptive control, it is assumed that coordinated actions can curb any further spread. In other words, the controlled area is always somewhat smaller under a coordinated authority-driven protected zone than under a control situation which is based on the actions of individual producers. In the latter case, the area controlled is the initial year spread times the initial invasion magnitude. In this analysis, the mean of initial year spread is 1.5. What this means is that if the initial invasion size is 400 ha, then under reactive control the area invaded during the first summer will be 600 ha, while under pre-emptive control it will be 400 ha. The distribution of the variable is restricted to be greater than or equal to 1 and the maximum value is 2.5. In 5 % of the iterations, the value is below 1.13, and in 5 % of the iterations it is above 1.87.

We compare the costs of pre-emptive control with two alternative spread scenarios of reactive control – the first with a logistic spread and the other with a linear spread.

Scenario 1 of reactive control assumes logistic spread. Put simply, the area invaded in year *t+1* is area invaded in year *t* times the spread variable. In reality, also new invasions, winter survival and the extent of the invasion in year *t* affect the spread. The mean of the spread parameter is 1.8 in the analysis. The distribution of the variable is restricted to be greater than or equal to 1 and the maximum value is 4.41. The variance of the variable is assumed to be fairly large. In at least 5 % of the iterations the value is 1, and in 5 % of the iterations it is above 2.84.

Scenario 2 of reactive control assumes linear spread. This means that the beetle will spread to a given area every year, regardless of the area it currently occupies. This area is always non-negative and assumed to be on average the same size as the original invasion, i.e., 400 ha with the maximum size being 860 ha. Ninety percent of the iteration values are located between 235 ha and 564 ha. In addition to stochasticity, the linear-spread area is affected by stochastic winter survival.

LOCAL CHANGE

A further component in the analysis is local change. This materializes through changes in the mean variable values governing the dynamics of the system over time. Three trends are studied, all at three different levels: i) no change; ii) slow change; and iii) rapid change. There are no data describing the dynamics, rather we simulate alternative future scenarios and evaluate subsequent realisations.

Trend 1: Local climatic change (population winter survival)

Through climatic change and changes in the beetle's winter tolerance, it is possible that the winter survival of the beetle population improves (Knight and Wimshurst 2005; Walker and Steffen 1997). In the simulation, the change materializes through increases in the percentage share of those who survive the winter. The winter survival variable is created with a linear trend in the deterministic mean of the variable, but in the analysis, stochastic variation is allowed around this mean. We assume that, in slow change, winter survival increases in 50 years from 30 % to about 45 %. In rapid change, the change is from 30 % to about 60 %.

Trend 2: Regional climatic change (invasion pressure)

Due to regional climatic change, increased trade, modified production practices and northward advancement of the permanent beetle population, it is to be expected that invasions will become more frequent. In the simulations, the invasion probability as well as the average size of an invasion increases over time. We assume that in 50 years the average size of an invasion increases from about 400 ha to about 600 ha in slow change and to about 800 ha in rapid change. The annual invasion probability increases from about 33 % to about 50 % in slow change and to about 65 % in rapid change.

Trend 3: Increasing pesticide resistance
The beetle is capable of quickly developing resistance to different pesticides. Thus, the effectiveness of pesticides decreases and the costs increase over time. In the analysis, the impact of increasing pesticide resistance functions through increasing costs of reactive control as well as the control substance component of the variable costs of protection. We assume that the variable costs of protection increase from € 20/ha to about € 40/ha in slow change and to about € 50/ha in rapid change. In reactive control, the costs increase from € 100/ha to about € 200/ha in slow change and to about € 250/ha in rapid change.

EX-ANTE SIMULATION ANALYSIS

The planning horizon in the ex-ante simulation is 50 years. In this period, invasion events take place randomly. The length of the analysed period is chosen to demonstrate the impact of changes, giving them sufficient time to materialize. The analysis is conducted for 300,000 iterations in order to have a sufficient representation of various variable combinations. We have computed the present values of the policies using a discount rate of 2 %.

Table 3 depicts the number of iterations (cases) in which one of the policies imposes lower costs than the other. For instance, in the case where all trends are slow, in 93.6 % of the iterations pre-emptive control imposes lower costs than reactive control. In other words, in 93.6 % of different realizations of future, pre-emptive control produces positive net benefits.

***Table 3**. Cases (%) where the one policy imposes lower costs than the other policy*

Cases %	Scenario	Pre-emptive control	Reactive control
No trend	Scenario 1	37.5 %	62.5 %
	Scenario 2	47.3 %	52.7 %
Slow trend	Scenario 1	93.6 %	6.4 %
	Scenario 2	67.6 %	32.4 %
Rapid trend	Scenario 1	100.0 %	0.0 %
	Scenario 2	93.1 %	6.9 %

When all trends are off, reactive control is the least-cost policy choice in the majority of cases (62.5 % under Scenario 1 and 52.7 % under Scenario 2). Similarly, when all trends are either slow or rapid, pre-emptive control is the least-cost policy choice in the majority of cases (93.6 % and 100.0 % under Scenario 1 and 67.6 % and 93.1 % under Scenario 2).

The trends thus enhance the profitability of protection. Whenever there is some anticipated change, pre-emptive control is the cost-minimizing strategy in 68-100 % of the cases. This result can also be looked at from the other perspective. Assuming a risk-neutral society and either no change in the future or certain 100 % winter mortality, it would be economically sensible to abandon the protection system. Under such assumptions reactive control would be the least-cost policy choice in 53-63 % of the possible realizations of future.

In all cases, the mean and median costs are very close to each other, indicating that the distribution of costs is fairly balanced. The differences in present value mean cost estimates under pre-emptive control and the two scenarios of reactive control are not very large in the context of no change (€ 8.3, € 8.0 and € 8.3 million, respectively) and to some extent under slow change (€ 13.1, € 17.3 and € 13.7 million, respectively). In the case of rapid change, the differences become larger (€ 18.9, € 40.0 and € 22.0 million, respectively).

The trends unambiguously increase the mean, minimum and maximum costs of both strategies, but increase the costs of reactive control relatively more. This is also evident from looking at the number of cases where pre-emptive control is cheaper in Table 3. There we already noticed that pre-emptive control becomes more preferred the more change there is. This is because with the increasing trends the pest is able to spread to larger areas and survive the winters better, and becomes more expensive to control. Finally, if there is no winter survival, costs are unambiguously lower with reactive control than with pre-emptive control.

As for the variability of the cost estimates, it is remarkable how the present value of costs varies from the minimum cost of Scenario 1 under no change of less than € 0.9 million (or less than € 0.4 million with no winter survival) to the maximum cost of Scenario 1 under rapid change of nearly € 121 million. The highest possible estimate is thus over 140 times greater than the lowest estimate.

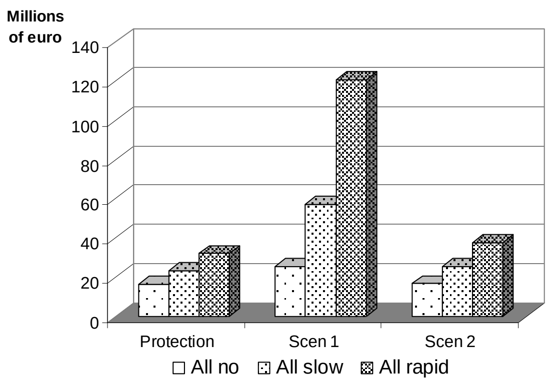

Figure 2. *Maximum present-value costs of protection and reactive control (Scenarios 1 and 2).*

This result can also be seen by looking at the maximum costs of the policies, as depicted in Figure 2. The maximum costs under rapid change in Scenario 1 can be very much higher than the maximum costs associated with pre-emptive control. Hence, if we are fairly certain that Scenario 1 is the more adequate description of the likely spread of the CPB, then should we choose to abandon protection, the risk from doing so would be very high indeed. However, if we consider Scenario 2 to be a more truthful description (or if we think that there will be no change in the future), there is not so much difference in the risk associated with the two policy options.

Another way to look at the results is to compute the benefit:cost ratios (BCRs) by dividing the benefits of the protection system (i.e. avoided reactive-control costs) by the costs of the protection system (Table 4). BCR denotes *by how much* one of the policies is more economical than the other. Any ratio below 1 implies that protection is more expensive than reactive control, and for instance the mean ratio of 1.32 for slow change under Scenario 1 means that giving up pre-emptive control would on average be 1.32 times more expensive than continuing with it.

Table 4*. The BCRs of each strategy and scenario*

B:C RATIOS		**Scenario 1**	**Scenario 2**
NO CHANGE	Min. | Mean | Max.	0.30 | 0.96 | 2.40	0.39 | 1.00 | 1.90
SLOW CHANGE	Min. | Mean | Max.	0.54 | 1.32 | 3.77	0.57 | 1.06 | 1.75
RAPID CHANGE	Min. | Mean | Max.	0.86 | 2.12 | 7.04	0.67 | 1.17 | 1.90

The minimum BCRs are systematically below 1. Hence, protection cannot be automatically regarded as a dominant least-cost strategy. On the other hand, the maximum BCRs are systematically greater than 1, and therefore by a similar argument reactive control cannot be regarded as a dominant least-cost strategy. Interpretation of results is further complicated by the fact the mean BCRs are at a range of 0.96-2.12, depending on the scenario and the level of change. Hence, the mean BCRs are fairly close to 1 and on either side of it, indicating that the variable values that have been used are such that it cannot be established for certain which policy is the more economical choice.

However, again the trends strengthen the viability of the protection system. The more we expect the climate and the pest to change, the more economical the investment in the protection system becomes. The mean BCRs can be compared to the BCR of 7.5 estimated by Mumford et al. (2000) for the British CPB protected zone.

At an extreme, the protection system is about three times more expensive than reactive control (BCR of 0.30 under Scenario 1 with no change). At the other extreme, reactive control is about seven times more expensive than protection (BCR of 7.04 under Scenario 1 with rapid change). These results again raise the same arguments as those mentioned when the maximum costs of the policies were discussed. Somewhat more interesting is the fact the BCR under Scenario 2 is fairly robust and hardly affected by the level of change, implying that the spread of the beetle is not promoted by change as much under Scenario 2 as is the case under Scenario 1. This is largely due to the fact that spread of the beetle is much more modest under Scenario 2 than under Scenario 1 and, hence, the potential damages are also lower.

Figure 3 plots the cumulative density functions of net benefits under different levels of change in Scenario 1 (panel on the left) and Scenario 2 (panel on the right). The points marked with dashed lines represent the probabilities at which the net benefits of the protection system (cost of reactive control less the cost of pre-

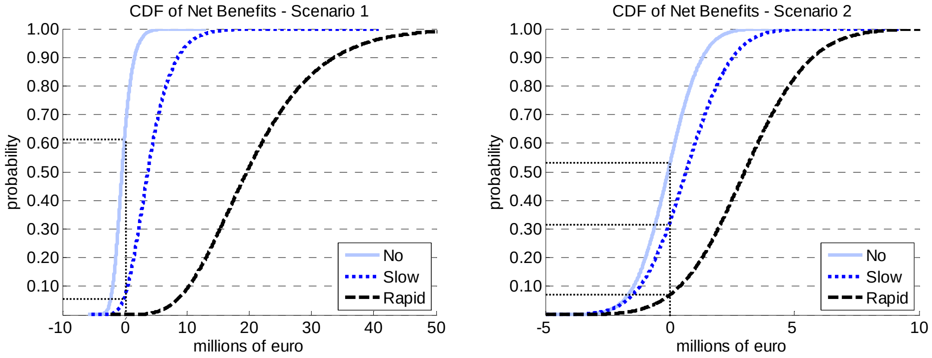

Figure 3*. Cumulative distribution of net benefits of protection in Scenario 1 and Scenario 2*

emptive control) are positive under the two scenarios when subjected to different levels of change. These levels are the same as the percentages reported in Table 3. Figure 3 clarifies how to take into account the level of risk we are willing to accept. For instance, under Scenario 1 there is a 50% probability that the net benefits of protection are negative (no change), less than ca. € 4 million (slow change) or less than about € 20 million (rapid change). Similar assessment can be done for all probabilities and the associated net benefits.

Winter survival

To account for uncertainty, a standard sensitivity analysis with low/high values was carried out. The variable that was found to be most influential was winter survival. Figure 4 represents the impact of different levels of winter survival on the mean BCRs. Winter survival is an important variable especially under Scenario 1, in terms of both mean costs and the mean BCR. It should be noted that, for instance, 100 % winter survival would imply that the BCR is about 30 under Scenario 1 and about 14 under Scenario 2, suggesting very high costs for giving up protection.

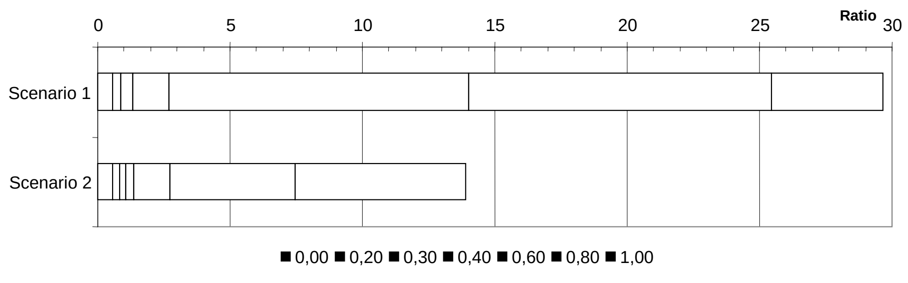

Figure 4*. The mean BCRs with different levels of winter survival*

It is evident that if the level of winter survival is even moderately greater than assumed (say, 40 % instead of 30 %), the mean results are not as ambiguous as before. With 40 % winter survival the mean BCR is greater than 1 under both scenarios, implying that protection is economical. If the level is moderately lower (say, 20 %), the mean BCRs under both scenarios are less than 1, implying that protection is more expensive than reactive control. Furthermore, slightly greater changes in the survival rate (assume, say, 60 % survival) take the mean BCR to 14 under Scenario 1 and to about 3 under Scenario 2. Hence, the importance of this variable is immense, and the implications of the analysis are very much dependent on the value of winter survival that is chosen.

The level of winter survival then naturally affects not only the BCRs but also the mean and maximum costs of the policies. For instance, with 100 % winter survival the present-value mean costs of reactive control under slow change would increase from about € 13-17 million to € 230-490 million. Similarly, the maximum costs would increase from about € 25-57 million to € 410-755 million.

Change through trends

In the basic results, all trends are simultaneously either off, slow or rapid. In the sensitivity section, all trends are set at slow. Let us now have a look at the trends separately. The four different categories of change are: i) local change; ii) regional change; iii) local and regional change; and iv) development of pesticide resistance.

On basis of the analysis, local change is the most important trend. This is consistent with the results of the sensitivity analysis, where it was found out that winter survival is the single most important variable, and it is that same variable that is increasing in local change but not in any other separate trend.

Regional change (increasing invasion pressure) plays a role in increasing the mean present value of all future costs of the policies, but not so much in the relative profitability of different policies (BCRs). The impact of local and regional change combined is similar to the impacts of local change, only with higher magnitude.

Increasing pesticide resistance plays only a minor role, both in terms of impacts on BCRs as well as in the mean present-value costs. It is plausible that the increase in control costs is relatively insignificant when compared to the other policy costs incurred. This result is consistent with the finding that the reactive-control cost is fairly insignificant and can be increased by 50 % without any real influence on the results. Whether its value has been set too low in the analysis is a point of discussion.

Although the trends themselves are plausible and likely in the future, the functional form and the magnitude of the trends are uncertain – they are subject to much scientific uncertainty and call for further research.

DISCUSSION

The Colorado potato beetle is a typical wide-spread plant pest and a nuisance in North America, Europe and to an increasing extent in Asia, affecting productivity of an important food crop. Hence, it is of general interest worldwide. In terms of the European Union, the case is of specific interest as protected zones are an EU-wide instrument that has been designed for protecting plant production. In Finland, the case is of interest because potato is a relatively important national food crop. Furthermore, the CPB provides a convenient case for studying the effects of invasions, uncertainty and local change in fairly manageable circumstances with some data on invasions available and relatively few externalities present.

Given the life-history characteristics of the CPB, there are five important factors to take into account from an economic point of view. First, the beetle has spread very rapidly across the continent, although its spread has slowed down as it has approached its ecological limits. Second, in propitious environmental conditions, its population size can increase extremely rapidly. Third, it is capable of causing significant damage to potato plants. Fourth, cold summers and winters present an obstacle to its establishment, but so far its ability to establish itself permanently in Finland has been difficult to predict. Finally, lack of natural predators and ability to develop resistance to chemical control substances make the beetle difficult and expensive to control

In this analysis, we have concentrated mainly on direct costs and benefits of protection. The general results indicate that protection is economically viable, provided that there will be some future change and non-insignificant level of winter survival of the pest population. Under the conditions and assumptions of this study, we can give up protection if we are certain that there is no future change or that winter survival stays permanently below about 20 %.

The risk associated with giving up protection is, however, much larger than that associated with protection. At the extreme, the cost of giving up protection may be over twenty times greater than continuing with it. Sensitivity analysis conducted for a range of variables reveals that winter survival is the most important variable. Other significant variables include logistic spread rate and the variable cost of protection.

The analysis above is mainly concerned with economic efficiency of the policy concentrating on direct benefits. In a complete analysis, indirect benefits and effectiveness of institutions have to be accounted for. For instance, coordinated protection system versus decentralized decision-making by numerous independent farmers may indirectly affect the outcome through development of resistance or loss of export possibilities. Similarly, social-justice issues need more attention. Imperfect markets mean that changes in domestic supply can have price effects. The economic implications of this come through changes in consumer and producer surplus, and various types of transfer mechanisms can be designed to make sure that certain agents pay for the costs. It is a task of policy makers to decide who pays the costs of the policy and who gets to take part in making the policy. Also, when in time those costs occur and decisions are made is a matter of social justice.

In the course of the analysis, a need for more information has surfaced. Besides the need for natural-science data, the following issues could be of interest when making policy decisions: i) who pays for the policies and when in time do the costs of different policies occur? ii) what are the impacts of possible nonlinearities in costs of prevention and reactive control? iii) what are the impacts of different policies on foreign trade in the form of sanctions, reputation and pesticide use? iv) how do different reactive-control alternatives rank in terms of economic efficiency? v) what are the implications from the fact that one of the policies (giving up protection) is irreversible, whereas the other one is not? vi) what are the implications from the fact that there are both professional and habitual potato producers, whose behaviours may differ from each other? vii) what are the implications from the fact that the protected zone acts as a buffer zone protecting potentially also Sweden and Norway? viii) if protection is given up at some point in the future, what is the optimal timing for such a switch? ix) what are the lessons learned from the case of the CPB for a more general assessment of invasive plant pests in Finland? and finally x) what is the role of the CPB protection policy in the wider framework of biosecurity measures given limited resources by the state? These issues should be examined in later work.

REFERENCES

EPPO, *Data sheets on quarantine pests: Leptinotarsa decemlineata*. [http://www.eppo.org/QUARANTINE/insects/Leptinotarsa_decemlineata/LPTNDE_ds.pdf]

European Commission, 2000. EC Council Directive 2000/29/EC of 8 May 2000 on Protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community. *Official Journal of the European Communities*, L 169/1 (10.7.2000), 1-112 and subsequent amendments. [http://europa.eu.int/eur-lex/pri/en/oj/dat/2000/l_169/l_16920000710en00010112.pdf]

Grafius, E., 1997. Economic impact of insecticide resistance in the Colorado potato beetle(Coleoptera: Chrysomelidae) on the Michigan potato industry. *Journal of Economic Entomology*, 90 (5), 1144-1151.

Knight, B.E.A. and Wimshurst, A.A., 2005. Impact of climate change on the geographical spread of agricultural pests, diseases and weeds. *In:* Alford, D. and Backhaus, G. eds. *Introduction and spread of invasive species:symposium, 9-11 June 2005, Berlin, Germany*. British Crop Protection Enterprises. BCPC Symposium Proceedings no. 81.

MacLeod, A., Baker, R.H.A. and Cannon, R.J.C., 2005. Costs and benefits of European Community (EC) measures against invasive alien species: current and future impacts of *Diabrotica virgifera virgifera* in England & Wales. *In:* Alford, D. and Backhaus, G. eds. *Introduction and spread of invasive species:symposium, 9-11 June 2005, Berlin, Germany*. British Crop Protection Enterprises. BCPC Symposium Proceedings no. 81.

Mumford, J., Temple, M., Quinlan, M., et al., 2000. *Economic policy evaluation of MAFF's plant health programme: report to Ministry of Agriculture Fisheries and Food*. ADAS Consulting, London.

Mumford, J.D., 2002. Economic issues related to quarantine in international trade. *European Review of Agricultural Economics*, 29 (3), 329-348.

Parkkonen, M., 2002. Venäjän pelloilla aletaan viljellä tuholaisia tappavaa perunaa. *Helsingin Sanomat* (26.09.2002), C1.

Raman, K.V. and Radcliffe, E.B., 1992. Pest aspects of potato production. Part 2. Insect pests. *In:* Harris, P.M. ed. *The potato crop: the scientific basis for improvement*. 2nd edn. Chapman & Hall, London, 477-499.

Walker, B. and Steffen, W. (eds.), 1997. *A synthesis of GCTE and related research: the terrestrial biosphere and global change: implications for natural and managed ecosystems*. The International Geosphere-Biosphere Programme, Stockholm. IGBP Science no. 1.