Optimising import phytosanitary inspection

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Abstract

World trade is a major vector of spread of quarantine plant pests. Border phytosanitary inspection is a major barrier against introductions of quarantine pests through imported commodities, although the inspection resources are limited. This thesis provides conceptual and empirical insights that may help optimise import inspection under limited resources.

The developed conceptual models analysed inspection policies under capacity constraints and in the absence of capacity constraints. The empirical models focused on finding the optimal inspection policies of propagating materials imported in the Netherlands. The results indicate that inspection effort should focus on commodities, whose inspection yields *ceteris paribus* greater marginal reduction in the expected costs of pest introduction. The results show that under binding capacity constraints, inspection of chrysanthemum cuttings in the Netherlands has a high marginal benefit, ranging from 8 to 49 euros for every marginal euro of inspection cost. The results further indicate that in the presence of fixed inspection costs, attaining the unconstrained allocation of inspection effort from the current, capacity constrained levels, is relatively inexpensive and greatly reduces costs to society. To expand current inspection capacities, the costs and likelihoods of pest introduction should be carefully estimated. Using the developed models for optimal allocation of inspection resources, the efficacy of the 'reduced checks' import inspection system in the EU was analysed. The results indicate that the expected costs of pest introduction in the EU under reduced checks could further be reduced if the economic impacts of pest introduction through various commodities are accounted for when calculating the frequencies of reduced checks. Finally, a multinomial logistic model was developed to analyse factors that determine the likelihoods of rejecting imported commodities due to phytosanitary and non-phytosanitary reasons. The results suggest that the geographical position of the exporting country, the characteristics of the importing company, the size of imported shipments, and the intended use of the commodity, among others, are significant factors based on which shipments of plant commodities can be targeted for inspection.

Inspecting agencies can considerably facilitate the design of optimal inspection frameworks for the management of import phytosanitary risks by sound data-recording procedures that enable scientific analysis and provide a solid basis for reliable and applicable results.

Keywords: quarantine pest, plant health policy, optimization, import phytosanitary inspection, 'reduced checks', optimal allocation of resources, multinomial logistic regression, the Netherlands

Preface

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Ilya
Wageningen, August 2007

Abbreviations

CCs	Chrysanthemum cuttings
EPPO	European Plant Protection Organization
FAO	Food and Agricultural Organization of the United Nations
HBAG	Hoofdbedrijfschap Agrarische Groothandel
IPPC	International Plant Protection Convention
ISPM	International Standard for Phytosanitary Measures
LEI	Dutch Agricultural Economics Institute
MINLNV	Dutch Ministry of Agriculture, Nature and Food Quality
MNL	Multinomial Logistic
MPPHCs	Minimum Proportion of Plant Health Checks
PD	Plantenziektenkundige Dienst, the Dutch Plant Protection Service
ROW	Rest of the World
SPS	Sanitary and Phytosanitary Agreement
WTO	World Trade Organization

Contents

Chapter 1 General Introduction

1.1 Introduction

Plant pests represent a serious threat for agricultural and horticultural production worldwide. A ‘pest’ is defined as any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products (IPPC, 2006a). It has been estimated that weeds currently have the highest loss potential of the key cash crops in the world- 32%, followed by animal pests (18%) and pathogens (15%) (Oerke and Dehne, 2004). Numerous pests in many countries are in fact ‘invasive’ (exotic) pests that were introduced from elsewhere. Invasive pests’ contribution to the overall pest’s damage estimate is substantial. Although the actual costs of invasive species are difficult to estimate and are rather uncertain (e.g. Eiswerth and van Kooten, 2002), available studies put the cost estimate at tens of billions of dollars in the US alone (Pimentel et al., 2005; U.S. Office of Technology Assessment, 1993) and to billions of dollars in many other countries (Pimentel et al., 2001). The International Plant Protection Convention (IPPC) defines those pests that have potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled as ‘quarantine’ pests (IPPC, 2006a). In view of potentially high economic impacts, governments and plant protection agencies around the world invest substantial resources to prevent potential introductions of quarantine pests.

In recent decades, the likelihood of unintentional introduction of exotic quarantine pests has increased dramatically. The continuing growth of international trade and tourism are the main drivers behind the spread of quarantine pests (Bright, 1999; Campbell, 2001; Mumford, 2002). Moreover, the increase in the speed of transit of commodities has increased the volumes of trade in fresh horticultural products such as fruits, vegetables, cut flowers, living plants, and propagating materials; these products are hosts for many quarantine pests. Many commodities are shipped in containers that are difficult to inspect (Mumford, 2002). Furthermore, containers themselves and other commodity packaging materials (e.g. wooden pallets) can host quarantine pests and pose thus a considerable quarantine threat (Bright, 1999; Mumford, 2002; Stanaway et al., 2003).

The developments described above put a significant pressure on responsible agencies in importing countries to provide an adequate level of protection against invasion of quarantine organisms. Border phytosanitary inspection of imported commodities is currently the major tool for prevention of possible introductions of quarantine pests. However, the resources available for inspection are usually limited. Therefore, currently in many countries, inspection of only a fraction of the imported commodity volume is possible (Hayden cited in Everett, 2000; National Research Council of the United States, 2002).

Limited resources for inspection must be allocated in the best possible way. However, it is not clear that plant protection agencies allocate their current efforts most effectively. In the

US, inspection of a random sample within a population of imported consignments is used (U.S. Department of Agriculture, 1998) and the majority of imported consignments is not inspected. However, the effectiveness of resource allocation by the US Animal and Plant Health Inspection Service was questioned (National Plant Board, 1999; U.S. General Accounting Office, 1997). Recently, in the EU the system of 'reduced checks' of certain plant products was introduced, whereby the proportion of imported consignments that is inspected has been reduced for some products of low risk of pest introduction (European Commission, 2002b). However, it is uncertain whether reduced checks provide the best possible allocation of inspection effort and minimise the costs of introductions of quarantine pests in the EU.

Decisions of quarantine agencies can be facilitated through a greater use of predictive models and risk-based models of resource allocation (National Plant Board, 1999). Predictive models could help focus inspection effort on those commodities or shipments with certain characteristics that are more likely to bring quarantine pests. Furthermore, predictive models could provide inputs for the risk-based models of resource allocation. Risk-based models could provide insights into what share of resources should be devoted to inspection of various commodities depending on relative risks of introduction of quarantine pests through these commodities. Thus far, however, both the general pest management literature and literature on the economics of plant health paid little attention to development of these models. Efforts to develop predictive models for import inspection were partial (Caton et al., 2006; Dobbs and Brodel, 2004) and existing findings cannot be easily generalized to multiple commodities. Likewise, scientific efforts to develop risk-based models of resource allocation were very limited. Some authors theoretically studied the optimal design of import inspection (Batabyal and Beladi, 2006; Batabyal et al., 2005) but provided little guidance into how the scarce resources should be allocated. Most of the existing economic studies focus on a more general problem of optimal management of invasive species, including both prevention and control measures (see Olson, 2006 for a review). The lack of empirical applications is a general limitation of this literature. It is thus difficult to see how theoretical recommendations can be implemented into every day inspection practices. Furthermore, previous studies considered the problem of optimal management of invasive species from the first-best perspective, i.e. when there is no resource constraint (e.g. Horan et al., 2002; Perrings, 2005). However, under limited resources, the first-best framework is an inadequate representation of reality (Barrett and Segerson, 1997). Therefore, a theoretical and empirical analysis of the import quarantine inspection policy under the resource constraint is highly policy relevant.

1.2 The scope and objective of the thesis

The overall objective of this thesis is to develop conceptual and quantitative insights that can help maximize the efficacy of import quarantine decision making in the presence of capacity constraints. Although the conceptual contributions of this thesis are applicable to any importing country, all the quantitative applications in this thesis are based on import inspection practices and data on phytosanitary import inspections of ornamental plant commodities in the Netherlands. The Netherlands is one of the largest importers and exporters of the ornamental cut flowers, potted plants and propagating materials in the world (AIPH/Union Fleurs, 2006). Within the European Union, the Netherlands accounts for over a 50% value share of the total third-country import of ornamental commodities (AIPH/Union Fleurs, 2006). A substantial part of these ornamental commodities, especially cut flowers, is re-exported to other EU countries (Wijnands, 2005). Therefore, the phytosanitary quality of ornamental plant commodities is very important for the Netherlands and the EU as a whole. In setting its plant health and import inspection policy, the Netherlands follows the EU plant health regulations, namely the EU Directive 2000/29 (European Council, 2000). Thus, a special attention in this thesis is devoted to current import plant health policies applied in the EU with a special focus on the system of 'reduced checks' applied for the ornamental plant commodities.

Given the scope of the thesis, the following specific objectives of the research are formulated:

1. To develop conceptual and empirical models of optimal import phytosanitary inspections. More specifically:
    a. Analyse optimal inspection policies under alternative assumptions on constraints that a given inspecting agency may have
    b. Develop a model of optimal allocation of the limited inspection capacity to minimize the expected costs of pest introduction
    c. Taking into account the costs of pest introduction for society, analyse the unconstrained inspection policies that minimize the sum of the costs of pest introduction and the inspection costs, and inspection policies that minimize the costs of pest introduction under the inspection capacity constraints
2. To empirically and theoretically analyze the optimality of the 'reduced checks' import inspection system recently introduced in the European Union
3. To investigate which factors influence the likelihood of rejecting commodities during import inspection and assess the feasibility of using predictive models in import phytosanitary decision making.

1.3 The outline of the thesis

The relation between the objectives and structure of the thesis is illustrated in Figure 1. The first objective is addressed in Chapters 2 through 4. The theoretical part of Chapter 2 analyzes the optimal inspection policy under two alternative objective functions of the inspecting agency. These are 1) minimization of the total inspection costs subject to the maximum acceptable risk constraint and 2) minimization of the total pest risk subject to the available budget constraint. The numerical application focuses on the case when the available budget is constrained. The inspecting agency's objective in this application is to minimize the total number of consignments with infested propagating materials pertaining to six different ornamental commodities imported in the Netherlands. The empirical application determines the optimal length of inspection of imported consignments depending on their size and the likelihood of infestation of every unit in a consignment.

Chapter 3 presents a conceptual model of optimal import phytosanitary inspection under the capacity (budget) constraint. Whereas the analysis in Chapter 2 focuses on the probability of pest introduction only, the pest costs in Chapter 3 are given by the expected costs of pest introduction, i.e. taking into account the probability of pest introduction and the costs if introduction occurs. Theoretical conditions for optimal allocation of the available budget are presented. The quantitative application finds the optimal inspection policy of chrysanthemum cuttings (CCs) imported in the Netherlands given the expected costs of pests species that may be introduced through CCs. Assuming that pest outbreaks do not affect the prices, the costs of pest introduction are calculated as a reduction in the revenue of producers of the affected crops in the Netherlands.

Chapter 4 provides theoretical and empirical analysis of inspection policies that minimize the total societal costs of pest introduction and the inspection costs, and of policies that minimise the expected costs of pest introduction under the inspection capacity constraint. The costs of pest introduction are modelled as welfare losses for the affected producers and consumers of susceptible crops in an importing country. As in Chapter 3, the empirical application focuses on the inspection policy of CCs in the Netherlands. However the welfare losses due to introduction of pest species through CCs are calculated using a partial equilibrium model that relaxes the assumption of Chapter 3 that pest introduction has no impact on prices.

Chapter 5 analyzes from two perspectives the EU inspection policy of 'reduced checks' with respect to imported ornamental cut flowers. First, the chapter analyses whether rates of pest interception for certain genera of cut flowers imported in the Netherlands support the application of reduced checks. Secondly, the chapter analyses whether the reduced checks system is actually an *optimal* system. Using a hypothetical example, the expected costs of pest introduction under reduced checks and under the theoretically optimal capacity-constraint models of Chapters 3 and

4 are compared. Stochastic simulations are used to explore the trade-offs arising when moving away from a theoretically optimal system of inspection.

Under binding capacity constraints, insight into factors that determine the probability of rejecting certain commodities for import due to the presence of quarantine pests could increase the efficacy of inspection. Chapter 6 fits a multinomial logistic (MNL) model to data on inspections of ornamental commodities imported in the Netherlands in the period 1998 to 2001 to investigate whether the likelihood of pest infestation or other quality defects of imported ornamental commodities can be predicted given a set of generally available explanatory variables. The generality of the MNL model is tested by applying it to data pertaining to all ornamental commodities in the dataset, to a subset of ornamental commodities and to specific ornamental commodities. The chapter discusses the importance of collecting the management data during import inspection.

Chapter 7 summarizes the key findings from the previous chapters and provides their critical discussion. The main conclusions of the thesis and policy recommendations are also presented in this chapter.

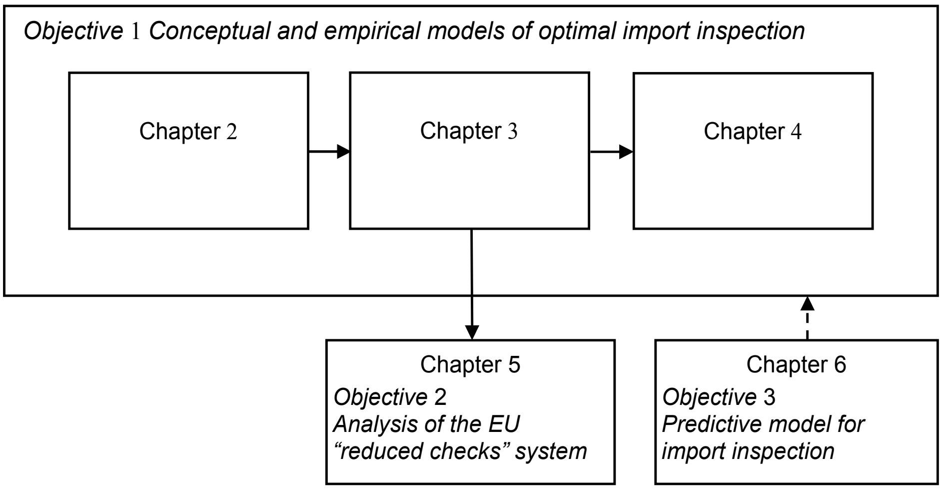

Figure 1 The objectives and structure of the thesis

Chapter 2 Designing optimal phytosanitary inspection policy: a conceptual framework and an application

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Abstract

Optimal allocation of available resources to minimise quarantine risks related to international trade is a problem facing plant protection agencies worldwide. In this paper a model of budget allocation to minimise quarantine risks is developed. Theoretical conditions that budget allocation should satisfy are derived. These conditions imply that optimal allocation of resources is achieved when the marginal pest risks are equalised across risky pathways. Furthermore, an empirical model of budget distribution is developed. In the empirical model, the protecting agency wants to minimise the expected number of infested ornamental plants imported in a given country. The model is parameterised using data on import of ornamental commodities, the associated quarantine risks and costs of import phytosanitary inspections pertaining to the Netherlands.

The results of the empirical model suggest that under specific assumptions (such as constant risk) greater risk reduction can be achieved by allocating larger funds to inspection of riskier pathways, and less or no funds to less risky pathways. The protecting agency has to trade off the risks from pathways that vary in terms of risk.

2.1 Introduction

Phytosanitary import inspection is an important component of quarantine policies worldwide. In many instances, import inspection is the only real and last barrier where exotic quarantine plant pests brought in together with imported commodities can be intercepted. The inspection capabilities of the responsible agencies are however under a constant pressure of the ever-growing volumes of importing commodities. There is evidence that in some countries the resources of the quarantine agencies are already lagging behind the increasing volumes of import (Everett, 2000; National Research Council of the United States, 2002). In addition, the broad assortment and origins of incoming consignments diversify phytosanitary risks and complicate inspection tasks of responsible agencies.

The economic rationale calls for the best use of available inspection resources, including monetary and human. More attention should therefore be paid to development of inspection policies in which scarce resources are allocated optimally and risks associated with import of various commodities are minimized. The treatment of this issue in the economic literature so far has been limited. Relevant studies focused on economics of controlling and preventing biological invasions (e.g. Barbier, 2001; Horan et al., 2002; Olson and Roy, 2002; Saphores and Shogren, 2005) which is a somewhat broader phenomenon. A most relevant study on the economics of import inspection is a recent paper of Batabyal and Beladi (2006) in which queuing theory is applied to analyse the optimal allocation of resources for inspection of cargo ships. The general feature of these studies is that, though they provide theoretical conditions for optimal resource allocation, numerical examples are lacking. As a result, it remains unclear how these theoretical conditions may be translated into practical decision-making.

This paper adds an applied focus to the problem of optimal allocation of quarantine resources. Specifically, the main question addressed in the current work is: how can available resources be allocated to inspection of imported commodities such that the phytosanitary risks associated with these imports are minimized? To answer this question, first, a theoretical model of optimal budget allocation is proposed. In this model, the decision-maker- the Quarantine Agency of an importing country- faces a problem of resource allocation to minimize quarantine risks stemming from different pathways (defined as commodity- country combinations). Based on this theoretical model, the empirical model is then developed. In this model the Agency wants to minimize the number of infested plants imported into the country. Data from the phytosanitary import inspections of ornamentals imported to the Netherlands were used to parameterise the model. The results of the optimal budget allocation are then presented. The paper concludes with a discussion.

2.2 Theoretical model

Consider a country *H* that imports *j* commodities from *i* exporting countries in period *t*. Each of the *j* commodities may host *k* quarantine pests, currently not present in *H*. The Quarantine Agency considers the presence of any of these pests inside *H* as equally (economically) unacceptable. The Agency thus has no specific aversion towards specific pest species. The latter assumption has a simplifying implication that the Agency applies the same quarantine measures to all *ij* pathways. The only phytosanitary measure applied by the Agency is the visual inspection of incoming consignments along each of the *ij* pathways. For inspection, a sample of a pre-defined size is taken from every consignment. If at least one specimen of a quarantine organism is found in a sample, the entire consignment is rejected for import. Otherwise, the consignment is freely imported.

Denote the quarantine risk associated with the *ij*th pathway in period *t* as $r_{ij}^{t} \geq 0$. (The superscript implies that risk is period specific; however, as the discussion henceforth is confined to a single period *t*, the superscript will be omitted). Assume that *r* is measured in units that the Agency deems appropriate to reflect the quarantine risk associated with imported commodities. In reality, *r* may be expressed e.g. as the expected economic costs due to pest incursion, the probability of pest establishment in *H*, the number of infested plant units or any other ‘real’ risk metric. The total import quarantine risk in period *t* is given by $R_t=\Sigma_{ij}r_{ij}$, assuming that risks from different pathways are not correlated.

The Agency realises that no inspection measures can reduce risk to zero. Hence, the Agency may impose a risk threshold below which risk is considered acceptable; consequently, commodities satisfying this threshold are imported without inspection. The Agency may choose to set the *total* risk threshold $\overline{R}$ or *individual* pathway risk threshold $\overline{r}$[1]. In the former case, total risk from all commodities should be lower than or equal to $\overline{R}$, i.e. $R_t \leq \overline{R}$; likewise, in the latter case, pathways’ risks should not exceed $\overline{r}$, i.e. $r_{ij} \leq \overline{r}$. It is however more difficult to maintain $R_t \leq \overline{R}$ than $r_{ij} \leq \overline{r}$ constraint because management efforts should change with fluctuation in the trade volumes (Bigsby, 2001). With the individual pathway constraint, management effort is constant. Henceforth we assume that the Agency imposes an individual pathway risk constraint $\overline{r}$. The inspection measures applied by the Agency are consistent with the imposed constraint; i.e., the sampling procedure is such that the acceptable level of risk is maintained.

[1] There is a third option: to minimize risks for specific pests (Bigsby, 2001); we ruled this possibility out by assuming non pest-specific risks.

Inspection and sampling are, of course, costly. To reflect this, an inspection budget $b_{ij} \geq 0$ is allocated to each pathway. As a result, the quarantine risk per pathway is a function of the allocated budget, i.e. $r_{ij}=r(b_{ij})$. Assume that $r'(b) <0$ and $r''(b)>0$, so that risk is decreasing with budget, but the marginal risk reducing-effect of an extra unit of budget is decreasing. In relation to visual inspection this implies that an extra inspection effort reduces the quarantine risk; however subsequent inspection efforts decrease risk less than proportionally reflecting the increasing difficulties in pest detection.

We can now formulate the optimization problem of the Agency. The relevant objective is to minimize the inspection costs subject to the acceptable risk constraint. The minimisation problem (model *MB*) therefore reads as:

Minimise $B = \sum_{ij} b_{ij}$ (1)

subject to $r(b_{ij}) \leq \bar{r}$ $\forall\ i,j,$

$b_{ij} \geq 0.$

Because the risk constraint may not be binding, the solution to (1) will be given by Kuhn-Tucker conditions (Chiang, 1984). The first-order conditions (FOC) to this problem are given by $\frac{1}{\varphi_{ij}} = r'(b_{ij}) < 0$ and $r'(b_{ij}) = \bar{r}$, where φ is the Lagrange multiplier associated with the *ij*th constraint. The FOCs imply that the optimal budget allocation is the one that makes individual pathway risks exactly equal to the constraint; at the same time, for pathways with initial risks strictly below $\bar{r}$, the budget should optimally be zero. Note that the Agency with unlimited budget may alternatively insure itself from all risks above $\bar{r}$ by trivially applying the same inspection procedures for all pathways, irrespective of actual r_{ij}'s. The spending of resources in this case will be clearly sub-optimal as pathways with risks strictly lower than $\bar{r}$ will be inspected.

More relevant for import quarantine decision-making is the situation when the budget is limited. Note that although the budget itself may be sufficient (because in most cases importers pay inspection fees), the complete inspection of all pathways may be unfeasible e.g. due to the lack of qualified employees or the lack of inspection premises. Thus, with limited budget *B* (in period *t*), the Agency solves the following programme (model *MR*):

Minimise $R_t = \sum_{ij} r\ (b_{ij})$ (2)

subject to $\sum_{ij} b_{ij} \leq B \qquad \forall\, i,j,$

$b_{ij} \geq 0.$

The constraint in fact should be binding in the optimum because it is always preferable to spend the budget 'a little bit more' to reduce risk marginally. Hence, the FOC is given by $r'(b_{ij}) = \lambda$ implying that in the optimum budget should be allocated such as to equalise the marginal pest risks across all pathways. The Lagrange multiplier λ is the 'shadow price' (Chiang, 1984) of the budget constraint; it shows how the total risk will decrease (because $r'(b_{ij}) < 0$) when the budget constraint is relaxed. The limited budget in this model implies that in the optimal solution not all pathways may be inspected at the level satisfying $\bar{r}$. As a result, quarantine risks from some pathways may exceed the acceptable level $\bar{r}$.

Altogether, the results of *MB* and *MR* models provide an indication of how the Agency should allocate its resources optimally. As was mentioned in the Introduction, most quarantine agencies worldwide face binding budget constraints. Hence, the empirical model in the next section is based on the *MR* model.

2.3 Empirical model

To translate a conceptual MR model into an empirical one, firstly, we need to specify a concrete objective function to be minimised – i.e. assume a specific risk function r, and secondly, establish relations between the costs of inspections (i.e. b_{ij}) and their efficacy (i.e. $r'(b)$). Obviously, for the model to yield practical insights, assumed empirical specifications should resemble the actual import inspection practice.

Given our earlier assumption that the Agency has no bias against specific pests, the relevant objective function is to minimise the expected number of infested commodity units imported into *H*. For concreteness, assume that the imported commodity is the ornamental materials for propagation (for example, cuttings or small plants for propagation; hereafter, simply 'plant') of *j* ornamental species. We thus implicitly assume that each infested plant may lead to realisation of a quarantine risk in *H* with constant and independent (of other infested plants) probability of success. Given the limited budget *B,* the objective of the Agency is to:

Minimise $E(N) = \sum_{ij} N_{ij}(b_{ij})$ (3)

subject to $\sum_{ij} b_{ij} \leq B$

$b_{ij} \geq 0$,

where $N_{ij}(b_{ij})$ is the expected number of infested plants imported along the *ij*th pathway after import inspection. Specifically, N_{ij} is given by:

$$N_{ij}(b_{ij}) = V_{ij} p_{ij} \alpha(b_{ij}), \tag{4}$$

where V_{ij} is the volume of plants imported along *ij*th pathway in period t, p_{ij} is the proportion of infestation with quarantine pests in the total population of ornamental plant j in country i and $\alpha(b_{ij})$ is the probability that inspection will fail to detect at least one infested plant in the infested consignment. The probability of inspection failure is assumed to be decreasing and convex in the inspection budget, i.e. $\alpha'(b)<0$ and $\alpha''(b)>0$. V_{ij} is defined as $\sum_{z=1}^{Z} h_z^{ij}$ where h_z^{ij} is the size of the *z*th consignment. The proportion of infestation p_{ij} is estimated according to the following formula:

$$p_{ij} = \frac{u_{ij}}{v_{ij}} p_{\text{inf}}, \tag{5}$$

where v_{ij} is the total volume of commodity imported along the *ij*th pathway in periods preceding t, u_{ij} is the total volume of consignments found infested with quarantine pests during import inspection for the same periods and p_{inf} represents the assumed percentage share of u_{ij} actually infested with quarantine pests (see section 'Data' for explanation).

The Agency may vary the intensity of visual inspection by taking larger samples hence lowering the probability $\alpha(b_{ij})$ that an infested plant remains undetected. We assume that detection probability is independent of the pest type and the type of propagation material. Statistically, the probability of detecting an infested plant in a given consignment is a function of the proportion of infestation p_{ij} and the sample size s (when s is small relative to consignment size), assuming binomial distribution of infested plants. Because the proportion of infestation is always unknown, the common convention is to assume a certain critical level of infestation p_c below which a consignment is deemed free from quarantine organisms (e.g. Couey and Chew, 1986; Kuno, 1991). The resulting sample size is a function of this threshold and the acceptable level of error α. The exact formula is given by Kuno (1991):

$$s = \frac{\ln(\alpha)}{ln(1-p_c)} \quad (6)$$

Equation 6 implies that s is decreasing in α, that is, a higher error probability is associated with smaller sample; also, s is decreasing in p_c reflecting that a smaller sample is required when the Agency is prepared to tolerate higher infestation level in a consignment. Equation 6 suggests that the pathway risk accepted by the Agency (i.e. $\bar{r}$) is a function of both α and p_c. For the purposes of the current model we assume that the Agency fixes p_c and may vary sample size to achieve lower error probability. Specifically, we assume p_c=0.005. This is a common maximum infection level required by quarantine agencies worldwide e.g. in New Zealand (Biosecurity New Zealand, 2006) and in the countries - members of the European Plant Protection Organisation (EPPO) (Anonymous, 2005). With p_c fixed, equation 6 can be solved for different α's.

Next, we relate the costs of inspection and sample size. Larger samples require more inspection time and are therefore more costly. We assume that inspection time is measured in 15 minutes intervals during which the inspector may examine a fixed number of plants (equal to the sample size). Within 30 minutes, the inspector may inspect a larger sample, and so on. His productivity is however diminishing. Data about the costs of inspection came from the Dutch Plant Protection Service (PD) that charges a fixed rate for every 15 minutes of inspection. The costs for 0-105 minutes' inspections together with corresponding error levels and sample sizes, are shown in Table 1.

Table 1Relation between sample size, error level α, inspection length and sample costs (p_c=0.005)

Inspection length, minutes	Sample size, units	α	Inspection costs ('15 minutes' fee + 'call out' fee)*, euros
0	0	1.0000	0
15	300	0.2223	61.61
30	570	0.0574	83.28
45	825	0.0160	104.95
60	1,065	0.0048	126.62
75	1,260	0.0018	148.29
90	1,434	0.0008	169.96
105	1,587	0.0004	191.63

*callout fee- 39.94 euros, '15 minutes' fee- 21.67 euros. Source: MINLNV (2004).

The chosen inspection lengths were based on presumption of the reasonable length. One might argue that the inspection lengths longer than 60 minutes are unfeasible in practice; nevertheless, for completeness, longer inspection intervals were included. The second column shows the assumed sample sizes that can be inspected within a corresponding inspection time. Note that the sample size is a concave function of the inspection time. This reflects the assumed diminishing marginal productivity of an inspector. α's are obtained by solving (6) for fixed p_c and s. Examining the relation between the last two columns one finds that α is decreasing and convex in inspection costs (consistent with our earlier assumptions about $\alpha(b_{ij})$).

2.4 Data

In the empirical model, nine pathways are considered: three countries each exporting three ornamental species (propagating materials) to the Netherlands. Countries are indexed as A, B and C for confidentiality reasons. The exact pathways are the following: country A- Chrysanthemum, Rose, and Dianthus; country B- Chrysanthemum, Dianthus and Impatiens, and country C- Chrysanthemum, Yucca and Dracaena. (Henceforth, unique pathways will be referred to by the name of the underlying ornamental species only (i.e. Rose, Yucca, Impatiens and Dracaena); for the remaining pathways a letter denoting the country index will be added to the species name, e.g. DianthusA). The chosen pathways give a representative sample of the important channels of ornamental materials for propagation imported to the Netherlands. So, for example, in 1998-2001, the six ornamental species chosen for the model accounted for more than 81% of Dutch import volume of ornamental plants and propagating materials. (The total number of imported ornamental species for the same period was approximately equal to 1,200). Chrysanthemum and Dianthus contributed with by far the largest volume shares: 66.8% and 11.6%, respectively. Remaining pathways shares' vary between 0.3% and 2.7%. The exporting countries were selected as important suppliers of respective ornamental species. For example, country A accounted for 30% of Chrysanthemum exports and 38% of Rose exports; country B supplied 18% of Dianthus and 43% of Impatiens; finally, country C exported 11% of Chrysanthemum and dominated the export of Dracaena with 84% share. At the same time, for non unique pathways (e.g. Chrysanthemum), there is a significant variation in imported volumes between exporting countries (see next paragraph). This circumstance plus the differences in historical findings of quarantine organisms (see below) were the final criteria based on which the pathways were chosen. Data on import volumes and results of import phytosanitary inspections were obtained from the database of inspection reports composed by the PD inspectors in the period 1998-2001. It should be noted that information in the database was presented at the *lot* level, with a lot typically representing a collection of imported plants or plant materials of a given species coming from a given country. A c*onsignment*, on the other hand may consist of different lots covered by a single phytosanitary certificate (IPPC, 2006a).

For the purposes of the data analyses we consider each lot in the database as a single consignment.

Table 2 presents both historical data on import volumes and findings of quarantine organisms[2] and input data for the model. Consider first historical import data. Consignment-wise, Dianthus and Dracaena were imported in largest numbers compared to other ornamental species. In terms of the average consignment size, Chrysanthemum is leading. Yet for both parameters, there is substantial intra-pathway variation. For the model, the average volume of import expected in a given period t along the ijth pathway, V_{ij}, can be obtained by a straightforward multiplication of the number of consignments and their average size. It is however unlikely that all consignments will have the same size. We chose a pragmatic approach to represent this variation in size splitting the historical distribution of consignment sizes into discrete intervals, represented by the lower 5%, 5-25%, 25-50%, 50-75%, 75-95% and upper 95% percentiles. The expected number of consignments of a specific size was thus split according to these percentiles. This transformation is not shown due to space limitations but can be obtained upon request. The important issue to keep in mind is that the increasing percentile implies a greater consignment size (i.e. lower 5% percentile gives 5% of the smallest consignments, 5-25% percentile represents 20% of consignments of larger size, etc.). For further reference, the total number of plants to be imported (calculated for average consignment sizes) is approximately 671 mln.

Data on findings of quarantine pests reveal that consignments of Dianthus have the largest relative and absolute rejection rate. (It is assumed that 1) inspection procedures applied were the same for all pathways and 2) all infested consignments were detected). Most notably, DianthusA has the highest rejection rate among all pathways, suggesting that the underlying pathway is the most risky from the quarantine perspective. The second highest rejection rate among ornamental species pertains to consignments of Chrysanthemum. Finally, consignments of Dracaena have the lowest positive rejection rate. The remaining pathways (i.e. Rose, Impatiens and Yucca) had a zero rejection rate suggesting that these are the safest pathways from a phytosanitary perspective.

The rejection rate of consignments is not sufficient to deduce the true proportion of infestation p_{ij} of a given pathway. Reliable data on the proportion of infestation can be obtained

[2] We use term ‘quarantine’ in the remainder of the paper to emphasize that the pest that caused the rejection of a particular consignment was not tolerated by the importing country. In reality consignments in the database were rejected due to both quarantine and non-quarantine pests; however, for the purposes of the numerical model we consider all cases of rejections as due to quarantine pests. This is consistent with the set-up of the model in which the Agency considers all pests as equally damaging. For an official definition of the ‘quarantine pest’ see (IPPC, 2006a).

Table 2 Data and parameter values for the model*

Parameter	Ornamental species					
	Chrysanthemum	Rose	Dianthus	Yucca	Dracaena	Impatiens
A						
Consignments imported during 1998-2001	2,375	153	2,909			
Average consignment size	703,996	62,278	56,078			
Consignments infested with a quarantine pest	6	0	60			
Expected number of consignments in the model[a]	600	125	700			
Estimated proportion of infestation p_{ij}[b]	4.97E-05	1.05E-07	3.65E-04			
B						
Consignments imported during 1998-2001	1,008		7,255			818
Average consignment size	7,743		34,318			30,023
Found infested with a quarantine pest	8		106			0
Expected number of consignments in the model[a]	150		1,815			210
Estimated proportion of infestation p_{ij}[b]	7.43E-05		2.02E-04			1.22E-7
C						
Consignments imported during 1998-2001	606			586	6,354	
Average consignment size	1,013,192			5,477	23,109	
Consignments infested with a quarantine pest	1			0	2	
Expected number of consignments in the model[a]	155			150	1,560	
Estimated proportion of infestation p_{ij}[b]	1.20E-06			9.33E-07	3.54E-05	

* 9 pathways (3 ornamental species coming from 3 countries) are represented
a) based on 2001 data
b) own estimation

only when the exact number of infested plants in every consignment found infested is counted[3]. Unfortunately, such data were not available for our model. To estimate the proportion of infestation we used the following approaches. If no consignments of the *ij*th pathway were rejected during import inspection, p_{ij} was estimated using the upper 95% confidence limit using formula $0.95 = 1-(1-p_{ij})^{v_{ij}}$ from Couey and Chew (1986), where v_{ij} is the total number of plants imported through the *ij*th pathway in 1998-2001.

2.5 Results

Prior to discussing the results of the model, it is useful to present the expected pest risks in the absence of import inspection. Recall that in our model quarantine risk is measured as the expected number of infested plants entering the importing country. Straightforward application of equation 4 yields the required estimate. Thus, the expected number of infested plants in the absence of inspection is calculated as the product of the expected volume of imported plants and the estimated proportion of infestation associated with the given pathway. Parameter α is equal to unity in this case to reflect the absence of import inspection. The resulting risk estimates for different pathways are presented in Table 3 below.

Table 3 shows that the largest number of infested plants is expected from Dianthus pathways, reflecting relatively high proportions of infestation and volumes (especially in terms of number of consignments). Large number of infested plants can be also expected from ChrysanthemumA pathway, reflecting mainly the large volume of incoming plants along this pathway. As can be expected, pathways with higher proportions of infestation and large volumes of import represent the largest quarantine threat. Pathways with estimated (very) low p_{ij} thus

Table 3 Expected number of infested plants per pathway[*1]

Country	Ornamental species					
	Chrysanthemum	Rose	Dianthus	Yucca	Dracaena	Impatiens
A	23,905	<1	21,172			
B	265		23,112			<1
C	177			<1	1,289	

[*]Calculated as the summed product of p_{ij} (Table 2) and the average consignment size in each of consignment size categories.

represent a lower quarantine risk. The total number of infested plants expected from all pathways is about 69,872. The average proportion of infestation is approximately equal to 0.0001 (69,872/ 671 mln).

[3] This is the approach adopted by e.g. Roberts et al. (1998) and Wearing et al. (2001) in the quantitative risk assessments of, respectively, fire blight and codling moth introductions via trade in fruits.

To obtain a plausible value for the constraint *B* we then ran the model for the situation that is assumed to reflect current inspection practices. Here, the Agency applies the same inspection treatment to all pathways. The inspection length is fixed at 30 minutes with an error level of approximately 5% (see Table 1). The resulting costs of inspections are obtained by multiplying the corresponding inspection tariff (i.e. 83.28 euros) with the total number of consignments imported along all 9 pathways. The costs per pathway were defined only by the number of consignments to be imported along a given pathway. The resulting total inspection cost amounted to 455,125 euros. The expected number of infested plants after application of such a uniform inspection rule is approximately equal to 4,010. The efficacy of quarantine inspection is thus about 94.3% (1 - 4,010/69,872).

It is the total inspection costs obtained in the model above (i.e. 455,125 euros) that were used as a constraint in the main optimisation model. The model should thus allocate these funds freely to minimize the expected number of infested plants imported into the country. Table 4 presents the results of the budget allocation between the pathways in the model. In Table 4 the sum of all pathway budgets equals the value of the constraint, i.e. 455,125. The budget is thus fully used. The allocation of budget to pathways is however very different. First, note that no budget is allocated for inspection of Rose, Yucca and Impatiens. This is consistent with the very small quarantine risks that they pose (see Table 3).

Table 4 Budget allocation per pathway, after minimizing risk (1000 euros)

Country	Ornamental species					
	Chrysanthemum	Rose	Dianthus	Yucca	Dracaena	Impatiens
A	85.67	-	86.30			
B	7.32		169.22			-
C	12.50			-	94.11	

Among pathways with a positive budget allocation, the largest shares of total budget are allocated for inspection of DianthusB and Dracaena. The DianthusB pathway received a large allocation because of both a high number of infested plants expected and a large number of imported consignments. The large absolute inspection costs allocated for Dracaena pathway are explained mainly by the large expected number of imported consignments; the quarantine threat posed by Dracaena is much lower than, for example, by ChrysanthemumA (see Table 3). In general, the results of budget allocation presented in Table 4 are consistent with numbers presented in Table 3. Pathways with larger expected number of infested plants *ceteris paribus* receive larger budget allocation. To see how pathways budgets are allocated, let us inspect Figure 1.

Figure 1 shows the distribution of the inspection lengths for a given pathway for consignments of different sizes within the pathway. Figure 1 indicates that budget as a function of inspection time is allocated differently not only across pathways, but also across different consignment size categories within pathways. The general trend is that larger consignments receive lengthier inspection treatment than smaller ones. Furthermore, pathways with larger expected number of infested plants *ceteris paribus* are inspected with more time. Compare again results for DianthusB and Dracaena pathways. The consignments coming along the former pathway should be inspected with more time than consignments coming along the latter. This finding reflects the difference in quarantine risks between these two pathways and supports an earlier argument that Dracaena received large absolute budget allocation mainly because of the large number of imported consignments.

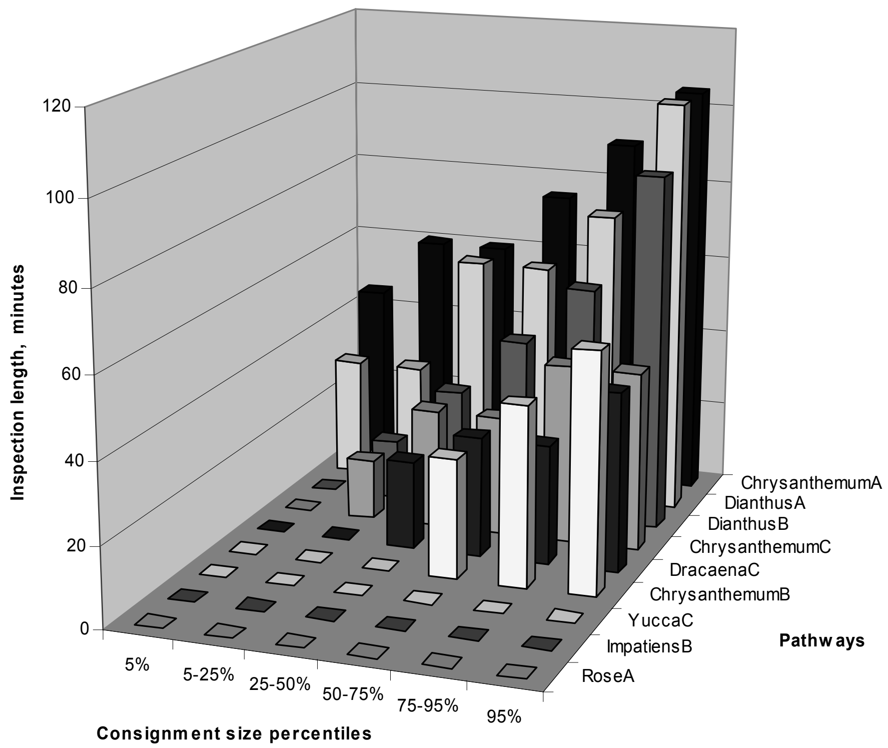

Figure 1 Distribution of inspection times across pathways and sizes groups

The expected number of imported infested plants in this model is equal to 380, suggesting that the Agency may reduce the initial risk by 99,4%. This is due to allocation of larger budgets and longer inspection times for *a priori* more risky pathways. In fact, there is a re-distribution of budget toward riskier pathways at the expense of pathways with comparatively lower risks. This explains why the reduction in the expected risk in this model is higher compared to the model in which all pathways are inspected with equal time and budget per inspection. On the other hand, some pathways (Rose, Yucca and Impatiens) remain completely uninspected implying that the Agency should bear the risk that some infested plants might be imported along these pathways.

It is worthwhile noting that obtained results remain stable when there is a change in the quarantine budget. An increase (decrease) in the total budget leads to an increase (decrease) in the average time of inspection of a pathway. The direction of budget distribution also remains consistent with observed trends: more risky pathways and larger consignments receive proportionally higher budgets. Another important result is related to the shadow price of the budget constraint. Recall from the theoretical model that the shadow price indicates the change of objective value had the constraint been changed by one euro. The shadow price in the model was equal to -0.0032, implying that the 312.5 euro increase in the total budget would lead to approximately 1 unit decrease in the expected number of infested plants. A 50% increase (decrease) in the total budget resulted in shadow prices equal to -0.00032 (-0.0198). These results are in line with the premise that import inspection has high marginal efficacy with low budgets and low efficacy with high budgets (because it is more difficult to detect a marginal infested plant).

2.6 Discussion

In this paper we presented a model of optimal allocation of budget resources to minimise import quarantine risks. The theoretical model implies that the available resources should be allocated so that the marginal pest risks are equalised across import pathways. The results of the empirical model suggest that pathways with larger expected risks *ceteris paribus* should receive a larger share of the budget and longer inspection treatment. Within pathways, larger consignments must be inspected more intensively than smaller ones. This finding reflects the implicit assumption that for a fixed proportion of infestation, larger consignments have more infested plants, and require thus more thorough inspection treatment (assuming that the probability of detecting a pest does not depend on the consignment size). The model output also suggests that some pathways with *a priori* low risks may remain completely uninspected. This finding is consistent with Horan et al. (2002, p. 1309) who noted that it is optimal to devote more resources to confront (quarantine) events that are considered more likely and to allocate few or no resources to confronting event that are considered less likely. Yet, it is obvious that the Agency should be prepared to bear some quarantine risks in this case (due to no inspections of certain pathways).

The main message from these results is that, with limited resources, the inspection of all risky pathways may not be optimal (let alone feasible). For quarantine policy-making, this implies that the Agency should focus on *ceteris paribus* riskier pathways and leave other pathways uninspected or inspected with lower effort. Presumably, this is the current practice in many countries worldwide. A possible solution to alleviate the quarantine risks remaining along unchecked pathways would be for the Agency to rely on self-protection efforts of importers of risky commodities (or other interested stakeholders).

Some reservations related to the model setup and assumptions should be mentioned. The first reservation is related with data. Quantitative data related to quarantine risks are generally scarce (Gray et al., 1998) and the proportions of infestation are very hard to estimate at the low levels that are prevalent. However, the actual application of the model developed in this paper crucially depends on the availability and quality of the quantitative estimates. The procedure to estimate the proportion of infestation - a key factor influencing the optimal allocation of resources among different pathways - in the current work was indirect, implying that the estimates of p_{ij} may be biased. This bias may be in part due to a triangular distribution used to estimate the proportion of infestation in rejected consignments. Conceivably, this distribution gives only a limited approximation of the true proportion of infestation. Given that the exact computation of actually infested plants is almost infeasible, other non-parametric distributions with more parameters (for example, discrete) could be used as possible alternatives. Data on parameters in these distributions may come from experts.

The discussion in the previous paragraph underscores the importance of the proper account of uncertainty in estimating quarantine risks associated with different pathways. Another important characteristic that the model fails to address is the variability in quarantine risks (Gray et al., 1998). The model found the optimal solution based on the premise that the proportion of infestation of a given pathway is fixed. Specifically, it was expressed as the mean of the probability distribution $f(p_{ij})$ of the proportion of infestation. As a result, in the model every consignment is assumed to carry a positive number of infested plants, which is somewhat counterintuitive. In reality one would expect a significant variation in the p_{ij} within the pathway, e.g. due to stochastic fluctuations or due to variations in the quality of plants imported from different producers in the exporting country. This variation most probably takes the form that some of the consignments are completely free from quarantine organisms (after all, most consignments successfully pass import inspection) and others are infested with varying extent. A more realistic model should take this issue into account.

These shortcomings suggest clear avenues for improvement of the presented empirical model. Overall, we believe that the presented model is a useful step towards development of more effective quarantine inspection policy.

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Chapter 3 A model of optimal import phytosanitary inspection under capacity constraint

Based on: Surkov, I.V., Oude Lansink, A.G.J.M., van Kooten, O. and van der Werf, W. A model of optimal import phytosanitary inspection under capacity constraint. *Submitted*.

Abstract

Growth and liberalization of world trade have increased risks of introduction of quarantine plant pests into importing countries. Import inspection of incoming commodities is a major tool for prevention of pest introductions related to world trade, but inspection capacities are limited. This paper develops a theoretical and an empirical model for the optimal allocation of inspection effort for phytosanitary inspection of imported commodities when the inspecting agency has a limited capacity. It is shown that the optimal allocation of inspection effort equalizes marginal costs of pest introduction across risky commodity pathways. The numerical illustration finds the optimal allocation of inspection effort of chrysanthemum cuttings imported in the Netherlands. The numerical results suggest that *ceteris paribus* greater inspection effort should be allocated to pathways whose inspection yields a greater reduction in the expected costs of pest introduction. The numerical results also suggest that import inspection has a high marginal benefit. In particular, we found that each additional euro of the inspection capacity decreases the expected costs of pest introduction from 18 to 49 euros, depending on the initial inspection capacity.

3.1 Introduction

International trade is the major vector for spread of quarantine plant pests and diseases in the world (Campbell, 2001). Quarantine pests are those pests that have potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled (IPPC, 2006a). The yearly economic costs from the introduction of quarantine pests may reach tens of billions of dollars (Pimentel et al., 2005). Border phytosanitary inspection is a key element of the quarantine policy and is often a last barrier where quarantine pests associated with imported commodities can be intercepted. Inspections usually focus on agricultural, horticultural and forestry products because these products pose the largest risks of carrying pests. Commodities belonging to these product groups have been responsible for introducing many pests in different parts of the world (Kiritani and Yamamura, 2003; National Research Council of the United States, 2002).

Inspecting agencies face ever-increasing volumes of imported commodities that require inspection. The range of commodities to be inspected is broad and expanding, especially in large importing countries. For example, the recent amendments to the EU Directive 2000/29/EC (European Council, 2000)—main document specifying the list of commodities requiring inspection upon import in the EU—implied a significant increase in the range of commodities to be inspected (European Commission, 2002a). At the same time, resources available for import inspection are limited (U.S. Office of Technology Assessment, 1993). In the U.S., resources to conduct spot checks of less than 2% of all incoming shipments at borders, air, and seaports are available (National Research Council of the United States, 2002). In New Zealand, only about 18% of more than 300,000 containers imported annually can be inspected (Hayden cited in Everett, 2000). It should be noted that although in most cases importers pay fees which should cover (at least, partially) the inspection costs, it may still be impossible to fully inspect imported commodities because of e.g. the shortage of qualified inspectors (Simberloff, 2006).

To deal with the problem of limited resources, some countries introduced reduced inspections of certain commodities. Recently, in the EU the system of ‘reduced checks’ has been introduced (European Commission, 2002b). Under this system, commodities (mainly cut flowers and fruits) from some countries may be inspected with a reduced frequency. However, the scientific underpinning for ‘reduced checks’ system is unclear. In the U.S., import inspection is generally based on random sampling from the population of arriving commodity shipments (U.S. Department of Agriculture, 1998). It was noted however that the U.S. Animal and Plant Health Inspection Service had little assurance that the limited inspection resources were allocated efficiently because of the weaknesses in the staffing model used to make such decisions (U.S. General Accounting Office, 1997, p. 7).

Allocation of resources for import inspection has received little attention in the agricultural and resource economics literature. Existing studies theoretically analyzed a related but a more general issue of the economics of biological invasions[1] (see Olson, 2006, for a review). The main finding from this literature is essentially a first-best allocation of resources, i.e. marginal costs of preventive measures should equal to the expected marginal benefits (avoided pest costs) (e.g. Horan et al. (2002), Perrings (2005)). None of the studies in this literature recognized that in reality there are binding capacity constraints that may not allow reaching first-best outcomes (Barrett and Segerson, 1997). Another limitation of this literature is that it is entirely theoretical; no empirical applications of how the resources should be allocated are presented. Batabyal et al. focused on properties of import inspections in the invasive species management (see Batabyal and Yoo, 2006, and references therein). Yet, neither likelihoods nor costs of pest introduction[2] factored in their analysis of resource allocation for import inspection, which is counterintuitive and strongly contradicts to the regulatory[3] literature. Also, these authors have not accounted for the presence of a capacity constraint in import inspection.

More attention has been paid to the use of import tariffs as a regulatory measure (see Paarlberg et al., 2005, and references therein). Authors in this literature, calculated import tariffs tailored to the risk of introduction of animal diseases, such as Foot-and-Mouth disease. McAusland and Costello (2004) analyzed the optimal policy mix of import tariffs and border inspections and concluded that when the proportion of infected commodities from a certain country is high, border inspection should be zero, replaced by a prohibitively high tariff. However, their analyses may have a limited value since it is unlikely that such tariff discrimination is allowed under the WTO rules. It is also unlikely that imported commodities have at present high rates of infestation by quarantine pests because this is against exporting countries' interests.

A general problem with the use of tariffs is that they are not a designated regulatory measure under the International Plant Protection Convention, which underpins the WTO Agreement on Application of Sanitary and Phytosanitary Measures (SPS Agreement). Thus, using the wording of Roberts (1998), tariffs may not be 'rebuttably presumed' to be in compliance with the SPS Agreement. Accordingly, there is no evidence that any importing country has actually implemented tariffs tailored to the risk of introduction of a harmful pest or

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[1] Biological (biotic) invaders are species that establish a new range in which they proliferate, spread, and persist to the detriment of the environment (Mack et al., 2000).

[2] In Batabyal and Yoo (2006, p.2), the costs of pest introduction were postulated as 'stoppage in economic activity…' due to containers being inspected. It is questionable that such a definition correctly represents the actual costs that introduction of an invasive species imposes on society.

[3] According to the ISPM No 11 'Pest Risk Analysis for Quarantine Pests' (IPPC, 2006c), the likelihood and the associated economic impacts of pest introduction are to be taken into account when the appropriate risk management options are considered.

disease. Conversely, import inspection is a recognized regulatory measure applied worldwide but has been scarcely studied in relevant literature.

This paper makes two distinctive contributions. Firstly, motivated by the above mentioned gaps in the agricultural economics literature, the paper develops a model of constrained resource allocation for quarantine inspection of imported commodities. In this model, the Agency needs to allocate its limited inspection capacity to minimize the expected costs of pest introductions associated with imported commodities. The only quarantine measure available is the import inspection of imported commodities. Thus, our model assumes that the Agency accepts all the imported commodities and only needs to determine how these commodities should be inspected given the available capacity. The second contribution of the paper is an empirical application that shows *how* the theoretical model can parameterized. Thus, we intend to fill in the gap in the literature on optimal management of invasive species which is predominantly theoretical. The empirical application in the paper focuses on finding an optimal inspection regime of chrysanthemum cuttings imported in the Netherlands.

The remainder of the paper is structured as follows. First, a conceptual model is presented, followed by the application. The final section presents discussion and conclusions.

3.2 Conceptual model of optimal capacity allocation

Consider a country H that imports j commodities from i exporting countries in period t. Henceforth, each exporting country-commodity combination is referred to as a pathway. Let q be the pathway index and assume that there are Q (q=1,…,Q) pathways. Assume that each of the Q pathways may serve as a vector for k (k=0,…,κ,…,K) quarantine pests. Assume further that $k\in[0, \kappa]$ pests are already established in H. As a result, the economic costs associated with the introduction[4] of the kth pest, d_k, may vary depending on whether this pest is already established in H or not. If the pest has already been established, then the economic costs due to new introductions have limited spillover effects for the economy or trade[5]. Introduction of a new pest in H implies both direct (e.g. losses due to damaged or destroyed crops) and indirect costs (among others, higher future production costs due to higher application of pesticides, profits' decrease due to possible trade restrictions or environmental impacts). We assume that domestic prices for crops that may be affected by pest outbreaks are world market prices and hence changes in supply due to pest outbreaks would have only marginal impacts on prices in country

[4] Essential terminology and notation used in the paper are presented in Appendix.
[5] New introductions of a pest already present in a country H add new pest populations to the existing ones. The economic impacts in this case will only concern growers that have not been involved in outbreaks related to existing pest populations. Likewise, no influence on trade is expected since trade partners should have already been aware of the presence of a pest on the territory of country H.

H. Further, we assume that d_k is given by the present value of all the costs associated with the introduction of the *k*th pest, given the distinction between pests introduced above.

The probability of introduction of a pest, p_{qk}, via the *q*th pathway is the product of its probabilities of establishment $s_k(h_k)$ and entry $u_{qk}(V_q,\gamma_{qk},\alpha_{qk})$, i.e.:

$$p_{qk} = s_k(h_k)u_{qk}(V_q,\gamma_{qk},\alpha_{qk}) \ . \qquad (1)$$

$s_k(\cdot)$ depends on the conditions for survival existing for the *k*th pest in the importing country, denoted as h_k. $u_{qk}(\cdot)$ is a non-decreasing continuous function of the volume of import along the *q*th pathway, V_q, and the proportion of import infested with the *k*th pest, γ_{qk}. Also, the probability of entry u_{qk} depends on the probability α_{qk} that an import inspection applied with respect to imported commodities fails to detect a pest. α_{qk} will be discussed in more detail below.

Following Horan et al. (2002) we assume that the probability of introduction p_{qk} via the *q*th pathway is independent of introductions via other pathways. This assumption requires that p_{qk}'s are small[6] for $\forall\ q,k$. This requirement implies that the Agency accepts imported commodities along all the pathways: otherwise, if p_{qk}'s are too high for some pathways, *H* may simply impose an import ban on commodities imported through these pathways.

In the absence of any preventive quarantine measures, the present value of economic costs of *k* pests associated with the *q*th pathway is given by the sum of their economic costs d_k weighted by the respective probabilities of introduction p_{qk}, i.e. $D_q = \sum_k p_{qk} d_k$. Thus, pathways with a larger number of pests (higher *k*), more dangerous pests (higher d_k) or higher probabilities of introduction p_{qk} *ceteris paribus* imply higher expected pest costs. The economic impact of a given pest depends largely on the biological characteristics of a pest itself (e.g. how fast it can spread). In turn, the range of pests associated with a given pathway is a result of the interplay of the commodity (how suitable is the commodity as a host for the pest) and the country (whether the conditions in an exporting country are suitable for certain pests) factors. Hence, identical commodities coming from different countries may have different pest ranges; as a result, the expected pest costs associated with these pathways may differ. Crop protection measures applied in the exporting countries influence p_{qk}; thus, pathways associated with countries with more effective crop protection measures and stricter export inspection procedures, which lower the probability of exporting an infested commodity, will have *ceteris paribus* lower p_{qk}'s and, thus, imply lower expected pest costs.

We assume that the Agency's objective is to minimize the expected pest costs from all pathways and import inspection of incoming commodities is the only available preventive

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[6] This assumption also implicitly motivates positive imports along all pathways because pest risks are small compared to benefits resulting from importing commodities by importers in country *H*.

measure. Inspection entails a visual examination of a sample taken from each arriving lot. If at least one specimen of a quarantine pest is detected in the sample, the entire lot is rejected for import; otherwise, it is freely imported. We assume that inspection is not pest-specific; hence, sampling methods are not restricted to specific pests. The probability of an inspection error - the failure to detect a pest when it is present in a lot - is denoted as $\alpha_{qk}(b_q, \Omega_{qk}) \in [0,1]$. α_{qk} is assumed to be a function of two variables: the capacity b_q available for inspection of lots coming along the qth pathway and a stochastic and unobservable variable Ω_{qk} that captures the variation in the probability of detection of different pests. Furthermore, Ω_{qk} accounts for characteristics of individual pathways that may influence the detection probability of a given pest (for example, the way commodity units are arranged in a lot, the type and way of packaging, etc).

The problem of the Agency is to choose α_{qk} as a function of the capacity b_q allocated for a given pathway. We assume that $\frac{\partial \alpha_{qk}}{\partial b_q} < 0$ and $\frac{\partial^2 \alpha_{qk}}{\partial b_q^2} \geq 0$, $\forall$ q,k. Thus, the marginal productivity of import inspection is decreasing.

Furthermore, we assume that the probability of pest entry u_{qk} is also a convex function of the inspection capacity b_q. Specifically, we need to have $\frac{\partial u_{qk}}{\partial b_q} = \frac{\partial u_{qk}}{\partial \alpha_{qk}} \frac{\partial \alpha_{qk}}{\partial b_q} < 0$ and $\frac{\partial^2 u_{qk}}{\partial b_q^2} = \frac{\partial^2 u_{qk}}{\partial \alpha_{qk}^2} \left(\frac{\partial \alpha_{qk}}{\partial b_q} \right)^2 + \frac{\partial u_{qk}}{\partial \alpha_{qk}} \frac{\partial^2 \alpha_{qk}}{\partial b_q^2} \geq 0$. These expressions have required signs, given the earlier assumptions on $\alpha_{qk}(b_q)$, as long as $\frac{\partial u_{qk}}{\partial \alpha_{qk}} > 0$ and $\frac{\partial^2 u_{qk}}{\partial \alpha_{qk}^2} \geq 0 \; \forall$ q,k. We assume that these conditions, implying that the probability of pest entry is an increasing function of the inspection error, are satisfied. Given the assumed convexity of u_{qk} in b_q and treating the probability of pest establishment s_k as constant, the probability of the kth pest introduction, p_{qk} (equation 1), is a convex function of the inspection capacity b_q, allocated for a given pathway, i.e. $\frac{\partial p_{qk}}{\partial b_q} < 0$ and $\frac{\partial^2 p_{qk}}{\partial b_q^2} \geq 0$. Therefore, the prevention efforts of the Agency have a diminishing effect on the probability of pest introduction. This is in line with a common assumption that prevention costs have diminishing effects on the probability of an environmental risk (Barrett and Segerson, 1997). In the following, we will write the probability of pest introduction as a function of the allocated inspection capacity, i.e. $p_{qk} = p_{qk}(b_q)$.

The expected pest costs associated with the qth pathway, as the function of the inspection measures, are given by $D_q(b_q) = \sum_k p_{qk}(b_q) d_k$. Thus, Agency's efforts influence the probabilities of pest introduction but not their costs[7]. The Agency wants to minimize the expected costs of pest introduction from all pathways subject to the total capacity, B:

Minimize $\sum_q D_q(b_q)$ (2)

subject to: $\sum_q b_q \leq B$, $b_q \geq 0 \quad \forall\, q$.

The relevant Lagrangean is given by:

$$L = \sum_q D_q(b_q) + \lambda(-B + \sum_q b_q), \quad (3)$$

where λ is the Lagrange multiplier, representing the shadow value of the inspection capacity constraint. The Kuhn-Tucker optimality conditions for (3) are given by:

$$\frac{\partial L}{\partial b_q} = \frac{\partial D_q(b_q)}{\partial b_q} + \lambda \geq 0 \text{ , } b_q \geq 0 \text{ and } b_q\left(\frac{\partial D_q(b_q)}{\partial b_q} + \lambda\right) = 0 \ \forall\, q \quad (4)$$

and

$$\frac{\partial L}{\partial \lambda} = -B + \sum_q b_q \leq 0 \text{ , } \lambda \geq 0 \text{ and } \lambda(-B + \sum_q b_q) = 0 \qquad \forall\, q. \quad (5)$$

The interpretation of the optimal conditions is intuitive. Condition (4) implies that the optimal pathway capacities b_q should be allocated such that the marginal pest costs are equalized across all pathways that receive a positive capacity allocation, i.e. $\frac{\partial D_q(b_q)}{\partial b_q} = -\lambda \ \forall\, q$ with $b_q>0$. Condition (5) means that the capacity constraint should be satisfied with equality in order to have $\lambda>0$. If the constraint is not satisfied with equality, then λ should be zero. This means that a (small) change in the value of the constraint B will not change the optimal solution. Note that λ shows the marginal benefit of import inspection, which is higher than its marginal cost when $B \to 0$ and lower when $B \to \infty$.

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[7] We assume that actions of the Agency do not influence the overall supply of a given commodity on the country *H* market. Agency's actions could potentially influence the supply if imports would have had high infestation rates. In reality, most commodities currently have low infestations rates. If this were otherwise, large shares of imported commodities would be detained at the border, which is not the case now. Thus, in our framework we assume that detention of some lots due to pest infestation has no noticeable impacts on the import volumes and prices.

3.3 A numerical application

We apply the conceptual model to inspections of chrysanthemum cuttings (CCs) (*Dendranthema grandiflora*) imported in the Netherlands. Cuttings are a propagation material that goes directly to the production chain; because of that, their risk of introduction and spreading of pests is greater than of for example cut flowers, which are destined for consumer market (Roozen and Cevat, 1999). In view of the high phytosanitary risk, the EU Directive 2000/29 prescribes that every lot of propagating materials should be inspected at import. Note that from a regulatory perspective, any optimization of the CCs inspection regime is not needed simply because the current policy requires that every lot of CCs to be inspected. Nonetheless, the choice of inspection of CCs for a numerical application is pertinent because, 1) the situation of a limited inspection capacity can easily be created, 2) the obtained results for any alternative inspection regimes can be compared with a benchmark case of the current policy, in which all lots should be inspected, and 3) because inspection of CCs *has been* compulsory, sufficient data for parameterization of the numerical model are available.

Inspection of CCs occupies a large share of the overall inspection workload of the Dutch Plant Protection Service (Plantenziektenkundige Dienst, PD). For example, during 1998-2001, out of more than 135,000 imported lots with ornamental products (including cut flowers, potted plants, and propagation materials) inspected at the Dutch border, approximately 5.3% (7,151) were lots of chrysanthemum cuttings. In total, lots originated from 28 countries. For numerical analysis, we selected the six largest countries with a combined share of import of approximately 95% in terms of the number of inspected lots (see Table 1). Thus, in the numerical model there are six pathways (q=6) A to F[8]. Next, we defined pest species that have been associated with these pathways. We analyzed data on pest interceptions during import inspections of CC presented in the two databases: the Annual reports of the diagnostic department of the PD for 1998-2000 (PD Diagnostic Department, 1998-2000) and the electronic database of import inspections for 1998-2001.

From these databases we selected the cases of interceptions of pests that have a quarantine status for the Netherlands[9]. The rationale for restricting our application to quarantine pests was that quarantine pests imply greater economic losses than pests not having this status[10]. According to the dataset (Table 1), three quarantine pest species were intercepted in lots coming through the selected pathways in the period 1998-2001: *Bemisia tabaci* (tobacco whitefly), *Thrips palmi* (palm thrips), and *Liriomyza huidobrensis* (serpentine leaf miner). Of these pests only *T. palmi* has the 'absent' status in the Netherlands while the other two pest species are

[8] We coded the real names of exporting countries for confidentiality.
[9] The quarantine pests for the Netherlands are listed in the EU Directive 2000/29/EC.
[10] In fact, a mere definition of the pest as 'quarantine' implies that it has an economic importance compared to a pest not having this status.

Table 1 Inspected and rejected lots of chrysanthemum cuttings, 1998-2001

Parameter	Pathway						All pathways
	A	B	C	D	E	F	
Number of imported lots	2,303	855	594	1,071	1,229	703	6,755
Average lot size (1,000 cuttings)	725	943	1,033	879	552	608	748
Lots rejected due to:							
B. tabaci	3	0	0	0	0	0	3
T. palmi	0	1	0	0	0	0	1
L. huidobrensis	0	0	0	1	1	0	2
Non quarantine pests	3	3	3	6	1	1	17
Total rejected lots	6	4	3	7	2	1	23

Source: authors' calculation based on the PD electronic data base of import phytosanitary inspections and PD Diagnostic Department (1998-2000)

currently present (and are officially controlled) in the country (EPPO, 2006). In estimating the costs of introduction we took the difference in pest statuses into account (see Section 3.2.2).

3.3.1 Empirical model

The empirical model is specified so as to represent the actual inspection activities of the PD. Currently, the PD charges importers for each minute of inspection of every imported lot of CCs. Specifying the empirical model, we adopt and extend this setting by relating the length and cost of a minute of inspection to the efficacy of inspection (the probability to detect a pest if it is present in a lot). The available inspection capacity is represented by a monetary 'budget' constraint[11]. Note that, technically, the PD has no budget constraint. As mentioned in the Introduction, it is usually other constraints, for example the lack of the qualified personnel, that render the complete inspection of all imported lots impossible. Nonetheless, imposition of a monetary constraint in the empirical model most naturally represents the problem of constrained resources[12]. Therefore, in the empirical model, in year t the Agency needs to choose the length of inspection l (l=0,…,L) of every imported lot to:

Minimize $$\sum_q \sum_k p_{qk} d_k \qquad (6)$$

[11] Henceforth, we use the word 'budget' to express inspection capacity in monetary terms. Thus the phrases 'budget constraint' and 'capacity constraint' are used interchangeably.

[12] Essentially any constraint can be represented in a monetary form. For example, the limited number of employees to conduct inspections could be expressed as the total funds to pay the direct costs (salary of inspectors). Alternatively, one could impose the same constraint in a non-monetary form by e.g. specifying the total amount of employees-hours available for inspection in a particular year.

subject to $\sum_q \sum_l b_{ql} \leq B$

$$b_{ql} = n_q \varepsilon_{ql} c_l$$

$$\sum_l \varepsilon_{ql} = 1 \qquad \forall\, q, \qquad \varepsilon_{ql} \in [0,1]$$

$$b_q \geq 0 \qquad \forall\, q,$$

with q=A, B, C, D, E, F and k=*B. tabaci*, *T. palmi*, *L. huidobrensis,*
where n_q is the expected number of lots along the qth pathway, c_l is the cost of inspection of one lot with l minutes, ε_{ql} is the proportion of lots of the qth pathway inspected with l minutes, and b_{ql} is the cost of inspection of $n_q\varepsilon_{ql}$ lots with l minutes. Probability of introduction p_{qk} as a function of inspection efforts is given by the following expression[13]:

$$p_{qk} = 0.1[1 - \prod_l (1 - \gamma_{qk}\alpha_l)^{n_q \varepsilon_{ql}}], \qquad (7)$$

where α_l is the error probability not to detect a pest associated with inspection of length l and γ_{qk} is the proportion of lots of the qth pathway infested with the kth pest. For every pathway, the probability of the kth pest introduction p_{qk} is the increasing function of the proportion of lots infested with the kth pest, γ_{qk}, the volume of import along the qth pathway, n_q, and the inspection error α_l. The probability of pest establishment after inspection is assumed equal to 0.1 for all pests in the model[14]. The assumption is based on the 'tens rule' of the literature on biological invasions (Williamson and Fitter, 1996), which states that approximately 10% of invading species establish after initial entry.

The model has to find optimal combinations of the proportion of lots ε_{ql} inspected with a given length l and the associated inspection error α_l that minimize the probability of pest introduction (7) and thus the total expected pest costs (equation 6). For simplicity we assume that α_l is not pest specific; thus, the inspection error is the same for all pests. If none of the lots along a given pathway is inspected (i.e. α_l=1 $\forall$ n_q), then inspection has no impact on the probability of pest introduction p_{qk}. Equation (7) also implies that the probability of introduction is zero, when n_q=0 or γ_{qk}=0.

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[13] Alternatively, p_{qk} could be modeled using a linear approximation, viz. $p_{qk} = 0.1[1 - \prod_l (1 - \gamma_{qk} a_l \varepsilon_{ql} n_q)]$. In this case, however, the part in square brackets may be greater than one for some values of parameters, which is unrealistic. The formula in text avoids this problem. Note that because equation 7 is a power function, it is less sensitive to changes in the parameters, e.g. inspection error α_l or the number of lots n_q, than its linear approximation.

[14] For example, Horan and Lupi (2005) used the same assumption when modelling the probability of establishment of a number of marine invasive species in the Great Lakes.

3.3.2 Data

Proportion of infested lots

Proportion of infested lots γ_{qk} is one of the key parameters in the model. Historical data (Table 1) show that at most one quarantine pest species was intercepted along pathways A, B, D and E and no quarantine pests were intercepted along pathways C and F. Thus, for most pathways, the proportion of lots infested with a particular pest cannot be calculated directly. We assume that the proportion of infested lots is approximated by its upper confidence interval γ_{qk}^{U} that can be calculated from the available data. Assuming that the proportion of infested lots γ_{qk} follows the binomial distribution with x successes (number of lots found infested with a pest) and n trials (the total number of inspected lots), the upper confidence interval for γ_{qk} is given by (Couey and Chew, 1986):

$$\sum_{x=0}^{x=s} \frac{n!}{x!(n-x)!} (\gamma_{qk}^{U})^{x} (1-\gamma_{qk}^{U})^{n-x} = 1-C, \quad (8)$$

where C is the required confidence level.

Applying equation (8) to historical data (Table 1) and taking C=0.95 we calculated $\hat{\gamma}_{qk} = \gamma_{qk}^{U}$ for all the pathways, including those with zero historical numbers of infested lots (Table 2). Estimated $\hat{\gamma}_{qk}$'s are *ceteris paribus* higher for pathways with lower historical numbers of inspected lots (e.g. pathway C and F) and pathways with a greater number of lots infested with a particular pest (pathway A, *B. tabaci*). Values in Table 2 are conservative estimates of the true proportion of infested lots γ_{qk} and may best represent an Agency that is risk-averse with respect to low numbers of inspected lots and zero historical pest interceptions associated with some pathways. In the former case, the Agency has not accumulated sufficient data to consider a particular pathway as safe. In the latter case, the Agency assumes that lots

Table 2 Parameter values of n_q[a] and γ_{qk}[b] for the numerical model

Parameter	Pathway					
	A	B	C	D	E	F
Expected number of lots n_q	600	200	155	250	300	160
Proportion of infestation $\hat{\gamma}_{qk}$:						
B. tabaci	0.00336	0.00350	0.00503	0.00279	0.00243	0.00425
T. palmi	0.00130	0.00554	0.00503	0.00279	0.00243	0.00425
L. huidobrensis	0.00130	0.00350	0.00503	0.00442	0.00385	0.00425

[a] Based on the average yearly number of lots imported during 1998-2001

[b] Estimated using the upper 95% confidence interval (equation (8)) applied to historical numbers of inspected and rejected lots (Table 1)

from all the pathways have non-zero proportions of infestations with *B. tabaci*, *T. palmi* and *L. huidobrensis*.

Table 2 also shows the number of lots in year *t* expected through every pathway, which was taken at the average yearly level of import based on 1998-2001 data.

The costs of pest introduction

We estimated the costs of pest introduction following approaches of Temple et al. (2000) and Macleod et al. (2004). The costs included only the direct costs for the growers of susceptible crops; for simplicity we ignored other possible costs of pest introduction (e.g. costs due to export bans; however these costs would be pertinent for *T. palmi* only since this pest species is not present in the Netherlands). To estimate the costs of pest introduction, we defined the range of crops that are at risk of *B. tabaci*, *L. huidobrensis* and *T. palmi* in the Netherlands. The selection of susceptible crops was based on literature (European Plant Protection Organization (EPPO) (2006); see also references to Tables 3A and 3B) and interviews with Dutch experts.

Table 3A Assumed impacts of an outbreak of *B. tabaci* and *T. palmi* on vegetable crops, %

Type of impact	Crop			
	Tomato	Cucumber	Sweet pepper	Eggplant
B. tabaci				
Yield reduction	-10[a]	-5[b]	-5[c]	-
Crop protection costs	+150[a]	+75[b]	+75[c]	-
T. palmi				
Yield reduction	-	-10[d]	-8[d]	-15[d]
Crop protection costs	-	+100[d]	+100[c]	+100[c]

[a] Assumption based on 'low numbers of whiteflies' in Morgan and Macleod (1996)
[b] Based on Temple et al. (2000)
[c] own assumption
[d] based on MacLeod and Baker (1998)

Table 3B Assumed impacts of an outbreak of *B. tabaci*, *T. palmi* and *L. huidobrensis* on susceptible ornamental crops

Time of an outbreak	Crop protection costs,%	Yield reduction,%	Probability of an outbreak
Growing	+100[a]	-5[a]	0.95[b]
Harvest	+100[a]	-50[a]	0.05 [b]

[a] Based on conversations with Dutch growers and extension specialists
[b] Temple et al. (2000)

The assumptions on the impact of an outbreak of *B. tabaci* and *T. palmi* on the affected grower of vegetable crops are summarized in Table 3A (we assume that outbreaks of *L. huidobrensis* do not affect vegetable growers). Table 3B presents similar assumptions for ornamental crops. Assumed impacts differ for vegetable and ornamental crops because stricter requirements are applied for visual quality of the latter. (The loss in the yield of ornamental crops if an outbreak occurs during harvest can be very large.) The assumed ornamental crops affected by different pests: *B. tabaci*- Begonia, Gerbera, Poinsettia; *L. huidobrensis*- cut and pot chrysanthemum. Because *T. palmi* is a highly polyphagous pest, following McLeod et al. (2004) we assumed that 10% of all ornamentals in the Netherlands is susceptible; for these ornamental crops we calculated the costs of *T. palmi* introduction based on the gross margin for an average Dutch grower of ornamental crops.

Given the assumed pest impacts, we estimated the reduction in the average gross margin for a single grower of a given crop affected by the outbreak. The gross margin was calculated as the revenue minus variable costs based on data from Applied Plant Research (2004). Further, we determined scenarios representing the sizes of outbreaks i.e. the percentage of growers affected by yearly outbreaks. We assume that the sizes of pest outbreaks on supply of affected crops are relatively small and do not affect the price (also see footnote 15). Assumed sizes of outbreaks included low (1%), medium (5%) and high (15%) percentage of growers of susceptible crops affected. The percentages of affected growers were multiplied with estimated costs of an outbreak per grower of a given crop, giving the total yearly costs of pest outbreaks for all growers of a given crop. These costs were summed over growers of different crops to give the total yearly costs of outbreaks per scenario. The estimated yearly costs of introduction for low, medium and high scenarios of outbreak were: *B. tabaci*- 1.31, 7.03 and 21.45 mln euros; *T. palmi*- 1.09, 8.73, 18.35 mln euros; *L. huidobrensis*- 0.21, 1.14 and 3.42 mln euros. The yearly costs of outbreaks for every scenario were multiplied with the probability of each scenario occurring; the assumed probabilities of scenarios were: low- 0.96, medium- 0.03 and high-0.01[15]. Finally, the expected pest costs per scenario were summed over all the scenarios to yield the total annual expected pests costs.

The estimated annual costs of introduction of *B. tabaci* and *L. huidobrensis* amounted to 1.68 and 0.277 mln euros, respectively. Because *T. palmi* is currently not present in the Netherlands, its costs of introduction were assumed to extend for 10 years. Thus, the estimated annual costs of *T. palmi* outbreaks, estimated at 1.46 mln euros, were discounted (r=5%) and

[15] This assumption is roughly based on Temple et al.'s (2000) assumptions concerning scenarios of outbreaks for *T. palmi* and *B. tabaci*. In general note that combined probability of high and medium scenarios of outbreaks of *B. tabaci* and *L. huidobrensis* is low (0.04) because impacts of these pest species are assumed to be limited by one year. For *T. palmi*, high impacts are also unlikely because this is a quarantine pest of high concern and presumably both growers and PD would apply substantial efforts to minimize the spread of this pest had it become established in the Netherlands.

summed over the 10-year horizon, yielding the total costs of introduction equal to 11.33 mln euros. For comparison, Macleod et al.'s (2004) estimate of costs of *T. palmi* establishment in England over the same time horizon ranged from 16.9 to 19.6 mln pounds. However, this estimate included export losses that were ignored in our calculations. Therefore, the estimated costs of pest introduction for *T. palmi* in the Netherlands are likely to be conservative.

Relating error probabilities of import inspection α_l, inspection lengths l and inspection costs c_l

Statistically, the probability of detecting an infested cutting in a given lot is a function of the proportion of infestation in the lot and the sample size *s* (when *s* is small relative to the lot size), assuming binomial distribution of infested cuttings. Because the proportion of infestation in a given lot *a priori* is always unknown, in quarantine practice sample size *s* is chosen so as to maintain the probability 1-α of detecting an infested unit given that the proportion of infested units in the lot is not lower than a certain detection threshold p_t (Venette et al., 2002). The relevant formula is given by Kuno (1991):

$$s = \frac{\ln(\alpha)}{ln(1-p_t)} \tag{9}$$

Equation (9) implies that a smaller sample size is associated with a higher inspection error. Sample size is also decreasing in p_t, reflecting that a smaller sample is required when the Agency is prepared to tolerate higher infestation level in a lot. For the purposes of the current model we assume that the Agency fixes p_t and may vary sample size to achieve lower error probability α. Specifically, we assume p_t=0.5%[16]. With p_t fixed, equation (9) can be solved for different α's.

Next, we relate the costs of inspection to sample size. Larger samples require more inspection time and are thus more costly. We assume that during each minute, the inspector may examine a fixed sample of 60 cuttings. The maximum length of inspection is limited by 20 minutes, assuming that inspection beyond this time is impractical. Feasible inspection lengths and the associated sample sizes are shown in the first two columns of Table 4. The third column of Table 4 gives the cost of inspection of a given length, based on the actual PD inspection tariffs. The inspection tariff includes a fixed 'base tariff' and a 'per minute' rate. The last column of Table 4 presents the error probability α_l calculated for each sample size *l* using equation (9).

[16] The same detection threshold is set in New Zealand for inspection of imported nursery stock (Biosecurity New Zealand, 2006). EPPO recommends setting detection threshold for propagating materials to less than 1% (Anonymous, 2005). In general, detection threshold may vary depending on the commodity, pest or the preferences of the Agency.

Table 4 Relation between sample size, inspection length, sample costs and error probability (p_t=0.5%)

Inspection length l, minutes	Sample size s, cuttings	Sample cost c_l ('base tariff' +'per minute' rate)[a], euros	Error probability α_l
0	0	0	1.000
1	60	46.07	0.740
2	120	47.78	0.548
3	180	49.49	0.406
4	240	51.20	0.300
5	300	52.91	0.222
6	360	54.62	0.165
…	…	…	…
20	1200	78.56	0.002

[a]'Base tariff' - 44.36 euros, 'per minute' rate- 1.71 euros. Source: (MINLNV, 2005).

3.3.3 Model scenarios

We analyzed five scenarios. In the 'Fixed allocation' scenario every imported lot must be inspected with exactly 5 minutes; this scenario is assumed to replicate the current inspection policy when every lot has to be inspected. The total costs of inspection of all lots in this scenario, equal to 88,095 euros (1,665 lots *52.91 euros/lot), serve as a budget constraint in other scenarios. In 'Optimal allocation' scenario, the model freely allocates the available budget. In 'Small budget' and 'Large budget' scenarios, the budget constraint of the 'Optimal allocation' scenario is, respectively, reduced and increased with 50% to represent the situation when the available budget is very small or very large. Finally, the 'Minimum proportion' scenario is identical to the 'Small budget' scenario except that an additional constraint requiring inspection of at least 20% of lots along every pathway with 5 minutes is imposed. This scenario is introduced to analyze the implications of imposing the minimum inspection percentage on the optimal solution.

3.4 Results

The expected costs of pest introduction in the absence of import inspections are shown in the first row of Table 5. The values are obtained by a straightforward multiplication of the probabilities of introduction (equation (7)), when α_l and ε_{ql} are both equal to one, and the associated costs of introduction d_k. *A priori*, pathway B implies the largest expected costs of pest introduction, 0.859 mln euros, because of a high estimated proportion of infested lots with *T. palmi*, the most damaging pest (see Table 2). The expected costs of pest introduction along each of the remaining pathways range from 0.657 to 0.775 mln euros. The total expected cost of pest introduction from all pathways amount to 4.38 mln euros.

Inspection of all lots with five minutes reduces the total expected pest costs to 1.32 mln euros (‘Fixed allocation’ scenario, Table 5), or 30% of their pre-inspection level. However, if the same budget is allocated optimally, the expected pest costs decrease to 0.621 mln euros, or 14% of their pre-inspection level. The largest decrease in the expected pest costs occurs for pathways B to F. This indicates that relatively more resources are allocated for inspection of lots along these pathways than along pathway A. The reason is that each of pathways B to F *ceteris paribus* has a higher proportion of infested lots or smaller number of imported lots compared to pathway A (see Table 2). Thus, for every euro of the available budget, inspection of an extra lot along pathways B to F yields a greater decrease in the probability of pest introduction, and hence the expected pest costs, than inspection of a lot of a pathway A.

Table 5 Expected costs of pest introduction (1,000 euros)

Scenario	Expected pest costs, per pathway						Total pest costs	λ
	A	B	C	D	E	F		
No inspection	775	859	720	673	693	657	4,377	-
‘Fixed allocation’	246	276	212	193	201	186	1,314	-
‘Optimal allocation’	531	20	11	19	27	13	621	-17.92
‘Small budget’	775	50	37	226	693	44	1,825	-48.67
‘Large budget’	3	3	2	2	2	2	14	0.00
‘Minimum proportion’	698	99	74	583	616	65	2,315	-32.93

The mechanism of budget allocation is illustrated in Figure 1. The height of the bar shows the share of lots of a given pathway inspected with a given length. Figure 1 shows that longer inspection times (14 and 15 minutes) are allocated to pathways with *ceteris paribus* smaller expected number of lots n_q or greater proportion of infested lots γ_{qk} (i.e. pathways C, B and F). Smaller inspection times should apply to pathways whose inspection yields smaller reduction in the expected pest costs (pathways D and E), for every euro of available budget. Finally, less than 50% of lots along pathway A should be inspected with 9 minutes while the remaining share of lots should remain uninspected. Both a positive share of uninspected lots and a shorter inspection time for inspected lots explain why the expected costs of pest introduction for pathway A are higher than for other pathways.

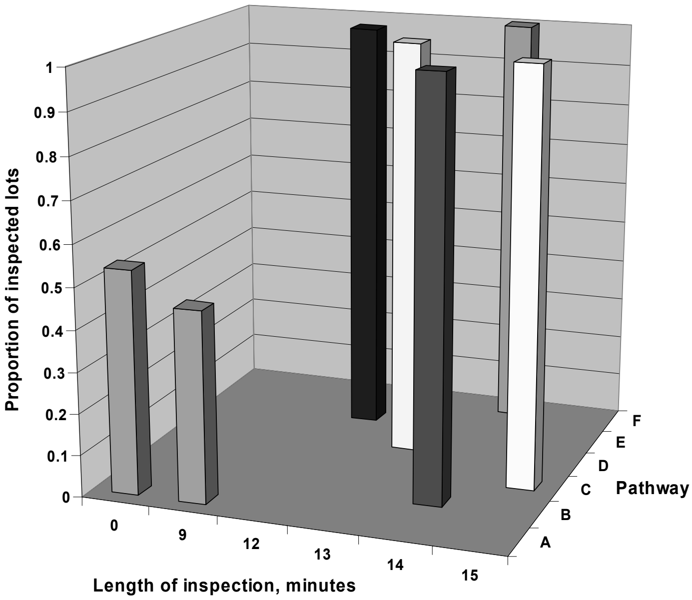

Figure 1. Allocation of inspection time, 'Optimal allocation' scenario

The results of the 'Small budget' scenario indicate that a 50% decrease in the available budget increases the total expected costs of pest introduction to 1.83 mln euros. In this scenario, lots along two pathways - A and E - remain completely uninspected. This can be seen from observing that the expected costs of pest introduction for these pathways did not change from their pre-inspection level (compare the first and fourth rows of Table 5). In this scenario, the shadow price of inspection constraint is high - λ=-48.67 euros. Thus, a one euro increase in the available budget would decrease the total expected costs of pest introduction with almost 49 euros compared to 18 euros under the 'Optimal allocation' scenario.

Conversely, under the 'Large budget' scenario, the total expected costs of pest introduction are negligible compared to their pre-inspection level because the available budget is large and all lots are inspected with 20 minutes. The shadow value of budget constraint is zero, indicating that the available budget is excessive; as a result, the Agency would be better off reducing the inspection budget.

The total expected costs of pest introduction under the 'Minimum proportion' scenario, equal to 2.32 mln euros, are higher than under the 'Small budget' scenario, because some of the resources are sub-optimally allocated for the mandatory inspection of 20% of lots with 5 minutes (Figure 2).

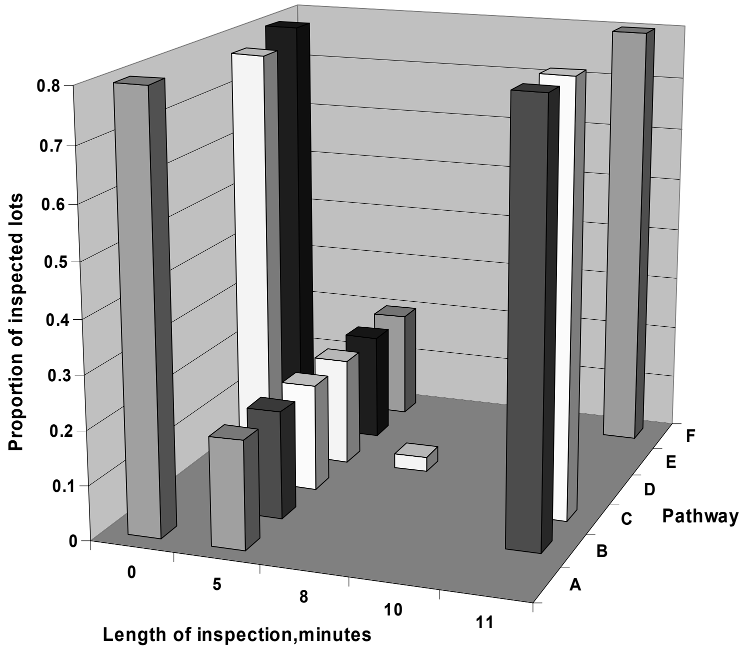

Figure 2. Allocation of inspection time, 'Minimum proportion' scenario

3.4.1 Sensitivity analyses

We conducted the sensitivity analyses on five parameters in the 'Optimal allocation' scenario. (Detailed results of the sensitivity analyses are available upon request.) An increase (decrease) in the size of the sample s (see equation (9)) that can be inspected during one minute of inspection makes inspection more (less) effective and hence decreases (increases) the probability of an inspection error (equation (9)). Thus, under a given budget, the inspection yields lower (higher) expected costs of pest introduction and shorter (longer) lengths of inspections. Even with a high, five-fold, increase in the size of a base sample, i.e. from s=60 to s=300 cuttings, the marginal benefit of inspection was large, equal to five euros for every euro of the inspection capacity. When a lower (higher) detection threshold p_t is required, this increases (decreases) the error probability of inspection for a constant sample size (equation 9). Consequently, both the length of inspection and the expected costs of pest introduction increase (decrease).

The model results appeared most sensitive to changes in the number of expected lots n_q. Even small changes in n_q significantly influenced the expected pest costs. This result is due to the sensitivity of the assumed functional form of the probability of pest introduction (equation 7) to changes in n_q (see footnote 13). Thus, a decrease (increase) in the expected number of lots along all the pathways lowers (rises) the probabilities and thus the expected costs of pest introduction and results in longer (shorter) inspection times. Furthermore, a simultaneous increase (decrease) in the expected number of lots along all pathways makes no inspection of a part or of all lots along pathway A that has the highest expected number of imported lots more (less) likely.

The numerical results are less sensitive to changes in the proportion of the infested lots, γ_{qk}. When γ_{qk} is higher (lower) then the expected costs of pest introduction and lengths of inspection increase (decrease), *ceteris paribus*. Finally, the changes in the costs of pest introduction, d_k, lead to proportional changes in the expected costs of pest introduction while leaving the inspection lengths unchanged.

3.5 Discussion and conclusions

The numerical results demonstrate that import inspection greatly reduces the expected costs of pest introduction. However, under limited inspection capacity, the optimal allocation of resources yields lower expected costs of pest introduction than when the same capacity is used to inspect all imported lots with a fixed length. Intuitively- and except for a coincidence- the optimal allocation will always be superior to the *a priori* imposed allocation when the latter is chosen without considering the expected pest costs associated with different pathways.

The results of the 'Small budget' scenario suggest that when the budget is small (or when there are large differences in the probabilities of introduction or costs of introduction between pathways), the model is likely to produce corner solutions in which some pathways are completely uninspected. From the inspection agency's perspective, such solution is undesirable because: 1) pests may still be associated with a pathway and stopping inspections forgoes an important surveillance and monitoring goals of import inspection; and 2) zero inspections of a certain pathway can make importers less diligent and lead thus to a decline of the phytosanitary quality of imported commodities along this pathway. The 'Minimum proportion' scenario addresses this problem by imposing the minimum inspection percentage of lots along all the pathways. This comes at the cost of a moderate (+26%) increase in the expected costs of pest introduction relative to the 'Small budget' scenario.

Sensitivity analyses suggest that the allocation of inspection effort remains consistent across pathways when the key parameters change in the same direction and magnitude. Our assumption that the proportion of infested lots is constant has also contributed to the consistency of budget allocation results. This is because inspection of an extra lot from a pathway with *ceteris paribus* higher proportion of infested lots always yields a greater reduction in the probability of introduction than of a pathway with lower proportion of infested lots. It may be more realistic to model the proportion of infested lots as varying between lots of e.g. various sizes (Surkov et al., 2007a). However, this would require strong assumptions and additional data that we do not possess.

The objective of this paper was to conceptually and empirically model import quarantine inspection policy under the capacity constraints. From a conceptual viewpoint, our results do not invalidate the results of earlier studies (e.g. Horan et al., 2002) but provide a more realistic approach to modelling the objectives of inspecting agencies under the binding capacity constraints. Rather than pursuing the unconstrained first-best allocation with marginal benefits equal to marginal costs, under capacity constraints, the inspecting agencies should allocate their resources so as to equalize the marginal costs of pest introduction across import pathways. The shadow value of the capacity constraint gives the marginal benefit of import inspection and allows assessing impacts of relaxation and tightening of the capacity constraints on the expected costs of pest introduction. Our numerical results suggest that import inspection of chrysanthemum cuttings in the Netherlands has high marginal benefits, ranging from 18 to 49 euros for every euro of the available inspection capacity. Marginal benefit of inspection was high even with substantial variation in assumed inspection efficacy.

Because data on probabilities and costs of pest introductions are usually scarce, the numerical applications of the model can best be suited to pathways with large volumes of import and substantial historical records of intercepted pests, as was the case in this paper. However, even if the available data are scarce, feasible assumptions (e.g. using the upper confidence intervals) can be made to represent the uncertainty associated with such parameters as the proportion of infested lots, the potential impact of a pest or the number of pests possibly associated with particular pathways. When more information on a pathway is collected, these assumptions can be supported by actual data.

A limitation of the model is that the possibility that a given pest may not actually become established in period t has not been accounted for. This may delay the costs of introduction for future periods and influence the estimate of damage d_k for kth pest in period t. To address this issue, a dynamic model of import inspection can be developed as an extension of the current model.

Although our model is static, a mechanism to incorporate reactions of private sector to changes in the stringency of import inspection is implicit in the model. If importers respond to longer inspection times by improving the phytosanitary standard of imported commodities, this should be reflected in a decrease in the number of pest interceptions during import inspection. The proportions of pest interceptions can then be re-calculated or updated in a Bayesian fashion and new budget allocation can be calculated based on an the updated data.

This paper suggests some implications for actual quarantine decision-making. First, the conceptual model presents a novel scientific framework in which the budget allocation problems of the inspecting agencies can be evaluated. The empirical framework (with the appropriate extensions) can be also used to test *ex ante* the effectiveness and costs of new import inspection policies, for example those allowed under the EU Directive 2000/29. Trade-offs in allocation of resources for import inspection between various commodities or pathways can also be analyzed. The framework can also be useful for other interested stakeholders (e.g. importers) to show the value and impact of import inspection. In summary, with appropriate extensions, the model presented in this paper can be useful both for researchers involved in the area of economics of import quarantine and for policy-makers seeking for tools to evaluate the efficacy of import inspection policies.

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Appendix

Terminology (IPPC, 2006a)

Pest entry- movement of a pest into an area where it is not yet present, or present but not widely distributed and being officially controlled

Pest establishment- perpetuation, for the foreseeable future, of a pest within an area after entry

Pest introduction- the entry of a pest resulting in its establishment

Consignment- a quantity of plants, plant products and/or other articles being moved from one country to another and covered, when required, by a single phytosanitary certificate (a consignment may be composed of one or more commodities or lots)

Lot- a number of units of a single commodity, identifiable by its homogeneity of composition, origin etc., forming part of a consignment

Notation

i = index of exporting countries $(i=1,\dots,I)$

j= index of commodities $(j=1,\dots,J)$

k= index of pests $(k=1,\dots,K)$

q= index of pathways, $(q=1,\dots,Q)$

V_q= volume of import along the qth pathway

d_k= present value of economic costs associated with introduction of the kth pest

γ_{qk}= the proportion of import volume V_q infested with the kth pest

α_{qk}= the probability that visual inspection of the lot following along the qth pathway fails to detect the kth pest

h_k= conditions for survival of the kth pest in the importing country

u_{qk}= the probability of introduction of the kth pest via qth pathway

s_k= the probability of establishment of the kth pest after introduction

p_{qk}= probability of introduction of the kth pest via the qth pathway

D_q= total costs of pest introduction associated with the qth pathway

b_q= budget for inspection of lots imported along the qth pathway

Chapter 4 Modelling optimal import phytosanitary inspection

Based on: Surkov, I.V., Oude Lansink, A.G.J.M., and van der Werf, W. Modelling optimal import phytosanitary inspection. *To be* s*ubmitted*.

Abstract

Growth and liberalization of world trade have dramatically increased the risks of spreading quarantine plant pests. Inspection of imported commodities plays a major role in preventing introductions of plant pests through world trade. An important policy question is whether the available resources for inspection are allocated optimally. This paper determines the optimal phytosanitary inspection policy of an imported commodity under two situations, i.e. (i) when the importing country has unlimited resources, and (ii) when the resources for inspection are constrained. The quantitative application in the paper focuses on the inspection policy of chrysanthemum cuttings imported in the Netherlands under three scenarios: the unconstrained allocation with no constraints imposed on inspection capacities, the constrained allocation when an exogenous constraint is imposed on the available inspection capacity, and a fixed inspection policy, in which every lot is assumed inspected with a fixed time. The numerical results indicate that inspection greatly reduces the expected pest costs. The results further indicate that in the presence of a fixed per unit inspection price, the unconstrained inspection policy that gives the lowest societal costs of pest introduction can be achieved at a low inspection cost. Specifically, the results show that the outcomes under the unconstrained allocation can be achieved with a 42% increase in the current inspection capacity, resulting in a 290% decrease in the expected costs of pest introduction to society, including the inspection costs. The quantitative results depend on parameters estimated, some of which are highly uncertain and warrant empirical study. In general, the developed model allows obtaining quantitative insights into the optimal levels of import inspection and trade-offs involved in optimizing phytosanitary inspection.

4.1 Introduction

Thousands of tons of commercial commodities are crossing the borders of importing countries every day. Trade has obvious economic benefits, but there are also costs associated with it. Trade has long been recognized as an important vector for spread of quarantine organisms (Bright, 1999; Jenkins, 1996; Perrings et al., 2005). Furthermore, trade has historically served as a vector of spread of biotic species that eventually became invasive and caused (and continue to cause) billions of dollars of economic damages in many countries (Pimentel et al., 2001).

Import inspection is the major barrier against introduction of quarantine plant pests and invasive species associated with world trade. Quarantine organisms are pests of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled (IPPC, 2006a).A continuing growth of world trade and generally limited resources available for inspection (National Research Council of the United States, 2002; Simberloff, 2006) put an increasing pressure on the capacities of inspecting agencies. In many countries, inspection of only a fraction of imported commodities is possible (Hayden cited in Everett, 2000; National Research Council of the United States, 2002). In this situation, it is imperative to allocate the available resources in the best possible way. Furthermore, even if the available resources are sufficient, inspecting agencies need to know whether they are allocated optimally, and how the current allocations may be improved. Insight in these issues is limited and there is only limited pertinent scientific work in this area.

Batabyal and co-workers explicitly analyzed properties of various inspection regimes in invasive species management (see Batabyal and Lee, 2006, and references therein) but offered no insights into the optimal allocation of resources for import inspection. Nor did they provide any empirical applications. Prestemon et al. (2006) in an applied paper analyzed the impacts of a pest invasion on the U.S. forest sector and of various policies to prevent it. However, their paper did not consider the optimal level of preventive measures under varying probabilities of pest invasion. A substantial literature that focused on a general analysis of prevention and control of biological invasions (Olson, 2006, for a review), has ignored the optimal allocation of resources for import inspection and lacks of empirical applications (e.g. Olson and Roy, 2002; Perrings, 2005).

Some useful theoretical and empirical insights can be gained from the literature that calculated optimal import tariffs in the presence of a risk of introducing an animal disease (Paarlberg and Lee, 1998; Wilson and Anton, 2006). However, tariffs have a limited scope for application as a quarantine measure because they are not a designated regulatory measure under the WTO Agreement on Application of Sanitary and Phytosanitary Measures (WTO, 1995). Also, there is no evidence that import tariffs have actually been applied in any importing country as a quarantine protection measure.

Surkov et al. (2007b) were the only authors who theoretically and empirically studied the optimal allocation of inspection effort under a capacity constraint. However, their paper assumed that inspection resources were limited and ignored the potential impacts of pest outbreaks on markets. The current paper extends the work of Surkov et al. by providing conceptual and empirical insights into the unconstrained allocation of inspection efforts, when the resources of the inspecting agency are unlimited, and the constrained allocation, in which resources are limited. As in Surkov et al. (2007), the empirical application focuses on finding the optimal allocation of resources for inspection of chrysanthemum cuttings (CCs) imported in the Netherlands given the estimated costs of pests that may be introduced through CCs. However, in contrast to Surkov et al. (2007), whose estimate of pest costs included only the direct costs for growers of the affected crops, in this paper the total societal costs of pest introduction in the Netherlands are estimated using a partial equilibrium model.

The paper proceeds by presenting the conceptual framework first. The empirical application is developed next. The empirical application analyses the optimal inspection policy of chrysanthemum cuttings (CCs) imported in the Netherlands, given the expected costs of pest introduction through CCs. The costs of pest introduction are calculated using a partial equilibrium model. After the empirical application, the results and sensitivity analyses are presented, followed by discussion and conclusions.

4.2 Conceptual framework

Consider a country *H*, which is a large agricultural producer, assumed to be actively involved in trade. The quarantine situation in country *H* is characterized by the pest population Z_t which represents a range of pest species permanently present in *H* in period *t*. In period *t*, *H* imports *j* commodities from *g* importing countries, which may possibly bring *k* (k=0,…,K) quarantine pest species that are currently not present in *H*. Henceforth, each commodity-exporting country combination is referred to as a pathway; we assume that there are *Q* pathways (q=1,…,Q). The probability of introduction of the *k*th pest through *q*th pathway, p_{qk}, is the product of the pest's probabilities of entry[1] $u_{qk}(V_q, \gamma_{qk}, b_q)$ and establishment s_k:

$$p_{qk} = u_{qk}(V_q, \gamma_{qk}, b_q)s_k \qquad (1)$$

The probability of pest establishment, s_k, varies for every pest species depending on the conditions for survival existing for the *k*th pest in the importing country. The probability of pest entry $u_{qk}(\bullet)$ is a non-decreasing continuous function of the volume of import along the *q*th pathway, V_q, and the proportion of import volume infested with the *k*th pest, γ_{qk}.

[1] Throughout the paper we use the terminology adopted in the international phytosanitary regulatory literature (IPPC, 2006a). The key definitions and notation used in the paper are presented in the Appendix.

The probability of pest entry u_{qk} is a decreasing convex function of the quarantine budget b_q allocated for the qth pathway, i.e. $\partial u_{qk}(\bullet)/\partial b_q<0$ and $\partial^2 u_{qk}(\bullet)/\partial b^2_q>0$. We assume that the budget b_q is spent by inspecting incoming lots, which is the only quarantine measure applied. Inspection entails a visual examination of a sample taken from each arriving lot via the qth pathway. If at least one specimen of a quarantine pest is detected in the sample, the entire lot is rejected for import; otherwise, it is freely imported. Inspection is imperfect and has a certain probability of missing a pest specimen in a sample, but this probability is a decreasing function of b_q.

Assume that once introduced, pest k cannot be eradicated. Then, pest introduction implies a flow of damages from pest outbreaks in period t and in all future periods. Pest damages entail direct losses to the affected producers of i susceptible crops through yield losses and increased crop protection costs. Introduction of especially damaging pest species may prompt imposition of export bans on H's exportable crops and/or imposition of tighter export quarantine measures. Furthermore, large outbreaks of the kth pest may induce a shift in supply curves of affected crops and consumers in H may also suffer losses due to increased prices of the affected crops. If country H is also a large exporter of the affected crops, pest outbreaks may have effects on the world price of these crops. Finally, some pest species may have detrimental impacts on the environment, by e.g. damaging trees and bushes.

In the period t=0, the value of future welfare losses $\overline{W_k}$ due to introduction of the kth pest can be expressed as the sum of changes in the respective producer surplus, $\overline{PS}_{kt}$, and consumer surplus, $\overline{CS}_{kt}$, in $t=0,1,\ldots,T$[2] future periods:

$$\overline{W_k} = \sum_{t=0}^{t=T} [\overline{PS_{kt}} + \overline{CS_{kt}}]\beta_t ,$$

where $\beta_t = 1\big/(1+r)^t$ is the discount factor and r is the discount rate. The surpluses $\overline{PS}_{kt}$ and $\overline{CS}_{kt}$ are expressed in monetary values. Thus, the economic impact from introduction of the kth pest represents the changes in future welfare (i.e. incremental welfare costs) of economic agents compared to situation when introduction has not occurred. The length of the period T during which the costs of pest introduction are incurred may depend on e.g. the time preferences of the inspecting agency and the characteristics of the pest species in question.

[2] By using a discrete rather than a continuous time framework we explicitly assume that the agency's planning horizon is less than infinite.

In period t, the changes in producer and consumer surplus are given by

$$\overline{PS_{kt}} = \sum_i [(-\int_a^{P_{it0}} S_{it}^0(P_{it})dP_{it} - \int_b^{P_{it1}} S_{it}^1(P_{it}, N_{kit})dP_{it})] \quad (2a)$$

and

$$\overline{CS_{kt}} = \sum_i \int_{P_{it0}}^{P_{it1}} D_{it}(P_{it})dP_{it} \; . \quad (2b)$$

In these expressions, $S^0_{it}(\bullet)$ is the period t supply function of the ith crop that would prevail had there been no pest introduction and $S^1_{it}(\bullet)$ is the supply function with pest introduction, P_{it0} and P_{it1} are the corresponding prices, $D_{it}(\bullet)$ is the period t demand function, and N_{kit} is the number of outbreaks of the kth pest on ith crop in period t arising due to the presence of pest k in H. $S_{it}(\bullet)$ and $D_{it}(\bullet)$ have the following properties:

$\partial S_{it}/\partial P_{it}>0$; $\partial S_{it}/\partial N_{kit}<0$

$\partial D_{it}/\partial P_{it}<0$.

Thus, the supply of the ith crop is a decreasing function of the number of pest outbreaks.

We consider three cases of allocation of inspection capacity: the unconstrained[3] allocation with no resource constraint; the constrained allocation with an exogenous constraint B on inspection capacity; and the case of a heuristic fixed allocation when the available inspection capacity B is equally allocated to each pathway[4], or $b_q=B/Q$.

The unconstrained allocation of inspection effort minimizes the sum of expected welfare losses from possible introduction of k pests through q pathways and the costs of inspection:

$$\sum_q \sum_k p_{qk}(b_q)\overline{W_k} + \sum_q b_q \; ,$$

with the first-order condition $-\sum_k \frac{\partial p_{qk}(b_q^*)}{\partial b_q}\overline{W_k} = 1$, $\forall$ q, with the asterisk indicating the pathway budget allocation in the absence of resource constraints. Thus, the marginal costs of inspection (right-hand side) should be equal to marginal benefits (decrease in the expected costs of pest introduction, left-hand side).

The constrained allocation of inspection effort minimizes:

[3] The name 'Unconstrained' is used for convenience to indicate only the absence of the inspection capacity constraint. The name of the scenario does not imply that other possible constraints in the society do not exist. Likewise, the name 'Constrained' implies only that the inspection capacity is limited.

[4] Assuming that the volume of import through each of the pathways is the same. If this is not the case, the budget allocation is proportional to the volume of import through each of the pathways.

$$\sum_q \sum_k p_{qk}(b_q)\overline{W_k}$$

Subject to $\sum_q b_q \leq B$.

Under the binding budget constraint, the first-order condition is given by $-\sum_k \frac{\partial p_{qk}(\widetilde{b}_q)}{\partial b_q}\overline{W_k} = \lambda$, $\forall$ *q*, with tilda indicating the budget allocation under the constrained resources. In this case, lambda - the shadow value of budget constraint - will be higher than 1, its value under the unconstrained allocation scenario. Thus the marginal costs of inspection are lower than marginal benefits and, hence, each extra unit of inspection capacity decreases the expected welfare losses from pest introduction more than proportionally. If the probabilities, p_{qk}, or the costs of pest introduction, $\overline{W}_k$, $\forall$ *k*, for a given pathway are zero, no inspection budget is allocated for this pathway under both the unconstrained and constrained cases.

In the third case, the expected welfare losses from pest introduction are given by:

$$\sum_q \sum_k p_{qk}(\frac{B}{Q})\overline{W_k} .$$

If the expected welfare losses from pest introduction are compared under all three scenarios, it can easily be established that:

$$\sum_{qk} p_{qk}(b_q^*) < \sum_{qk} p_{qk}(\widetilde{b}_q) \leq \sum_{qk} p_{qk}(\frac{B}{Q}) . \quad (3)$$

This expression implies that the sum of the expected probabilities of introduction of *k* pest species will always be the lowest under the unconstrained allocation (provided the budget constraint under the constrained allocation is binding), followed by the constrained allocation, which is always at least as good as the fixed allocation of the same budget. To verify the last inequality observe that $\sum_{qk} p_{qk}(\widetilde{b}_q) = \sum_{qk} p_{qk}(\frac{B}{Q})$ if an only if $\frac{B}{Q} = \widetilde{b}_q$; if $\frac{B}{Q} <> \widetilde{b}_q$, then the allocation of the fixed budget for the *q*th pathway is too low or too high compared to the constrained allocation case. The last inequality in expression (3) implies that inspecting agencies can in most cases reallocate their current budgets and achieve *lower* expected welfare losses due to pest introduction.

4.3 The empirical application

The conceptual framework is applied to inspections of chrysanthemum cuttings (CCs) imported in the Netherlands. CCs are a material for propagation that goes directly to the production chain and poses thus a risk of introduction and spread of quarantine pests, currently not present in the Netherlands, in the Dutch horticultural production chains. The objective of the empirical application is to analyze the inspection policy of CCs imported from six largest exporting countries[5], coded from A to F[6], given the expected costs of quarantine pests that may possibly be introduced in the Netherlands through CCs. The set-up of the empirical model partly follows that of Surkov et al. (2007). Contrary to Surkov et al (2007), this paper employs a partial equilibrium framework and computes the total societal costs of pest introduction, i.e. the costs for all consumers and for affected and non-affected producers,.

To identify pest species that may possibly be introduced through CCs, we analyzed data on pest interceptions during inspections of CCs imported in the Netherlands through pathways A to F in the period of 1998-2001 (Table 1). The data came from the two databases: the Annual reports of the diagnostic department of the Dutch Plant Protection Service (PD) for 1998-2000 and the electronic database of import inspections for 1998-2001. From these databases, we selected the cases of interceptions of pest species that have a quarantine status for

Table 1 Inspected and rejected lots of chrysanthemum cuttings, 1998-2001

Parameter	Pathway						All pathways
	A	B	C	D	E	F	
Number of imported lots	2,303	855	594	1,071	1,229	703	6,755
Average lot size (1,000 cuttings)	725	943	1,033	879	552	608	748
Lots rejected due to:							
B. tabaci	3	0	0	0	0	0	3
T. palmi	0	1	0	0	0	0	1
L. huidobrensis	0	0	0	1	1	0	2
Non quarantine pests	3	3	3	6	1	1	17
Total rejected lots	6	4	3	7	2	1	23

Source: authors' calculation based on the PD electronic data base of import phytosanitary inspections and PD Diagnostic Department (1998-2000)

the Netherlands[7]. According to the databases, three quarantine pest species were intercepted in lots coming along the six selected pathways in the period 1998-2001: *Bemisia tabaci* (tobacco

[5] The combined share of these countries in the total import volume of CCs in the Netherlands is over 95%. Note that, following the definition in the conceptual framework, these six countries represent six pathways of imported CCs.
[6] The real names of the exporting countries were coded for confidentiality.
[7] The quarantine pests for the Netherlands are listed in the EU Directive 2000/29/EC (European Council, 2000).

whitefly), *Thrips palmi* (palm thrips), and *Liriomyza huidobrensis* (serpentine leaf miner) (Table 1). Of these pests only *T. palmi* has the 'absent' status in the Netherlands while the other two pest species are currently present (and are officially controlled) in the country (EPPO, 2006). In estimating the costs of introduction we took the difference in pest statuses into account (see section 3.2).

4.3.1 Empirical models

Empirical models are specified so as to represent the actual inspection activities of the PD, taking into account scenarios developed in the conceptual framework. Two empirical models are specified. In the unconstrained allocation model, the inspection effort minimizes the expected costs of pest introduction and the inspection costs:

$$\sum_q \sum_k p_{qk}(b_q)\overline{W_k} + \sum_q \sum_l b_{ql} \qquad (4a)$$

$$b_{ql} = n_q \varepsilon_{ql} c_l$$

$$\sum_l \varepsilon_{ql} = 1 \qquad \forall\ q, \qquad \varepsilon_{ql} \in [0,1]$$

$$b_q \geq 0 \qquad \forall\ q,$$

with q=A, B, C, D, E, F and k=*B. tabaci*, *T. palmi*, *L. huidobrensis,*

where n_q is the expected number of lots along the qth pathway, c_l is the cost of inspection of one lot with l minutes, ε_{ql} is the proportion of lots of the qth pathway inspected with l minutes, and b_{ql} is the cost of inspection of $n_q\varepsilon_{ql}$ lots with l minutes.

In the empirical model with limited resources, an exogenous constraint B is imposed on the available resources. Thus, the Agency minimizes:

$$\sum_q \sum_k p_{qk}(b_q)\overline{W_k} \qquad (4b)$$

s. t. $\sum_q \sum_l b_{ql} \leq B$,

with all the parameters defined above.

In both models, the probability of pest introduction p_{qk} as a function of inspection efforts is given by the following expression:

$$p_{qk} = 0.1[1 - \prod_l (1 - \gamma_{qk} a_l)^{n_q \varepsilon_{ql}}], \qquad (5)$$

where α_l is the probability of not detecting a pest that is present in a consignment with inspection of length l, and γ_{qk} is the proportion of lots of the qth pathway infested with the kth pest. For every pathway, the probability of the kth pest introduction p_{qk} is an increasing function of the proportion of lots infested with the kth pest, γ_{qk}, the volume of import along the qth pathway, n_q, and the inspection error α_l. The part in square brackets in equation 5 represents the probability of pest entry (i.e. the term u_{qk} in equation 1) and 0.1 represents a nominal probability of pest establishment (the term s_k in the same equation). The probability of pest establishment is assumed constant for all pest species and is taken from the literature on biological invasions (Williamson, 1996), which postulates that 10% of invasive species survive after initial entry.

Therefore, the empirical models have to find the optimal combinations of the proportion of lots ε_{ql} inspected with a given length l and associated inspection error α_l, that minimize the total expected pest costs plus the costs of inspection (equation 4a), or the total expected pest costs subject to budget constraint (equation 4b). For simplicity we assume that α_l is not pest specific; thus, the inspection error is the same for all pests.

4.3.2 Calculation of the costs of pest introduction in the Netherlands

The aim of this section is to present a framework for calculating the costs of introduction $\overline{W_k}$ in equations 4a and 4b of the empirical model. The costs of pest introduction depend on the range of crops that are susceptible to a given pest species. We assume that greenhouse crops in the Netherlands are at risk of *B. tabaci*, *T. palmi* and *L. huidobrensis*. Field crops are considered non-hosts due to unsuitable abiotic environment. We determined the range of susceptible greenhouse crops based on literature (European Plant Protection Organization (EPPO), 2006); see also references to Tables 2 and 3) and interviews with Dutch experts. The assumed ornamental crops affected by different pests are Begonia, Gerbera, Poinsettia for *B. tabaci* and cut and pot chrysanthemum for *L. huidobrensis*. Because *T. palmi* is a highly polyphagous pest, following McLeod et al. (2004) we assumed that 10% of all greenhouse ornamental species in the Netherlands is susceptible. Table 2 summarizes the assumptions of the impact of an outbreak of *B. tabaci* and *T. palmi* on the affected grower of vegetable crops (we assume that outbreaks of *L. huidobrensis* do not affect vegetable growers) and Table 3 presents similar assumptions for ornamental crops. Assumed impacts differ for vegetable and ornamental crops because stricter requirements are applied for visual quality of the latter.

Table 2 Assumed impacts of an outbreak of *B. tabaci* and *T. palmi* on vegetable crops, %

Type of impact	Crop			
	Tomato	Cucumber	Sweet pepper	Eggplant
B. tabaci				
Yield reduction	-10[a]	-5[b]	-5[c]	-
Crop protection costs	+150[a]	+75[b]	+75[c]	-
T. palmi				
Yield reduction	-	-10[d]	-8[d]	-15[d]
Crop protection costs	-	+100[d]	+100[c]	+100[c]

[a] Assumption based on 'low numbers of whiteflies' in Morgan and Macleod (1996)
[b] Based on Temple et al. (2000)
[c] own assumption
[d] based on MacLeod and Baker (1998)

Table 3 Assumed impacts of an outbreak of *B. tabaci*, *T. palmi* and *L. huidobrensis* on susceptible ornamental crops

Time of an outbreak	Crop protection costs,%	Yield reduction,%	Probability of an outbreak
Growing	+100[a]	-5[a]	0.95[b]
Harvest	+100[a]	-50[a]	0.05[b]

[a] Based on conversations with Dutch growers and extension specialists
[b] Temple et al. (2000)

Introduction of a pest species in the empirical model implies two types of damages: yield reduction and increase in crop protection costs for affected growers. To calculate the possible impacts of these pest damages on producers and consumers of susceptible crops, we use a partial equilibrium model. The model calculates the annual welfare loss due to pest outbreaks for growers of susceptible crops and consumers of these crops in the Netherlands. The model distinguishes two regions: the Netherlands and rest of the world (ROW), which are related through excess demand (supply) equations. We assume that crops in the Netherlands and in ROW are perfect substitutes and their respective prices differ only by the transportation costs and tariffs. Demand and supply equations in the Netherlands and the ROW are of the Cobb-Douglas form. The basic equations in this part of the model are:

$$D_i = \chi_i P_i^{-\eta_i} \tag{6a}$$

$$SA_i = (1 - h_i)\beta_i (v_i P_i)^{\theta_i} z_i \tag{6b}$$

$$SN_i = \beta_i P_i^{\theta_i} (1 - z_i) \tag{6c}$$

$$S_i = SA_i + SN_i + M_i \tag{6d}$$

$$E_i = S_i - D_i \quad \text{(6e)}$$

$$P_i = WP_i + \mu_i \quad \text{(6f)}$$

$$X_i = \upsilon_i (WP_i)^{\omega_i} \quad \text{(6g)}$$

$$X_i = E_i , \quad \text{(6h)}$$

where D_i and S_i are, respectively, demand and total supply of the *i*th crop in the Netherlands, SA_i and SN_i are the supply of the *i*th crop by the affected and not affected producers, E_i is the excess supply (demand) of *i*th crop in the Netherlands, M_i is the volume of import of the *i*th crop in the Netherlands, X_i is the excess demand (supply) for the *i*th crop in ROW, P_i is the price of *i*th crop in the Netherlands, WP_i is the world market price of the *i*th crop, μ_i is the wedge between the price in the Netherlands and on the world market, η_i and θ_i are the elasticities of demand and supply of the *i*th crop in the Netherlands, ω_i is the elasticity of excess demand (negative) or supply (positive) of the *i*th crop in ROW and χ_i, β_i, and υ_i are parameters. In this model, the total supply of the *i*th crop in the Netherlands includes import (equation 6d), the constant value of which is unaffected by import inspection or pest outbreaks.

The impact of pest introduction on supply of the *i*th crop by the affected growers (equation 6b) is represented by three parameters: $h_i \in (0,100\%)$, a horizontal percentage shift in the supply curve due to yield reduction, v_i- a simultaneous vertical percentage shift in the supply curve because of the increase in the crop protection costs[8], and z_i - the size of an outbreak, i.e. the percentage of growers of the *i*th crop affected by pest outbreaks. Together, parameters h_i, v_i, and z_i represent the supply shifter N_{kit} in equation 2a of the conceptual framework. The assumed values of h_i and v_i for various crops are shown in Tables 2 and 3. The outbreak sizes z_i assume low (1%), medium (5%) and high (15%) percentages of growers affected by every pest species in the model. We assume that the probability distribution of these situations is: 0.96; 0.03; 0.01 (Surkov et al., 2007). Thus, the expected annual costs of pest introduction from all scenarios are weighted by the probability of each scenario occurring.

The annual costs of the *k*th pest introduction, $\overline{W_k}$, are calculated following the conceptual framework, as the sum of changes in producer and consumer[9] surpluses, summed over all the susceptible crops[10] (see equations 2a and 2b). We assume that producers bear all the

[8] The shifts of supply curves due to pest outbreaks are modelled following the literature on the technology induced shifts in agricultural supply (e.g., Lindner and Jarrett, 1978; Pachico et al., 1987)

[9] We assume that income effects are small and thus the consumer surplus is a pertinent welfare measure.

[10] We ignore possible substitution effects between various crops assuming that these are relatively small. Substitution possibilities among different *classes* of ornamental crops (e.g. cut flowers and flowering pot plants) are relatively low. For example, the cross-price elasticity between cut flowers and pot plants in the Netherlands

direct costs of controlling pest outbreaks and that the government bears no costs of pest introduction[11]. The change in the producer surplus is given by the sum of changes in surpluses of affected and not affected producers obtained by taking the integral over the respective supply curves (equations 6b and 6c). Because *B. tabaci* and *L. huidobrensis* are already present in the Netherlands, the costs of their introduction are assumed to be limited by the year of an introduction only. Because *T. palmi* is currently not present in the Netherlands, we assume that its costs of introduction, i.e. the producers and consumers welfare losses, will extend for a 10-year horizon due to recurrent outbreaks from the established populations. The ten-year horizon is chosen as a reasonable period of time during which most of the costs[12] of *T. palmi* introduction are incurred. After this period, producers in the Netherlands are assumed to fully adjust their production practices to the presence of *T. palmi*; thus the costs of controlling *T. palmi* outbreaks should become part of the average crop protection costs.

Because *T. palmi* is not currently present in the Netherlands, a potentially important component of the costs of introduction of *T. palmi* is the possible loss of export markets. Some countries may prohibit the import of Dutch horticultural products that are susceptible to *T. palmi*. In estimating the costs of introduction of *T. palmi* we ignored the potential loss of export market, because of the assumption that large scale outbreaks are unlikely. When the number of outbreaks is small, a properly functioning export inspection should make the likelihood of exporting *T. palmi* very small to the extent that importing countries continue to accept Netherlands exports[13]. Thus, 'no import bans' is the benchmark case for estimating the costs of introduction of *T. palmi*; the potential effects of a partial import ban due to the presence of *T. palmi* in the Netherlands on the estimated costs of introduction are considered in the sensitivity analysis (section 4.3.1).

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was found around 0.2 (van Tilburg, 1984). Substitution possibilities *within* a given class of ornamental crops (e.g. between chrysanthemum and rose) are likely to be greater but we have no data to account for such an effect. Finally, substitution possibilities between different vegetable crops are presumably low.

[11] Government may bear some costs of pest introduction, e.g. costs of extra research with respect to newly established pest species or costs due to the necessity to implement tougher export inspections. In this paper, we assume that all such costs are reflected in the crop protection efforts of producers.

[12] For r=5%, the costs incurred during the first 10 years after the initial introduction, account for approximately 40% of the overall future costs of pest introduction when $t\rightarrow\infty$. This can be shown using the usual annuity formula.

[13] This assumption critically depends on the risk attitudes of the countries to which the Netherlands exports ornamentals. Presumably, the same arguments on the safety of exported products from *T. palmi* may seem convincing for the EU countries but not for the non-EU trade partners of the Netherlands. The latter may take a highly risk averse stance and impose import bans on Dutch products. Yet, it should be noted that over 80% of the Netherlands export of vegetables and ornamentals goes to the EU countries (LEI, 2006b). Furthermore, in some of the important non-EU destinations of the Netherlands vegetable and flower exports, *T. palmi* is already present, e.g. in Japan, and in some territories of Australia (EPPO, 2006). Therefore, even if some countries ban some Dutch products, the expected extent of import bans would be relatively small.

4.3.3 Data and calibration

Proportion of infested lots

The proportion of infested lots γ_{qk} is one of the key parameters in the model. Historical data (Table 1) show that at most one quarantine pest species was intercepted along pathways A, B, D and E and no quarantine pests were intercepted along pathways C and F. Thus, for most pathways, the proportion of lots infested with a particular pest cannot be calculated directly. We assume that the proportion of infested lots is approximated by its upper confidence interval γ_{qk}^{U} that can be calculated from the available data. Assuming that the proportion of infested lots γ_{qk} follows the binomial distribution with x successes (number of lots found infested with a pest) and n trials (the total number of inspected lots), the upper confidence interval for γ_{qk}, γ_{qk}^{U}, is given by (Couey and Chew, 1986):

$$\sum_{x=0}^{x=s} \frac{n!}{x!(n-x)!} (\gamma_{qk}^{U})^{x} (1-\gamma_{qk}^{U})^{n-x} = 1 - C, \tag{7}$$

where C is the required confidence level.

Applying equation 7 to historical data (Table 1) and taking C=0.95 we calculated $\hat{\gamma}_{qk} = \gamma_{qk}^{U}$ for all the pathways, including those with zero historical numbers of infested lots (Table 4). Estimated $\hat{\gamma}_{qk}$'s are *ceteris paribus* higher for pathways with lower historical numbers of inspected lots (e.g. pathway C and F) and pathways with a greater number of lots infested with a particular pest (pathway A, *B. tabaci*). Values in Table 4 are conservative (i.e. high) estimates of the true proportion of infested lots γ_{qk} and may best represent an Agency that is risk-averse with respect to low numbers of inspected lots and zero historical pest interceptions associated with some pathways. In other words, the Agency has not accumulated sufficient data to consider a particular pathway as safe. Moreover, the Agency assumes that lots along all the pathways have non-zero proportions of infestations with *B. tabaci*, *T. palmi* and *L. huidobrensis*.

Table 4 also shows the number of lots in year t expected along every pathway, which was taken as the average yearly volume of import in the period 1998-2001.

Error probabilities of import inspection α_l, inspection lengths l and inspection costs c_l

Statistically, the probability of detecting an infested cutting in a given lot is a function of the proportion of infestation in the lot and the sample size s (when s is small relative to the lot size), assuming binomial distribution of infested cuttings[14]. Because the proportion of infestation in a

[14] The binomial distribution is based on the assumption that the inspection result for each sampling unit is independent of the result of other units. In reality, infested cuttings may be clustered in a lot, in which case the

given lot *a priori* is always unknown, in quarantine practice sample size s is chosen so as to maintain the probability $1-\alpha$ of detecting an infested unit given that the proportion of infested

Table 4 Parameter values of n_q[a] and γ_{qk}[b] for the empirical model

Parameter	Pathway					
	A	B	C	D	E	F
Expected number of lots n_q	600	200	155	250	300	160
Proportion of infestation $\hat{\gamma}_{qk}$:						
B. tabaci	0.00336	0.00350	0.00503	0.00279	0.00243	0.00425
T. palmi	0.00130	0.00554	0.00503	0.00279	0.00243	0.00425
L. huidobrensis	0.00130	0.00350	0.00503	0.00442	0.00385	0.00425

[a] Based on the average yearly number of lots imported during 1998-2001
[b] Estimated using the upper 95% confidence interval (equation 8) applied to historical numbers of inspected and rejected lots (Table 1)

units in the lot is not lower than a certain detection threshold p_t (Venette et al., 2002). The relevant formula is given by Kuno (1991):

$$s = \frac{\ln(\alpha)}{\ln(1-p_t)}. \quad (8)$$

Equation 8 implies that a smaller sample size is associated with a higher inspection error. Sample size is also decreasing in p_t, reflecting that a smaller sample is required when the Agency is prepared to tolerate higher infestation levels in lots that are not found infested at inspection. For the purposes of the current model we assume that the Agency fixes p_t and may vary sample size to achieve lower error probability α. Specifically, we assume p_t=0.5%. With p_t fixed, equation 8 can be solved for different α's.

Next, we relate the costs of inspection to sample size. Larger samples require more inspection time and are therefore more costly. We assume that during each minute, the inspector may examine 60 cuttings. Feasible inspection lengths and the associated sample sizes are shown in first two columns of Table 5. The third column of Table 5 gives the cost of inspection of a given length, based on the actual PD inspection tariffs. The inspection tariff includes a fixed

assumption of independence may not hold, and assuming the beta-binomial distribution would be more appropriate. With infested cuttings clustered, it is more difficult to detect an infestation in a lot (Venette et al., 2002). Thus, the inspection effort for a given sample size would be less effective, implying a lower likelihood of detecting a pest species than the one assumed in equation 8. However, to apply the beta-binomial distribution, data on the parameters of the beta distribution are required, which are very difficult to obtain. Such data were not available for this research. See Yamamura and Sugimoto (1995) and Yamamura and Katsumata (1999) for application of beta-binomial distribution in import quarantine inspection.

'base tariff' and a 'per minute' rate (PD, 2006). The last column of Table 5 presents the error probability α_l calculated for each sample size l using equation 8.

Table 5 Relation between sample size, inspection length, sample costs and error probability (p_l=0.5%)

Inspection length l, minutes	Sample size s, cuttings	Sample cost c_l ('base tariff' +'per minute' rate)[a], euros	Error probability α_l
0	0	0	1.000
1	60	46.07	0.740
2	120	47.78	0.548
3	180	49.49	0.406
4	240	51.20	0.300
5	300	52.91	0.222
6	360	54.62	0.165
…	…	…	…
20	1200	78.56	0.002

[a]'Base tariff' - 44.36 euros, 'per minute' rate- 1.71 euros. Source: (MINLNV, 2005).

Calibration of the partial equilibrium model

The partial equilibrium model was calibrated to represent the 2005 data on volumes of production, consumption, and import of the investigated crops in the Netherlands. Parameters α_i, β_i, and γ_i were calibrated for a fixed volume of import M_i in 2005 (equation 6d). Table 6 presents the data and the assumptions used to parameterize the model. Data on the volume of consumption of ornamental crops in the Netherlands are very limited (Jan Lanning, Hoofdbedrijfschap Agrarische Grrothandel (HBAG), *personal communication*). The available evidence suggests that 80% of the Dutch produced chrysanthemums and gerberas are exported (Neefjes, 2006; van Lier, 2003). Thus, for all ornamental crops in the model we assumed that 20% of Dutch production is consumed domestically. Table 6 shows that the Netherlands is a net exporter of all the crops in the empirical framework. The Appendix explains how the excess demand elasticities ω_i were calculated.

Table 6 Data for the partial equilibrium model*

Parameter	Crop								
	Tomatoes	Cucumbers	Eggplant	Sweet pepper	Chrysanthemum	Gerbera	Begonia	Poinsettia	Average ornamental crop[j]
Production[a], th. tons (mln stems/pots)	652.65	475.33	43.09	308.23	1,201.92	839.63	25.36	19.50	546.47
Import[b], th. tons (mln stems/pots)	322.24	64.87	8.37	86.01	2.78	19.10	0.00	1.70	0.00
Consumption in NL[c], th. tons (mln stems/pots)	195.63	145.48	12.34	71.24	240.94	171.75	5.07	4.24	109.29
Excess demand[d] (-), supply(+), th. tons (mln stems/pots)	134.78	264.98	22.38	150.98	958.18	648.78	20.28	13.56	437.18
Producer price[e] in NL, euro/kg (1 stem/pot)	0.93	0.24	0.94	1.46	0.22	0.20	1.00	1.25	0.70
World price[f], euro/kg (1 stem/pot)	1.21	0.72	1.25	1.58	0.22	0.20	1.00	1.25	0.70
Elasticity of demand[g], NL	-0.58	-0.58	-0.58	-0.58	-0.80	-0.80	-0.87	-0.87	-0.80
Elasticity of supply[h], NL	0.28	0.91	0.47	0.26	0.40	0.40	0.40	0.40	0.40
Elasticity of the excess demand[i]	-4.83	-5.49	-7.30	-3.91	-2.30	-2.30	-2.85	-2.85	-2.30

*Data on production, export and import volumes pertain to 2005

[a] Source: calculated based on gross margins data from the Applied Plant Research (2006)

[b] Source: vegetable crops- FAO (2007); ornamental crops Anonymous (2006)

[c] Source: vegetable crops- FAO (2007); ornamental crops– Production*20% (see the text for explanation)

[d] Calculated as: Production + Import - Consumption

[e] Source: Applied Plant Research (2006)

[f] The world price of vegetables is assumed to be the export price of the Dutch vegetables from the International Trade Center/WTO (ITC) (2007); for ornamental crops, the world price is the producer price in the Netherlands

[g] Source: vegetable crops- Michalek and Keyzer (1992); ornamental crops- cut flowers Bouman and Trip (1990), potted plants- van Tilburg (1984)

[h] Source: vegetable crops- Oude Lansink (2001); ornamental crops- assumption

[i] Source: see the Appendix

[j] Used for calculation of the economic impacts of introduction of *T. palmi*. The data on production, consumption and excess demand for this category are derived based on the data on gross margins for 1 m^2 of the 'average' cut flower and pot plant farm in the Netherlands (2006a; 2006b). It is assumed that without pest outbreaks, the average output is 100 units (stems or pots) per m^2 of an average farm.

4.3.4 Model scenarios

We analyzed three scenarios. Scenario ‘Unconstrained allocation’ represents the allocation of inspection effort with no budget constraint (equation 4a). Scenario ‘Constrained allocation’ represents the allocation of inspection effort with limited resources (equation 4b). The budget constraint *B* in this scenario is exactly the same as under the third scenario ‘Fixed inspection’. This scenario is assumed to replicate the current inspection practice, when every imported lot of chrysanthemum cuttings is inspected. We assume that under this scenario every lot is inspected with exactly 5 minutes. This yields the total inspection costs equal to 88,095 euros (1,665 lots times 52.91 euros/lot), see (Tables 4 and 5).

4.4 Results

4.4.1 The costs of pest introduction

The estimated annual costs of pest introduction in the Netherlands are presented in Table 7. Across all scenarios, the largest costs are from the introduction of *B. tabaci*, mainly due to high impacts of this pest species on tomato growers (Table 2) and because of the large number of tomato growers in the Netherlands (543 in 2003; LEI, 2006a). The estimated annual costs of introduction of *T. palmi* are significantly lower than those of *B. tabaci* due to two factors. Firstly, *T. palmi* has comparable impacts on cucumbers and sweet peppers as *B. tabaci* (Table 2). At the same time, *T. palmi* does not attack tomatoes but eggplants instead, which are grown on a comparatively smaller scale in the Netherlands (72 growers in 2003; LEI, 2006a). Secondly, the costs of introduction of *T. palmi* are mitigated because the excess demand for ornamental crops is less elastic compared to that for tomatoes (Table 6); thus the losses to producers in the Netherlands are partially compensated because consumers of ornamental crops in the ROW are less sensitive to a price increase than consumers of tomatoes. The costs of introduction of *L. huidobrensis* are the lowest among all the pest species because, by assumption, this pest species affects only chrysanthemum growers. In all the scenarios, both consumers and producers lose but the losses of the latter are substantially larger mainly due to the reduced crop yields of the affected producers. It should be noted that the losses in producers’ welfare reported in Table 7 are significantly smaller than losses in producers’ *revenue* reported in Surkov et al. (2007). This is because the increased crop protection costs and reduced yields of the affected growers are compensated to some extent by the price increase due to reduced supply of the affected crops. Table 8 shows the percentage increase in prices of affected crops in each of the scenarios. The observed price increase is small relative to situation of no pest outbreaks, largely because the reduction in the total supply of affected crops was small. (The results of changes in the supply and demand volumes are available upon request.)

The expected annual costs of pest introduction are obtained by multiplying the value of pest costs in every scenario with the assumed probabilities of each situation occurring (i.e., 0.96, 0.03 and 0.01) and summing over resulting values. This yields the following expected costs of pest introduction: $\overline{W}_{B.tabaci}$ =1.26 mln euros and $\overline{W}_{L.huidobrensis}$ =0.14 mln euros. The expected annual costs of introduction of *T. palmi*, equal to 0.61 mln euros, were discounted at *r*=0.05 and summed over 10-years horizon, to yield $\overline{W}_{T.palmi}$ = 5.62 mln euros.

Table 7 Annual costs of introduction of quarantine pests in the Netherlands as the change in the total societal surplus, mln euros

Pest species	Size of an outbreak		
	Low	Medium	High
B. tabaci			
Consumer surplus	-0.10	-0.48	-1.46
Producer surplus	-0.90	-4.52	-13.60
Total surplus	-1.00	-5.00	-15.06
T. palmi			
Consumer surplus	-0.06	-0.32	-0.97
Producer surplus	-0.42	-2.11	-6.35
Total surplus	-0.49	-2.43	-7.32
L. huidobrensis			
Consumer surplus	-0.02	-0.09	-0.27
Producer surplus	-0.10	-0.48	-1.45
Total surplus	-0.11	-0.57	-1.72

Table 8 Crops' prices in the Netherlands after pest introduction as the percentage to their level without pest introduction

Pest species/ size of an outbreak	Crop								
	Tomato	Cucumber	Eggplant	Sweet pepper	Chrysanthemum	Gerbera	Begonia	Poinsettia	Ornamental crop
B. tabaci									
Low	100.02%	100.01%	-	100.01%	100.03%	100.04%	100.03%	100.03%	-
Medium	100.11%	100.08%	-	100.06%	100.17%	100.17%	100.13%	100.13%	-
High	100.32%	100.22%	-	100.19%	100.50%	100.52%	100.40%	100.39%	-
T. palmi									
Low	-	100.02%	100.03%	100.02%	-	-	-	-	100.03%
Medium	-	100.11%	100.13%	100.10%	-	-	-	-	100.16%
High	-	100.32%	100.41%	100.29%	-	-	-	-	100.48%
L. huidobrensis									
Low	-	-	-	-	100.03%	-	-	-	-
Medium	-	-	-	-	100.17%	-	-	-	-
High	-	-	-	-	100.50%	-	-	-	-

4.4.2 The allocation of resources for import inspection

The expected costs of pest introduction in the absence of import inspection are equal to 2.14 mln euros (first row of Table 9). The costs are obtained by a straightforward application of equation 4b. The expected costs of pest introduction are *ceteris paribus* greater for pathways with a higher proportion of lots infested with a more costly pest, i.e. *T. palmi*, (pathway B) and for pathways with a greater number of imported lots (pathway A) (see Table 4).

The 'Unconstrained allocation' scenario implies that allocation that minimizes the sum of the costs of pest introduction and the inspection costs comes at an inspection cost of 125 thousand euros. With this budget, the expected costs of pest introduction through all the pathways are negligible; the total societal costs of pest introduction are only 138 thousand euros compared to 2.14 mln euros in the no inspection case. Under the 'Fixed inspection' scenario, in which all lots from all the pathways are inspected for 5 minutes, the total societal costs of pest introduction plus the inspection costs amount to 733 thousand euros or 34% of the initial pest costs. However, if the same budget is allocated optimally, under the 'Constrained allocation' scenario, the total societal costs of pest introduction constitute only 19% of the initial pest costs. This result implies, consistently with the conceptual model, that the current allocation of the inspection effort can generally always be improved. Under 'Constrained allocation' scenario, the shadow value of budget constraint is equal to 8 euros, meaning that increasing the current inspection budget with one euro would reduce the expected costs of pest introduction with 8 euros[34].

How the budget was allocated in all scenarios, is shown in Figure 1. The height of the bar shows the percentage of lots of a given pathway inspected with a given length in each scenario. Under the 'Fixed inspection' scenario, all lots are by assumption inspected with 5 minutes (observe all the dark bars in this inspection length category). The lengths of inspection under the unconstrained allocation (dark dotted bars) vary between 16 minutes for pathway A to 20 minutes for pathways B, C and F. This pattern of resource allocation is preserved under the 'Constrained allocation' scenario (light-grey bars), *viz*. lots of pathway A received the shortest and of pathways B, C and F the longest durations of inspection, with lots of the remaining pathways receiving an intermediate level of inspection effort.

The rationale of resource allocation under the 'Unconstrained allocation' and 'Constrained allocation' scenarios is the same. *Ceteris paribus*, more resources are allocated to pathways, whose inspection yields the largest reduction in the expected costs of pest introduction for every euro of the available inspection budget. These pathways have *ceteris*

[34] It should be noted that this shadow value is lower than the one reported in our earlier paper (Surkov et al., 2007c), which was equal to 17 euros. This is because the estimated costs of pest introduction in this paper are lower than the costs estimated in Surkov et (2007c). Intuitively, when the expected costs of pest introduction are lower, the marginal value of inspection is also lower.

Table 9 Expected costs of pest introduction, thousand euros

Scenario	Expected costs, per pathway						Costs of pest introduction	Inspection costs	Total societal costs	In % to 'no inspection' scenario
	A	B	C	D	E	F				
No inspection	391	411	351	326	337	319	2,135	0	2,135	100.00%
'Unconstrained allocation'	5	2	1	2	2	1	13	125	138	6.46%
'Fixed inspection'	128	131	103	94	98	91	645	88	733	34.33%
'Constrained allocation'	273	10	6	9	13	6	317	88	405	18.97%

Table 10 Changes in the costs of pest introduction relative to the base case estimate*

Pest species	θ_i		η_i		ω_i		Crop protection costs		Yield losses	
	-50%	+50%	-50%	+50%	-50%	+50%	-50%	+50%	-50%	+50%
T. palmi	121.3%	85.0%	98.9%	100.9%	70.5%	112.1%	96.9%	103.0%	53.2%	146.8%
B. tabaci	113.9%	89.4%	99.3%	100.7%	79.3%	108.4%	85.6%	114.3%	65.4%	134.6%
L. huidobrensis	117.5%	87.1%	97.9%	102.0%	62.0%	116.9%	82.1%	117.8%	69.1%	131.0%

*High size of outbreaks (Table 7)

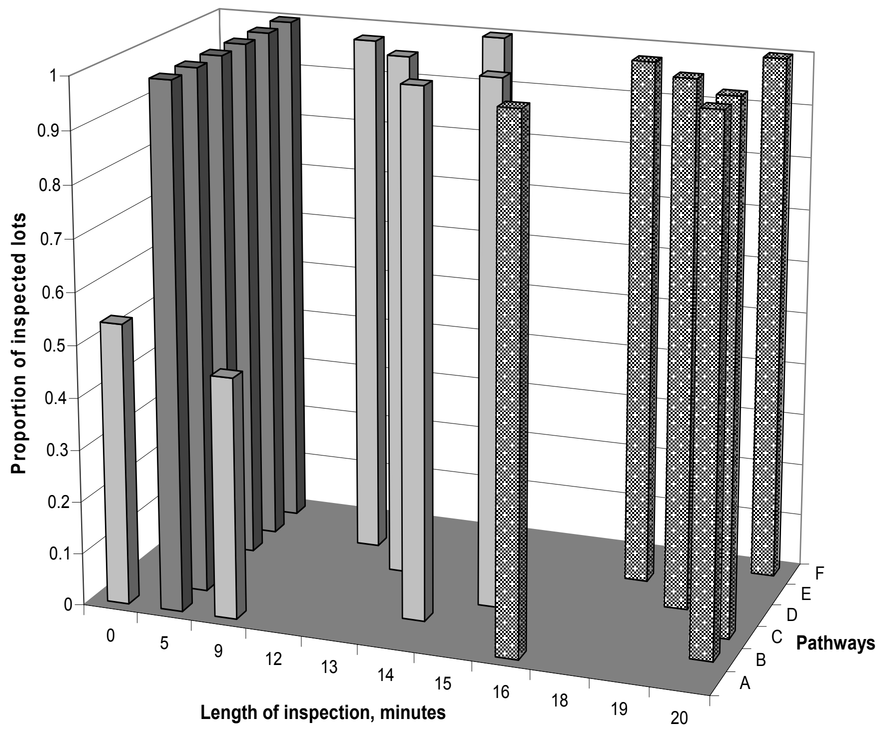

Figure 1 Allocation of inspection effort under various scenarios. Note: dark-grey bars- 'Fixed inspection' scenario; light-grey bars- 'Constrained allocation' scenario; dark-grey-dotted bars- 'Unconstrained allocation' scenario

paribus higher proportions of infested lots and smaller number of imported lots, e.g. pathways C, B, and F (see Table 4). Lots from other pathways should receive comparatively shorter inspection times or, as in case of the pathway A, some of the lots (approximately 50%, Figure 1) should remain partially uninspected.

The results from all the scenarios imply that inspection greatly reduces the expected pest costs. The benefit-cost ratio of inspection is larger than 15 in each of the scenarios[35]. The unconstrained and constrained allocation of inspection efforts results in lower societal cost of pest introduction than in the 'Fixed inspection' scenario because inspection resources are allocated more effectively to their next best use. The results suggest that a 42% increase in the

[35] The benefit-cost ratio is given by the difference between the total societal costs without and with inspection divided by the inspection budget for each of the scenarios.

inspection budget of the ‘Fixed inspection’ scenario (i.e. from 88 thousand to 125 thousand euros), virtually eliminates the costs of pest introduction. The presence of a fixed cost of inspection – a ‘base tariff’ (Table 5) - explains this result. Because in the ‘Fixed inspection ’ scenario, the base tariff has already been covered, the marginal costs of each extra minute of inspection in the ‘Constrained allocation’ scenario are low compared to this high fixed tariff. Therefore, it is beneficial to increase the length of inspection until the marginal inspection costs are equal to the marginal benefits.

4.4.3 Sensitivity analyses

Costs of pest introduction

We analysed the sensitivity of the estimated costs of pest introduction to -50% and +50% changes in the demand and supply elasticities in the Netherlands, the excess demand elasticities in the ROW, and to changes in the crop protection costs and yield losses. The costs of introduction under the high outbreaks situation in Table 7 served as the base case for comparison.

The costs of pest introduction were highly sensitive to changes in the assumed magnitude of yield losses, which is an expected result (Table 10). The costs of pest introduction were less sensitive to the variations in the crop protection costs, because the latter represent a relatively small share of the price of all crops. Furthermore, the estimated costs of pest introduction are substantially reduced, after a 50% decrease in the excess demand elasticities. This is because losses for Dutch producers are significantly reduced when excess demand is less sensitive to price changes in the Netherlands. The losses for producers are magnified, when the elasticity of supply in the Netherlands decreases. This is an intuitive result, as producers not affected by pest outbreaks become much less responsive to increased prices in the Netherlands and thus the overall producer losses increase. Finally, the changes in the demand elasticities in the Netherlands only marginally influenced the estimated costs of pest introduction because in general the increases in crop prices are small (see Table 8).

To analyse the economic impacts of import bans that may be imposed in some of the Dutch export markets if *T. palmi* would establish in the Netherlands, we modelled a 10% drop in the export demand for crops that are susceptible to *T. palmi*. As expected, the annual losses of an import ban are very high, amounting to over 29.9 mln euros, i.e. a 50-fold increase over the base estimate of 0.61 mln euros. The Dutch producers suffer the greatest loss (-35.9 mln euros) because they have to sell their products on domestic markets at lower prices; the Dutch consumers benefit from lower prices (+6.0 mln euros). This result shows that inclusion of export losses dramatically influences the estimated costs of pest introduction. High export losses due to

T. palmi may justify attempts to fully eradicate the pest from the Netherlands even when eradication costs are high.

Allocation of inspection effort

The allocation of inspection effort among pathways remains consistent as long as the expected costs of pest introduction from different pathways do not change relative to each other. If the expected costs of pest introduction for some pathways increase (decrease) relative to other pathways; more (less) inspection effort will be allocated to these pathways relative to other pathways. When the costs of pest introduction, $\overline{W}_k$, are constant, the main variables that may affect the expected costs of pest introduction are the number of imported lots n_q and the proportions of infested lots γ_{qk}, through their effect on the probability of pest introduction p_{qk} (equation 5). The model results are more sensitive to changes in the numbers of imported lots than to changes in the proportion of infested lots, because of the non-linear functional form of the probability of pest introduction p_{qk} (see Surkov et al. (2007) for more detail).

The allocation of inspection effort among pathways is consistent with respect to variations in parameters representing the efficacy of inspection given in equation 8, i.e. the sample size s, the detection threshold p_t and confidence level α. This is because the changes in these parameters do not affect the relative costs of pest introduction through different pathways. (The results of the sensitivity analysis on these parameters are similar to our earlier results (Surkov et. al., 2007). On the other hand, variation in the assumed efficacy of inspection, i.e. in the number of cuttings that can be examined per minute of inspection influences the probability of pest introduction for a minute of inspection effort, and thus the expected costs of pest introduction and the costs of inspection. For example, in the 'Unconstrained allocation' scenario, when the number of cuttings per minute of inspection increases to s=120 cuttings, inspection lengths vary from 9 (pathway A) to 11 (pathways B, C and F) minutes, compared to 16 and 20 minutes, respectively, under the base case (s=60). The associated costs of the pest introduction are equal to 7 thousand euros. The inspection costs are equal to 102 thousand euros, or 18% down from their base level of 125 thousand euros. Finally, a large, five-fold, increase in the inspection efficacy, i.e. s=300, implies that reducing the expected pest costs to their level under the base scenario would cost only 87 thousand euros.

4.5 Discussion and conclusions

The analysis in this paper shows that the expected costs of pest introduction plus the inspection costs are the lowest under the unconstrained allocation, greater under the constrained allocation, and are the highest under the fixed allocation of inspection effort. Unfortunately, in real world inspecting agencies have to pursue policies under resource constraints because of the lack of inspection capacities (e.g. qualified personnel) and continuously increasing volumes of world trade (U.S. Office of Technology Assessment, 1993). In this case, the optimal inspection policy equates the marginal costs of pest introduction across trade pathways.

The empirical application in the paper analyzed the fixed, and the resource-unconstrained and resource-constrained inspection policies of chrysanthemum cuttings imported in the Netherlands. The results show that import inspection greatly reduces the expected pest costs. The results indicate that a current allocation of a fixed inspection effort to every risky pathway can be turned into a constrained allocation with lower total societal costs of pest introduction. The results also suggest that in the presence of the fixed cost of inspection, e.g. the ‘call out fee’, the costs of moving from the constrained to unconstrained outcomes are low compared to benefits. This result suggests that expansion of the inspection capacity is beneficial. However, some aspects need to be carefully considered before the model can be taken to practice.

The first aspect is the expected cost of pest introduction. This is the decisive criterion determining the allocation of inspection effort. The expected costs of pest introduction include two essential components - the economic costs and the probability of pest establishment, - both of which require careful estimation and involve considerable uncertainties. The costs of pest introduction in this paper were modelled as welfare losses to affected producers and consumers. The partial equilibrium framework that was used assumed only two regions - the Netherlands and rest of the world- which is a simplification. It would be more realistic is to disaggregate the rest of the world into the major Netherlands export markets, for example the EU, US, Japan, etc. This would allow a better analysis of the impacts of pest introduction in the Netherlands in the key export markets, especially the potential export losses. The sensitivity analysis shows that inclusion of export losses in the cost of pest introduction dramatically influences the estimate of the annual costs of pest introduction. The allocation of inspection effort among pathways can be significantly altered if export losses are included in the estimate of pest costs. An impediment to modelling individual export markets is that data on volumes of production and consumption in other countries are required, and this data may be very difficult to collect.

The probability of pest introduction is the product of the probability of pest entry and the probability of pest establishment. In the numerical application we assumed that the probability of pest establishment is equal to 10% for all pest species, which is a crude approximation of the true probability of pest establishment. Realistically, this probability depends, among other factors, on the vectors of pest spread in the Netherlands and the suitability of environmental and climatic conditions. It is therefore pest-specific and should be estimated for every pest species of concern.

Another important aspect is the modelling of the proportion of infested lots. Because some pathways had no interceptions of some or all pest species in the model, we modelled the proportion of pest infestation as a 95% confidence interval, assuming that every pathway serves as a vector of *B. tabaci*, *T. palmi* and *L. huidobrensis*. This approach assumes a highly risk averse agency by giving high proportions of infested lots for pathways with low number of inspected lots, for example pathways C and F, that had no records of pest interceptions in the period 1998-2001. Thus the allocation of inspection effort, although consistent with this approach, is somewhat counterintuitive. One alternative to this approach is to check whether a certain pest species actually occurs in a given exporting country and then assign zero as a proportion of infestation if the pest species is not present in the country or otherwise calculate it using 95% confidence interval (Surkov et al., 2006). This approach may still imply no inspections for pathways with no occurrence of particular pest species, which may be undesirable from a quarantine perspective. Another alternative is to devote a part of the overall inspection budget to inspection of a certain – fixed - fraction of lots from a pathway and allocate the remainder of the budget in the optimal way (Surkov et al., 2007c).

A correct parameterization of the efficacy of import inspection is another important aspect requiring scrutiny. We used a statistical relationship to link the efficacy of inspection to its cost in the Netherlands. The analysis indicates high sensitivity of inspection effort to assumptions governing the efficacy of import inspection. Furthermore, the results may be sensitive to the functional form of the efficacy of inspection. If infested cuttings are clustered in a lot rather than distributed independently as assumed in the paper, the efficacy of inspection declines for a given cost; thus, more budget should be spent for inspection than found in this paper. Therefore, establishing a practical relation between the efficacy and the cost per unit of inspection is necessary. In practice, this relation may differ for various types of products (e.g. cut flowers and cuttings) and various crops (e.g. tomatoes and chrysanthemums).

A robust conclusion of the empirical application is that inspection efforts should be allocated to pathways whose inspection yields greater reduction in the expected costs of pest introduction for every unit of the available budget. Furthermore, the application supports the expansion of budget for inspection of chrysanthemum cuttings imported in the Netherlands However, uncertainties with respect to the costs and likelihoods of pest introduction and the efficacy of import inspection should be carefully considered and quantitative estimates obtained in this study must be consolidated by empirical studies of critical relationships. In general, the developed model allows obtaining quantitative insights into the socially optimal levels of import phytosanitary inspection and trade-offs involved in bringing the current levels of inspection to the optimal ones.

Acknowledgements

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Appendix

Table A1 Notation used in the paper

Parameter	Description
g	index of exporting countries $(g=1,...,G)$
i	index of susceptible crops $(i=1,...,I)$
j	index of commodities $(j=1,...,J)$
k	index of pests $(k=1,...,K)$
l	index of inspection lengths, in minutes (l=1,...,L)
q	index of pathways, $(q=1,...,Q)$
t	time index, t= (1,…,T)
b_q	budget for inspection of lots imported along the qth pathway
b_{ql}	the cost of inspection of lots imported through qth pathway with l minutes
c_l	the cost of inspecting one lot with l minutes
γ_{qk}	the proportion of import volume V_q infested with the kth pest
h_i	a horizontal percentage shift in the supply curve of the ith crop due to yield reduction
n_q	the expected number of lots imported through the qth pathway
p_{qk}	probability of introduction of the kth pest via the qth pathway
p_t	the proportion of infestation within an inspected lot
r	discount rate
s_k	the probability of establishment of the kth pest after introduction
u_{qk}	the probability of entry of the kth pest via qth pathway
z_i	the percentage of growers of the ith crop affected by pest outbreaks
ε_{ql}	proportion of lots of pathway q inspected with l minutes
α	the probability of not detecting an infested unit during an inspection of a lot
a_l	probability to detect a pest specimen in a lot inspected with l minutes
χ_i, β_i, υ_i	parameters in the partial equilibrium model
η_i	elasticity of demand for the ith crop in the Netherlands

the table continues on the next page

Parameter	Description
μ_i	the wedge between the price of the *i*th crop in the Netherlands and the world market price
θ_i	elasticity of supply of the *i*th crop in the Netherlands
s	the size of a sample taken from every inspected lot
v_i	a vertical percentage shift in the supply curve due to increase in the crop protection costs
ω_i	the elasticity of excess demand (negative) or supply (positive) of the *i*th crop in ROW
B	the size of inspection budget
$\overline{CS_{kt}}$	incremental change in surplus of consumers as a result of outbreaks of the *k*th pest in period *t*
D_i	demand of the *i*th crop in period *t*
E_i	the excess supply (demand) of *i*th crop in the Netherlands
M_i	volume of import of the *i*th crop in the Netherlands
N_{kit}	number of outbreaks of the *k*th pest in period *t*
P_{it}	price of the ith crop in period *t*
$\overline{PS_{kt}}$	incremental change in producer surplus as a result of outbreaks of the *k*th pest in period *t*
SA_i	supply of the *i*th crop by the affected producers
S_i	supply of the *i*th crop in period *t*
SN_i	supply of the *i*th crop by not affected producers
V_q	volume of import along the *q*th pathway
$\overline{W_k}$	present value of economic costs associated with introduction of the *k*th pest
WP_i	world market price of the *i*th crop
X_i	the excess demand (supply) for the *i*th crop in ROW

Terminology used in the paper (IPPC, 2006a)

Pest entry- movement of a pest into an area where it is not yet present, or present but not widely distributed and being officially controlled

Pest establishment- perpetuation, for the foreseeable future, of a pest within an area after entry

Pest introduction- the entry of a pest resulting in its establishment

Consignment- a quantity of plants, plant products and/or other articles being moved from one country to another and covered, when required, by a single phytosanitary certificate (a consignment may be composed of one or more commodities or lots)

Lot- a number of units of a single commodity, identifiable by its homogeneity of composition, origin etc., forming part of a consignment

Calculation of the elasticities of excess demand

The elasticity of excess demand ω_i for the ith crop can be calculated as follows (Johnson, 1977; Thursby and Thursby, 1988):

$$\omega_i = \sum_m e_{im}\phi_m [\frac{D_{im}}{E_i}\eta_{im} - \frac{S_{im}}{E_i}\theta_{im}], \qquad \text{(A1)}$$

where e_{im} is the price transmission elasticity of the ith crop's price in the Netherlands with respect to region m's price, ϕ_m is the weight of region m in the total Netherlands export of the ith crop, D_{im} is the demand in the mth region for crop i and S_{im} is the supply to region m of crop i from all regions other than the Netherlands, E_i is the total export of the ith crop from the Netherlands and η_{im} and θ_{im} are, respectively, demand and supply elasticities with respect to commodity i in the market m. Thus, ω_i is calculated as the sum of the excess demand elasticities in m=1,…,M export markets weighted by shares of these markets in the total Netherlands export of the ith crop.

For the empirical model we assume that e_{im}=1, so that the change in the price in the Netherlands is perfectly translated into the change in the prices in its export markets. This is a common simplification (Johnson, 1977) but one should recognize that trade barriers and transportation costs usually lower the value of e_{im} (Thursby and Thursby, 1988). Nonetheless, these factors may be relatively unimportant for our assumption since most of the Netherlands horticultural exports is destined for the EU market and thus the price transmission elasticities should be close to unity. Furthermore, we assume that the elasticities of demand η_{im} and supply θ_{im} are the same as in the Netherlands (Table 6); this assumption is consistent with other studies (Johnson, 1977). This last assumption implies that we can ignore ϕ_m in equation A1. The last column in Table A2 shows the calculated elasticities of excess demand for every crop in the model.

The calculated values of ω_i are *ceteris paribus* higher in absolute values the lower the share of the Netherlands is in the world supply of a given crop. Therefore, ω_i's are higher for vegetables and notably lower for ornamental crops because the Netherlands is a major exporter of the ornamental crops on the world market. We could find no elasticities of excess demand for Dutch vegetables in the literature; thus, it is difficult to compare the estimates in Table A1 with other work. However, the range of the estimated elasticities seems plausible based on discussion in agricultural economics literature (Bredahl et al., 1979). For ornamental crops, the only available estimate is from Honma (1991) who reported the demand elasticity in Japan for cut flowers imported from the Netherlands equal to -2.92, which is somewhat higher in absolute value than our estimate. However, the Japanese flower market has been known to be highly protected and thus the elasticity of import demand in Japan is likely to be higher than on the average Dutch export market.

Table A2 Calculation of the excess demand elasticities

Commodity	D_{im}/E_i [a]	S_{im}/E_i [a]	e_{im} [b]	η_{im} [c]	θ_{im} [c]	ω_i
Tomato	5.89	5.17	1.00	-0.58	0.28	-4.83
Cucumber	4.22	3.37	1.00	-0.58	0.91	-5.49
Eggplant	7.08	6.82	1.00	-0.58	0.47	-7.30
Sweet pepper	4.95	4.17	1.00	-0.58	0.26	-3.91
Cut flowers	2.25	1.25	1.00	-0.80	0.40	-2.30
Potted plants	2.57	1.57	1.00	-0.87	0.40	-2.85

Note: cut flowers- chrysanthemum and gerbera; potted plants- poinsettia and begonia

[a] Source: vegetables- calculated based on the physical volumes of export and import in 2005 (ITC, 2007); ornamental crops- based on values of export and import in 2004 (AIPH/Union Fleurs, 2006)

[b] Source: see text

[c] Source: Table 6 in the main text

Chapter 5 Interceptions of harmful organisms during import inspections of cut flowers in the Netherlands: An empirical and theoretical analysis of the ‘reduced checks’ system

Based on: Surkov, I.V., van der Werf, W., van Kooten, O. and Oude Lansink, A.G.J.M. Interceptions of harmful organisms during import inspections of cut flowers in the Netherlands: An empirical and theoretical analysis of the ‘reduced checks’ system. *EPPO Bulletin*, 2007, *forthcoming*.

Abstract

As of January 1st 2005, a system of reduced checks for phytosanitary inspections of certain plants and plant products imported in the European Union (EU) is in place. Under this system, plants and plant products satisfying special criteria may be inspected with a reduced frequency. These criteria are based on the EU-wide data on historical volumes of import and interceptions of harmful organisms in particular products. The objective of this paper is two-fold. Firstly, the paper analyses whether proportions of interceptions of harmful organisms associated with cut flowers imported in the Netherlands- the largest EU importer of cut flowers- support the application of reduced checks for certain genera and trades (commodity-exporting country combinations) of cut flowers. Secondly, the paper analyses how effective the reduced checks system is in minimising the expected costs of introduction of harmful organisms in the EU. For that, a theoretically optimal system for allocating inspection effort to commodities is described. Using an illustrative example and stochastic simulations, the expected costs of introduction of harmful organisms under the theoretically optimal system and the current system of reduced checks are compared. Examination of interceptions of harmful organisms supports application of reduced checks for most genera and trades of cut flowers in the Netherlands. The results of stochastic simulations show that reduced checks may not minimize the expected costs of introduction of harmful organisms in the EU. Accounting for possible economic impacts of harmful organisms in determining the frequencies of reduced checks may help optimize the current system.

5.1 Introduction

The plant health regime of plants and plant products entering the EU is regulated by the EU Council Directive 2000/29/EC (European Council, 2000) (hereafter, Directive). Part B of Annex V to the Directive lists plants and plant products that have to be inspected upon import in the EU. Before April 1st 2003, only a few cut flower species imported in the EU had to be inspected (e.g. cut flowers in the genera *Dendranthema* and *Dianthus* L.). After this date, the EU Directive 2002/36/EC (European Commission, 2002a) introduced mandatory inspections of cut flower species representing a sizeable share of the EU import (e.g. cut flowers in the genera *Rosa* L., *Aster* L., *Trachelium* L., *Eryngium* L., *Lisianthus* L., *Solidago* L. and in the family *Orchidaceae* Juss.). In general, every consignment of plants and plant products listed in Part B of Annex V to the Directive must be subjected to a visual phytosanitary inspection. However, the EU Directive 2002/89/EC (European Commission, 2002b) introduced the possibility of reduced frequency of inspections - 'reduced checks'- for plant products satisfying certain conditions. These conditions are laid down in the EU Commission Regulation (EC) No 1756/2004 (hereafter, Regulation 1756) (European Commission, 2004). Regulation 1756 stipulates that reduced checks may be applied to a product originating from a given country (this combination is referred to as 'trade' (European Commission, 2007b)) provided that:

- the average number of consignments over three years of this product introduced into the EU each year is at least 200,
- the minimum number of consignments of this product for which inspections have been carried out during the previous three years is at least 600,
- the number of consignments of this product each year which were found infected by the harmful organisms mentioned in Annexes I and II to the Directive (henceforth, simply 'harmful organisms') is less than 1 % of the total number of consignments of this product imported into the EU.

Given that the conditions above are satisfied, the EU Commission determines the minimum percentages of plant health checks (MPPHCs). The EU member countries can choose to inspect any percentage of imported consignments between the MPPHCs and 100%. MPPHCs are defined based on (a) the number of consignments of the given product intercepted for the presence of harmful organisms; (b) the estimated mobility of the harmful organisms at the most mobile stage to which the organism could develop on the relevant plant or plant product; (c) the number of consignments of the products on which a physical plant health inspection has been carried out; (d) any other factor relevant to a determination of the phytosanitary risk from the product (Regulation 1756). Reduced checks should no longer apply if at least 1% of imported consignments of a given product is found infested with harmful organisms (Regulation 1756).

Since January 2005, reduced checks have been introduced for in total 53 trades of plants and plant materials (European Commission, 2007a). Sixteen of these trades are cut flowers belonging to the three genera- *Aster* L., *Rosa* L. and *Dianthus* L. (Table 1). Ten of these cut flower trades qualified for reduced checks in 2005 and the other six- in 2006. All these trades of cut flowers also qualified for reduced checks in 2007, although for some trades the MPPHCs have been changed (see Table 1).

Table 1 Cut flower trades with reduced checks[a] and percentage shares[b] of the Netherlands in the EU import along these trades in 2005

Ornamental species in genera	Country of origin	Minimum % of reduced checks		The volume share of the Netherlands in the EU import,%
		Before 01.01.2007	After 01.01.2007	
Aster L.	Zimbabwe[c]	25	50	n.a.
Dianthus L.	Colombia[c]	3	3	25.7
	Ecuador[c]	15	15	71.8
	Israel[d]	25	25	73.2
	Morocco[c]	25	50	4.6
	Turkey[c]	25	25	7.5
Rosa L.	Colombia[c]	10	5	17.2
	Ecuador[c]	5	5	56.8
	Ethiopia[d]	25	25	64.5
	India [d]	50	50	39.3
	Israel [d]	10	10	66.8
	Kenya[c]	5	1	79.1
	Tanzania[d]	25	25	78.0
	Uganda[c]	5	5	97.3
	Zambia[d]	10	10	96.3
	Zimbabwe[c]	5	25	93.6

[a] Source: European Commission (2007a)
[b] Source: authors' calculation based on Tables 3.1 and 3.2 in AIPH/Union Fleurs (2006)
[c] Reduced checks applied from January 1st, 2005
[d] Reduced checks applied from January 1st, 2006
n.a. data not available

Two aspects of the reduced checks system motivate this paper. Firstly, the criteria for reduced checks are based on the EU-wide data on import volumes and numbers of consignments intercepted due to the presence of harmful organisms. It is instructive to analyse how actual interceptions of harmful organisms in a given EU country compare with the EU-wide decision to apply reduced checks. Thus, the first objective of this paper is to analyse whether proportions of interceptions of harmful organisms associated with cut flowers imported in the Netherlands support the selection of species and trades of cut flowers for reduced checks in the EU in 2006. The paper focuses on the Netherlands because it is the largest EU importer of cut flowers

(AIPH/Union Fleurs, 2006) and has large shares in total EU imports of most cut flower trades which are currently subjected to reduced checks (Table 1). For analysis of interceptions of harmful organisms associated with specific trades, the focus is on trades in which the Netherlands has more than a 50% share of the overall EU import volume, plus *Aster* L. (Table 1). The proportions of interceptions of harmful organisms for relevant cut flower species and trades are calculated using the Dutch Plant Protection Service's (Plantenziektenkundige Dienst, PD) database on import inspections of cut flowers imported in the Netherlands in the period of 2003 to 2005.

The second aspect motivating this paper is the question how effective the reduced checks system is in minimising the expected costs of introduction of harmful organisms in the EU. The current reduced checks system is based only on factors that determine the probability of spread and establishment of harmful organisms. It does not account for the expected costs of introduction of harmful organisms, which may be organism-specific. In this paper, the expected costs of introduction of a harmful organism are defined as the product of the likelihood of introduction of a harmful organism and the associated costs of introduction. The costs of introduction of a harmful organism include *all* the costs arising *after* a harmful organism is established in an importing country and include e.g. the eradication and control costs, product losses and increased crop protection costs for the affected growers, losses of export markets, etc., but exclude the cost of import inspection. If expected costs of introduction of harmful organisms are included in the computation of MPPHCs, a different distribution of inspection activities over commodities and countries of origin may be necessary. Thus, to address this question, a theoretically optimal system for allocating inspection effort to commodities and countries of origin is presented. Using an illustrative example and stochastic simulations, the expected costs of introduction of harmful organisms under the theoretically optimal and current system of reduced checks are compared. The implications of the findings for design of the optimal system of reduced checks are discussed.

5.2 Materials and methods

5.2.1 Database and analysis of interceptions of harmful organisms

The Dutch PD records the results of phytosanitary inspections of ornamental cut flowers, materials for propagation, and potted and bedding plants imported in the Netherlands in a general database of import inspections. Part of this database, including records of inspections of cut flowers in the period of 2003 to 2005, was made available for this research.

Each record in the database contains information on inspection of one or more imported lots of a single species of cut flowers from a single country of origin. Lot is defined as ‘a number of units of a single commodity, identifiable by its homogeneity of composition, origin, etc. forming part of a consignment’ (IPPC, 2006c). A consignment is defined as ‘a quantity of plants, plant products and/or other articles being moved from one country to another and covered, when required, by a single phytosanitary certificate (a consignment may be composed of one or more commodities or lots) (IPPC, 2006c). Therefore, records in the database covered by the same phytosanitary certificate were parts of the same consignment. A single consignment could include lots of various cut flower species.

Information for each record was compiled based on the first-hand reports of the PD personnel who conducted inspections. The following information is available for every record in the database: the date of inspection, the name of the cut flower species (at the level of genus or family), the number of a phytosanitary certificate that was accompanying imported lot(s), the result of inspection (i.e. lot(s) were allowed or rejected for import) and reasons for rejection. Inspected lots could be rejected if a harmful organism mentioned in the Directive was detected, because of the absence (or incorrect/incomplete filling in) of the necessary documents (e. g. phytosanitary certificate) or the low quality of the ornamental species (e.g. wilted cut flowers). Because this paper focuses on rejections due to findings of harmful organisms, the database was examined to make sure that all rejections for this reason are correctly identified. In the remainder of the paper, terms ‘rejected’ and ‘intercepted’ when referring to consignments mean ‘rejected due to the presence of harmful organisms’.

Regulation 1756 stipulates that the eligibility of a given trade for reduced checks is evaluated based on the proportion of consignments intercepted because of the presence of harmful organisms. Because a consignment is identified by its phytosanitary certificate, to count the number of inspected and rejected consignments it is necessary to calculate the number of phytosanitary certificates in the database. Note, however, that more than one lot of the same cut flower species and country of origin may be covered by one phytosanitary certificate. For the purposes of this paper, the total number of phytosanitary certificates that accompanied the inspected and rejected lots was counted irrespective of the actual number of lots covered by these phytosanitary certificates.

Based on the underlying number of phytosanitary certificates, the percentage of rejected consignments for every species of cut flowers was calculated for each year in the period of 2003 to 2005. This procedure was repeated for trades of cut flowers that were subjected to reduced checks in 2005 and 2006 and in which the Netherlands has more than a 50% share of the total EU import (Table 1). Although the percentage share of the Netherlands import of *Aster* from Zimbabwe in the total EU import is unknown, because the Netherlands accounts for over 95% share of the total EU cut flower import from Zimbabwe (AIPH/Union Fleurs, 2006), this trade was also included in the analysis of interceptions of harmful organisms.

5.2.2 An optimal system of the reduced frequency of inspections

The reduced checks system could be cast as an explicit mathematical optimisation problem (Surkov et al., 2007a; Surkov et al., 2007b). Surkov et al. presented a general model of minimizing the expected cost from introduction of harmful organisms into an importing country when the latter has limited resources for inspection of all the risky trades. In this model, the expected costs of harmful organisms from all trades are taken into account in finding the optimal allocation of resources across trades. Importantly, the objective function includes both the costs and likelihoods of introduction of harmful organisms via particular trades. The intuitive result is that trades involving greater expected costs of harmful organisms receive *ceteris paribus* more resources than trades involving smaller expected costs of harmful organisms. In the end, such reallocation of resources leads to minimization of the total expected costs of harmful organisms from all the trades. (See Surkov et al. (2007c) for mathematical conditions underlying the optimal allocation). Importantly, the optimal allocation does not depend on any arbitrary selection threshold (i.e. 1% criterion).

An illustrative example

An illustrative example based on artificial data on interceptions of harmful organisms and the associated economic impacts is developed to find the frequency of inspections and the expected costs of harmful organisms under the optimisation approach and under the current system of reduced checks. The purpose of this example is to compare the properties of the optimisation approach and of reduced checks, when the amount of resources available for inspection is the same under both approaches. *A priori*, it should be noted that since the reduced checks system focuses on probabilities of spreading and establishment rather than on the expected costs of introduction of harmful organisms, this numerical illustration should be considered as an imperfect representation of the reduced check system. The following general assumptions underlie both reduced checks and the optimisation approaches in the numerical example:

1) A country *H* imports commodities through *q* trades. Each trade poses a risk of introducing at most one species of harmful organisms currently not present in *H*. Each consignment imported through the *q*th trade (q=1,…,Q) is assumed to have a probability p_q of introducing a harmful organism.
2) Let d_q denote the 'cost of a harmful organism', defined as the present value of future economic costs (e.g. value of crop losses and control costs) incurred in the importing country after successful introduction of the harmful organism via the *q*th trade.
3) Let D_q denote the 'expected costs of introduction of a harmful organism' via the *q*th trade, *when import inspection is not applied*. D_q is calculated as the product of the number of consignments imported along a trade, V_q, the historical proportion of

consignments found infested with harmful organisms, p_q, and cost of a harmful organism d_q associated with a trade.

4) The length of inspection of each and every consignment is fixed. The probability α not to detect a specimen of harmful organisms when it is present in a consignment at or above threshold incidence is also fixed and is the same for all trades, consignments and species of harmful organisms.

5) The expected costs from introduction of harmful organisms via the qth trade, *when the reduced checks are applied*, are calculated as $EC_q=D_q*(\theta_q*(100-\alpha)+(100-\theta_q))$, where $\theta_q\in[0,100]$ is the reduced percentage of checks applied for the qth trade

Following Surkov et. al, the objective function for the optimisation approach can be formulated as follows:

$$\text{Minimize:} \qquad \sum_q \left(N_q + \alpha I_q\right) p_q d_q \qquad (1)$$

$$\text{Subject to:} \qquad \sum_q I_q \leq \sum_q \theta_q V_q \qquad \forall\ q,$$

where I_q and N_q are, respectively, the numbers of inspected and uninspected consignments associated with the qth trade ($I_q+N_q=V_q$ is the total import volume along the qth trade) and θ_q was defined above. Thus, the objective in (1) is to minimize the expected costs due to introduction of harmful organism from inspected and not inspected consignments subject to the condition that the total number of the inspected consignments cannot exceed the total number of consignments inspected under reduced checks. The latter condition guarantees that the available amount of resources, represented by the maximum number of consignments that can be inspected, is the same under the optimisation approach and reduced checks.

For a numerical example, assume that there are five trades (Table 5), three of which (A, C and E) qualify for reduced checks based on the historical proportions of interceptions of harmful organisms (for simplicity, it is assumed that the remaining conditions for reduced checks mentioned in Regulation 1756 are satisfied). Furthermore, assume that exactly 25% of consignments coming through trades A, C and E are to be inspected. In this example, the values of costs of introduction of harmful organisms via particular trades are assumed arbitrary and used for illustration only. However, the values of costs associated with trades with reduced checks (i.e. A, C and E) were intentionally taken twice as high as those associated with trades without reduced checks (B and D) to represent the situation when trades with low percentages of interceptions of harmful organisms but higher costs of harmful organisms are approved for reduced checks and trades with opposite characteristics are not. (For implications of relaxing this assumption, see Results and Discussion). Finally, the probability to intercept a specimen of a harmful organism if it is present in a consignment is equal to 95% and is the same for all consignments and trades. Under these assumptions, without inspection, the expected costs of harmful organisms from all trades are equal to $\sum D_q$=66.2 euros. Application of reduced checks reduces the expected costs of harmful organisms to $\sum EC_q$=32.67 euros (Table 5).

Next, the total number of consignments inspected under reduced checks (2,750) is used as a constraint for the optimization model in (1). Two scenarios of optimal allocation are considered. In the first scenario (Optimal), no additional constraints on the optimal solution are imposed; the second scenario (Optimal_MP) constrains the minimum percentage of consignments to be inspected for each of the trades to at least 25%. Then, the frequencies of inspection and the expected costs of harmful organisms under these two scenarios are compared with their counterparts under the current reduced checks system.

A further analysis has been performed to show that the numerical results do not depend on the selected values of the proportions of interceptions of harmful organisms (p_q), costs of harmful organisms (d_q) and assumed percentages of inspected consignments (θ_q) given in Table 5. Specifically, it was assumed that these parameters follow p_q=Uniform[0,2%], d_q=Uniform[0, 10] and θ_q=Uniform[0,100%] distributions. All other parameters in Table 5 remained unchanged. All the scenarios- Reduced checks, Optimal and Optimal_MP- were then simulated 100 times. The minimum percentage of consignments to be inspected under the Optimal_MP scenario in each simulation was equal to the random realisation of the parameter θ_q (proportion of reduced checks) in this simulation. Realisations of the expected costs of harmful organisms in each simulation were recorded for all scenarios.

5.3 Results

5.3.1 Analysis of historical records of interceptions of harmful organisms

From 2003 to 2005, 59,958 consignments of cut flowers were inspected upon import in the Netherlands (Table 2). Almost 72% of these consignments pertained to cut flowers in genera *Rosa* L., *Gypsophila* L., *Solidago* L. and in the family *Orchidaceae* Juss. (Henceforth, when referring to cut flowers belonging to specific genera or family, a construction 'cut flowers' plus the first part of a scientific binomial of a respective genus or family of cut flowers is used). The number of inspected consignments increased sharply in 2005 compared to the previous two years because the PD switched from its own system of reduced inspections, with considerably smaller percentages of inspections, to reduced checks with MPPHCs at the EU level. From 2003 to 2005, 23,952 consignments (40% of all the inspected consignments) pertaining to 16 trades that are currently subjected to reduced checks in the EU (see Table 1) were inspected in the

Netherlands. Therefore, trades with reduced checks account for a considerable part of the overall import of ornamental cut flowers in the Netherlands.

Table 2 Imported consignments of cut flower species inspected in the Netherlands in 2003-2005*

Ornamental species in genera[a]	Year			Total 2003-2005
	2003	2004	2005	
Rosa L.	6,409	4,742	9,790	20,941
Gypsophila L.	1,826	1,677	5,705	9,208
Solidago L.	1,823	1,674	4,358	7,855
Orchidaceae Juss.	1,165	1,989	2,451	5,605
Dianthus L.	1,230	1,043	2,202	4,475
Aster L.	970	919	1,956	3,845
Trachelium L.	728	450	1,507	2,685
Lisianthus L.	586	569	1,413	2,568
Eryngium L.	605	183	853	1,641
Dendranthema	88	127	92	307
Hypericum L.	122	6	13	141
Species in other genera	45	180	462	687
Total	15,597	13,559	30,802	59,958

* Source: authors' calculations based on the PD database of import inspections
[a] Family, for *Orchidaceae* Juss.

In total, 697 consignments (1.2% of the inspected consignments) were rejected for import in the Netherlands in the period of 2003-2005 (Table 3). The number of rejected consignments increased significantly in 2005, consistent with an increase in the number of inspected consignments (see Table 2). Percentages of rejected consignments of *Solidago*, *Gypsophila* and *Orchidaceae* were consistently high, in excess of 1%, throughout the period.

Consignments of *Rosa* and *Dianthus* demonstrated consistently low percentages of rejections due to the presence of harmful organisms in the period 2003 to 2005. This suggests a high phytosanitary standard of these genera of cut flowers. The percentage of rejected consignments of *Aster* was lower than 1% in 2003 and 2005 but increased to 1.5% in 2004. The percentages of rejected consignments of other cut flower species, although occasionally falling below 1%, in most years were sufficiently higher than 1%.

Among 16 trades of cut flowers subjected to reduced checks in the Netherlands in the period 2003-2005, only *Rosa* from Zimbabwe had more than one percent of intercepted consignments, in 2005 (Table 4).

Table 3 Consignments of cut flowers rejected for import in the Netherlands due to the presence of harmful organisms, 2003-2005*

Ornamental species in genera[a]	Year						2003-2005	
	2003		2004		2005			
	No	%[b]	No	%[b]	No	%[b]	No	%[b]
Rosa L.	14	0.22	19	0.40	39	0.40	72	0.34
Gypsophila L.	38	2.08	20	1.19	81	1.42	139	1.51
Solidago L.	52	2.85	45	2.69	116	2.66	213	2.71
Orchidaceae Juss.	22	1.89	25	1.26	35	1.43	82	1.46
Dianthus L.	8	0.65	3	0.29	18	0.82	29	0.65
Aster L.	7	0.72	14	1.52	8	0.41	29	0.75
Trachelium L.	9	1.24	4	0.89	38	2.52	51	1.90
Lisianthus L.	9	1.54	5	0.88	28	1.98	42	1.64
Eryngium L.	6	0.99	4	2.19	16	1.88	26	1.58
Dendranthema	0	0.00	3	2.36	3	3.26	6	1.95
Hypericum L.	6	4.92	0	0.00	0	0.00	6	4.26
Species in other genera	0	0.00	2	1.11	0	0.00	2	0.29
Total	171		144		382		697	

* Source: authors' calculations based on the PD database of import inspections
[a] Family, for *Orchidaceae* Juss.
[b] Relative to inspected consignments (Table 2)

Table 4 Percentage of consignments through trades with reduced checks rejected for import in the Netherlands due to the presence of harmful organisms*, 2003-2005

Ornamental species in genera	Country of origin	Year			Total number of inspected consignments in 2003-2005
		2003	2004	2005	
Aster L.	Zimbabwe	0.00	0.19	0.49	1,702
Dianthus L.	Ecuador	0.00	0.00	0.00	545
	Israel	0.00	0.00	0.78	770
Rosa L.	Ecuador	0.00	0.00	0.00	2,070
	Ethiopia	0.00	0.00	0.09	2,527
	Israel	0.22	0.18	0.82	3,176
	Kenya	0.23	0.29	0.00	4,006
	Tanzania	0.00	0.00	0.32	849
	Uganda	0.08	0.83	0.75	1,774
	Zambia	0.00	0.00	0.47	1,713
	Zimbabwe	0.19	0.38	1.30	1,593

* Source: authors' calculations based on the PD database of import inspections

Cut flowers of *Rosa* and *Dianthus* from Ecuador had no rejected consignments over three years, despite a large number of inspected consignments, suggesting consistently high phytosanitary standards of consignments imported through these trades. For other cut flower trades, a small year to year variation of the proportion of rejected consignments is noticeable (e.g. for *Rosa* from Zimbabwe and Uganda).

Table 5 Calculation of the expected costs of harmful organisms with and without reduced checks for the numerical illustration

Notation	Description	Trade					Total	Units
		A	B	C	D	E		
p_q	Percentage of interceptions of harmful organisms in previous three years	0.98	1.50	0.10	1.00	0.98	-	%
d_q	Cost of harmful organisms per trade	2	1	2	1	2	-	Euros
V_q	Expected number of consignments	1,000	1,000	1,000	1,000	1,000	5,000	No
D_q	Expected costs of harmful organisms without reduced checks $=p_q d_q V_q$	19.6	15	2	10	19.6	66.2	Euros
θ_q	Percentage of inspected consignments	25	100	25	100	25	-	%
α	Inspection efficacy	95	95	95	95	95	-	%
I_q	Inspected consignments under reduced checks = $V_q * \theta_q$	250	1,000	250	1,000	250	2,750	No
EC_q	Expected costs of harmful organisms after reduced checks (inspected +uninspected consignments) = $D_q*(\theta_q *(100\%-\alpha)+(100\%-\theta_q))$	14.95	0.75	1.53	0.50	14.95	32.67	Euros

5.3.2 Comparison of the expected costs of harmful organisms under reduced checks and optimal approach

The results show that the two scenarios with optimal allocation yield significantly lower total expected cost of harmful organisms than the current system of reduced checks (Table 6). The same mechanism is behind both scenarios: other things being equal, more resources are allocated to trades with higher expected cost of harmful organisms per consignment. Under the Optimal scenario, consignments of only three trades (A, B and E) are inspected, because the expected costs of harmful organisms per consignment of these three trades are higher than that of the remaining two trades (C and D). Thereby, trades A and E are inspected fully, whereas trade B, with lower expected costs of harmful organisms, is inspected partially.

Although the solution of the Optimal scenario is the optimal one under the assumptions of the numerical example, it may not be the best solution from a practical phytosanitary perspective because 1) harmful organisms may still be associated with uninspected trades, 2) importers along uninspected trades may become more lax and pay less attention to the phytosanitary quality of imported commodities, 3) no inspection of some trades forgoes the important task of monitoring trends in arrival of known harmful organisms and of new organisms that may potentially become harmful. Scenario Optimal_MP (i.e. at least 25% of imported consignments is inspected) addresses these concerns. The expected costs of harmful organisms under this scenario are also notably lower than under reduced checks (Table 6). Thus, even with the same minimum percentage of consignments to be inspected (i.e. 25%), the Optimal_MP scenario yielded noticeably lower expected costs of pest introduction than reduced checks. At the same time, the expected costs of introduction of harmful organisms under the Optimal_MP are greater than under the Optimal scenario because in the former scenario, consignments coming through trades with strictly lower expected costs of harmful organisms per consignment (i.e. trades C and D) have to be inspected.

Table 6 The number of inspected consignments and the expected costs of harmful organisms under reduced checks and optimal allocation models

Scenario	Inspected consignments					Total number of inspected consignments	Expected cost of harmful organisms, euros
	A	B	C	D	E		
No inspection	-	-	-	-	-	-	66.2
Reduced checks	250	1,000	250	1,000	250	2,750	32.67
Optimal	1,000	750			1,000	2,750	18.27
Optimal_MP	1,000	250	250	250	1,000	2,750	22.54

The numerical example, although simplified, suggests that the reduced checks system is not minimizing the expected costs of harmful organisms and is not providing the optimal allocation of inspection effort. This can be further demonstrated by the results form stochastic simulations (Figure 1). Panels A and B in Figure 1 illustrate that the expected costs of harmful organisms under the optimal scenarios were in most cases lower and never higher than the corresponding expected costs of harmful organisms under reduced checks (all circles are above or on the 45-degree lines). Panel C shows that any reallocation of resources away from the optimal scenario leads to higher expected costs of harmful organisms. However, the proximity of the circles to the 45-degree line indicates that in many cases solutions under Optimal_MP and Optimal scenarios are close.

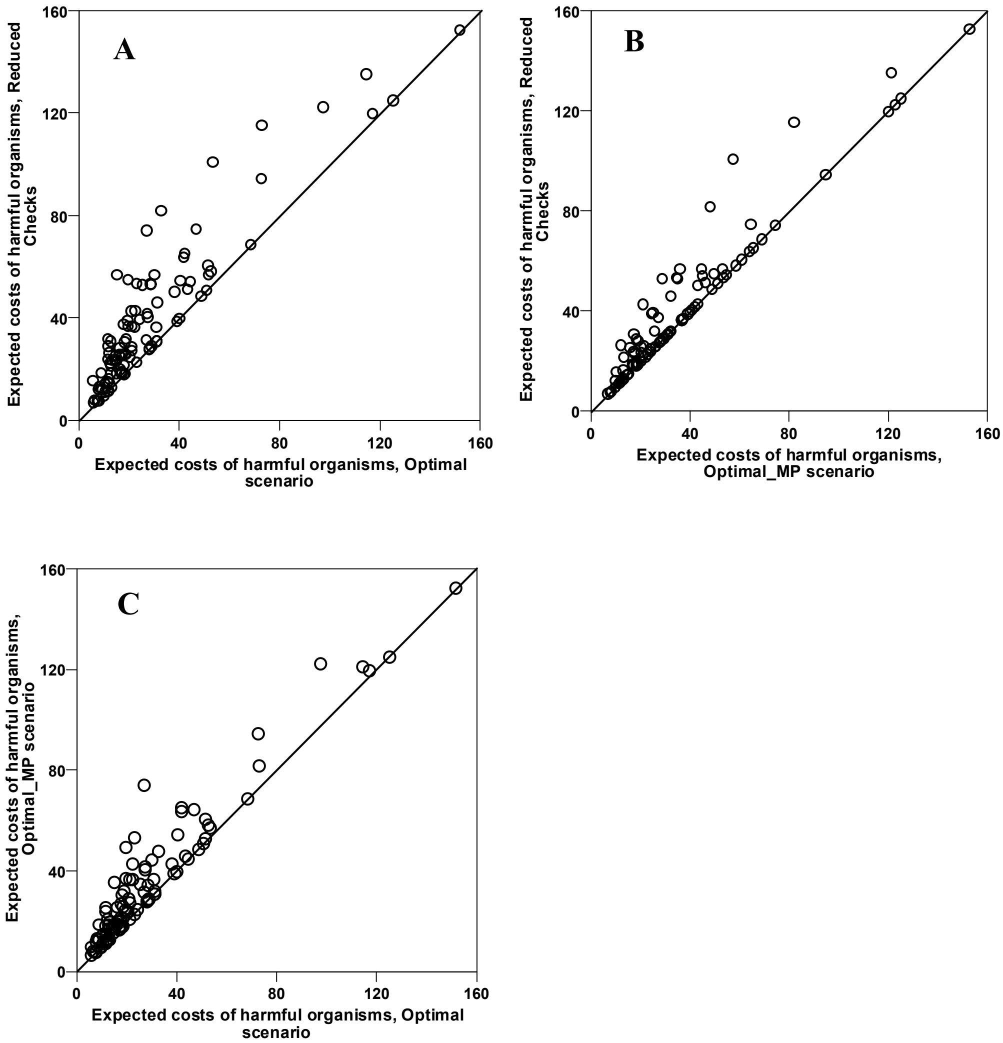

Figure 1 Scatter plots of the expected costs of harmful organisms for various scenarios when the proportions of interceptions, costs of harmful organisms and percentages of inspected consignments are stochastic: A Optimal vs Reduced Checks; B Optimal_MP vs Reduced Checks; C Optimal vs Optimal_MP

The differences between the results of the optimisation approach and reduced checks would be smaller if in the numerical illustration equal costs of harmful organisms (or percentages of rejected consignments) had been assumed for different trades. Then, all the scenarios would be based on a single decision parameter- the percentage of intercepted consignments (respectively, cost of harmful organisms), which would increase the likelihood of obtaining similar results under different scenarios. In fact, because of the same (by assumption) minimum percentages of inspections under the Optimal_MP and Reduced Checks scenarios, their results would be identical. The Optimal scenario would yield lower expected costs of harmful organisms than the Reduced Checks scenario but circles in Figure 1A would be closer to the 45-degree line and more of the circles would lie on the line itself.

5.4 Discussion

The first objective of this study was to examine whether interceptions of harmful organisms associated with cut flowers imported in the Netherlands support the ongoing application of reduced checks for certain species and trades of cut flowers in the EU. The results provide clear support for application of reduced checks for cut flowers of *Rosa* and *Dianthus*: the proportions of interceptions of harmful organisms associated with these genera of cut flowers were consistently low in the period 2003-2005 compared to cut flowers in other genera. Furthermore, the results support application of reduced checks for most trades of cut flowers, except *Rosa* from Zimbabwe. Nevertheless, this trade qualified for reduced checks in 2006 in the EU. This discrepancy is probably due to 'dilution' of the higher proportions of interceptions of harmful organisms in the Netherlands by their lower counterparts elsewhere in the EU.

Discrepancies between proportions of interceptions of harmful organisms and the application of reduced checks at the EU level may occur in any EU country. Different EU countries have different volumes and structure of imports that may justify different inspection policies than those for the entire EU. In case that the EU member country's data do not justify the application of reduced checks for a certain trade, the country may simply increase the frequency of inspection to 100%. However, when the proportion of interceptions of harmful organisms is sufficiently low (as in the present study was the case for *Rosa* and *Dianthus* from Ecuador) to justify lower MPPHCs than those for the entire EU, an importing country is not permitted to do so. Obviously, if single EU member countries were allowed to lower their MPPHCs compared to those of the entire EU, this could lead to (possibly, undesirable) redistribution of trade flows toward member states with lowest MPPHCs.

It should be mentioned that there is an inconsistency between the criteria to qualify for reduced checks - they are determined at the level of *consignments*, and actual implementation of the plant health inspections in the EU - these should be conducted at the level of individual *lots* in multi-lot consignments (article 13a of the Directive). When more than one lot of a single species from a single exporting country is present in imported consignments, proportions of interceptions of harmful organisms determined at the level of *lots* and at the level of *consignments* may differ for a given trade. This difference depends on whether infested lots are clustered in or evenly distributed among the infested consignments. Potentially, this difference could lead to opposite decisions on the eligibility of a given trade for reduced checks depending on whether the proportion of interceptions is calculated at consignment or lot level. A priori, the probability of this situation is unknown but its possibility should nevertheless be considered.

The second objective of the paper was to analyse the optimality of reduced checks. Using a numerical example and stochastic simulations, the expected costs of introduction of harmful organisms were compared under the theoretically optimal scenarios Optimal and Optimal_MP and under reduced checks. The results show that in most simulations, the optimal scenarios yielded lower and never higher expected costs of harmful organisms than reduced checks. Of the two optimal scenarios, Optimal_MP seems more attractive from the phytosanitary perspective because it gives a more optimal solution than reduced checks and because of possessing the useful properties of importers' surveillance and monitoring the arrival rate of harmful organisms, which are lacking in the Optimal scenario. Altogether, the results of the numerical simulations suggest that under reduced checks, the expected costs of introduction of harmful organisms in the EU may not be minimised for the available amount of resources. The divergence of solutions under reduced checks from the optimal ones is greater when both the costs and the probability of introduction of interceptions differ among risky trades. This suggests that accounting for potential economic impacts of harmful organisms in determining MPPHCs will increase the efficacy of the reduced checks system. In other words, the analysis illustrates that targeting limited resources for inspection of those trades that can cause the largest economic impact is more cost-effective than applying the reduced check system, in which only the probability of introduction and probability of establishment are taken into account but not the economic impacts of harmful organisms.

One should recognise the limitations of the presented numerical example. Currently, key information of the reduced checks system, such as how MPPHCs are exactly calculated, is not publicly available. It was thus impossible to develop a numerical application that would perfectly represent the current system of reduced checks. A limitation of the optimisation approach is that it may seem less transparent than the current system of reduced checks, which is based on clear (except the calculation of MPPHCs) criteria. Consequently, if the optimisation approach is implemented in reality, importers may not appreciate why a certain commodity with low proportion of intercepted consignments requires greater inspection frequency (because of the high *expected* costs of harmful organisms). Nevertheless, the results of this study suggest that it may be worthwhile to develop plant health inspection policies in the EU (or elsewhere) using more explicit optimization approaches.

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Chapter 6 Modelling the rejection probability in plant imports

Based on: Surkov, I.V., van der Werf, W., van Kooten, O. and Oude Lansink, A.G.J.M. 2007. Modelling the rejection probability in plant imports. *Submitted*.

Abstract

Phytosanitary inspection of imported plants and flowers is a major means for preventing pest invasions through international trade, but in a majority of countries resources do not allow inspection of all imports. Prediction of the likelihood of pest infestation in imported shipments could help maximize the efficiency of inspection by targeting inspection on shipments with the highest likelihood of infestation. This paper applies a multinomial logistic (MNL) regression model to data on import inspections of ornamental plant commodities in the Netherlands from 1998 to 2001 to investigate whether it is possible to predict the probability that a shipment will be (i) accepted for import (ii) rejected for import because of detected pests or (iii) rejected due to other reasons. Four models were estimated: (i) an All-species model, including all plant imports in the data set (ii) a 4-species model, including records on the four ornamental commodities that accounted for large numbers of imported and rejected shipments, and two models for single commodities with a large import volume and high numbers of rejections (iii) Dianthus and (iv) Chrysanthemum. All models were highly significant ($P<0.001$). The models for Dianthus and Chrysanthemum and for the set of four ornamental commodities showed a better fit to data than the model for all ornamental commodities. Variables characterizing the imported shipment's region of origin, the shipment's size, the company that imported the shipment, and season and year of import, were significant in most of the estimated models. The combined results of this study suggest that the MNL model can be a useful tool for modelling the probability of rejecting imported commodities even with a small set of explanatory variables. The MNL model can be helpful in better targeting of resources for import inspection. The inspecting agencies could enable development of these models by appropriately recording inspection results.

6.1 Introduction

International trade is considered as the major vector for spread of nonindigenous pests and pathogens (henceforth, pests) in the world (Campbell, 2001; Jenkins, 1996; National Research Council of the United States, 2002). Introduction and establishment of pests in the territories of importing countries may lead to tremendous economic losses (Pimentel et al., 2005; Schaad et al., 2006). Border phytosanitary inspection of incoming commodities is a major means for preventing pest invasion associated with international trade.

The volumes of imported commodities requiring inspection are ever-increasing as a consequence of a general growth of world trade. For example, it has been reported that an increasing percentage of air cargo imported in the United States consists of cut flowers, fruits and vegetables (National Plant Board, 1999). In Japan, a 150-fold increase in the volume of the inspected cut flowers was observed between 1970 and 1998 (Kiritani, 2001). The number of commodity pathways (commodity-exporting country combinations) to be inspected is also increasing. This may reflect both the natural emergence of new import pathways (e.g. a given country starts exporting a commodity that it did not export before) and also the inclusion of new pathways requiring inspection according to legislation of the importing countries. For example, the recently enacted European Council Directive 2000/36/EC implied a significant increase in the number of commodities and pathways that require inspection upon import in the European Union (EU) (European Commission, 2002a).

Overall, there is a significant pressure on inspecting agencies to provide an adequate level of inspection of imported commodities. In fact, given usually limited resources of the inspecting agencies (National Research Council of the United States, 2002), a complete inspection of all commodities requiring inspection is almost impossible (U.S. Office of Technology Assessment, 1993). Several importing countries have attempted to solve this problem by allowing for a reduced inspection frequency of commodities along risky commodity pathways. For example, the system of ‘reduced checks’ (European Commission, 2004) recently introduced in the EU implies that for some commodity pathways (e.g. of cut flowers), the proportion of shipments that receives inspection may be reduced. In the United States, inspection is based on a random sampling within the population of incoming commodities (U.S. Department of Agriculture, 1998). When only a fraction of the overall population of commodity pathways (or shipments within commodities pathways) can be inspected, it is crucial to make a proper choice of the objects to inspect. A quantitative analysis of factors that influence the probability of rejection of imported commodities because of pest infestation can be very helpful in designing efficient inspection schemes. Little research in this area has been done (Caton et al., 2006; Dobbs and Brodel, 2004). Studies that quantitatively analyzed pest interceptions pertaining to (groups of) specific commodities (Brockerhoff et al., 2006; Haack, 2001;

McCullough et al., 2006; Work et al., 2005) generate results that are not easily generalized to a context of multiple commodities, nor do they provide *a priori* predictions for new pathways. There is a need for general models that would allow prediction of the risk of pest infestation across commodities and countries of origin, such that *ex ante* risk assessments could be made *before* familiarity with a new import pathway is obtained during import practice.

In this paper, multinomial logistic (MNL) regression is applied to investigate whether the probability of rejecting imported commodities due to phytosanitary and non-phytosanitary reasons can be predicted on the basis of generally available variables characterizing the shipment of an imported commodity. Explanatory variables also represent the economic characteristics of an exporting country of a shipment to test whether these characteristics are significant for predicting the likelihood of rejecting imported shipments. An MNL model is proposed in this study instead of the more familiar binary logistic model because commodities may be rejected for import due to both phytosanitary (i.e. a pest is found) and non-phytosanitary reasons (e.g. poor quality of the commodity or the absence of required documents). Non-phytosanitary reasons for rejecting shipments may actually indicate potential phytosanitary problems associated with an imported shipment. Therefore, a MNL model can generate useful insights into factors underlying quality problems in imported commodities both on phytosanitary and non-phytosanitary grounds. Furthermore, as the MNL model essentially represents a linked set of binary logistic models, parameter estimates in the MNL model are consistent with parameter estimates of the binary logistic models (Scott Long, 1997).

The explanatory variables were selected from a data set with results of phytosanitary inspections of ornamental plant commodities imported in the Netherlands from 1998 to 2001. Using this data set, we explore the generality of the parameter estimates of the MNL model by fitting it to single ornamental commodities, to a subset of ornamental commodities and to all ornamental commodities in the data set. Thereby we address the questions: (i) is it possible to predict the probability of pest infestation, using an MNL model? (ii) what is the explanatory power of an MNL model in this context? (iii) is it possible to build a general model that can be used across different commodities and countries or regions of origin, or can predictions only be made for specific commodity-country combinations? (iv) which variables characterizing imported shipments can be considered as risk or non-risk factors, indicative of high, respectively, low probability of pest infestation?

6.2 Materials and methods

6.2.1 Data collection

This research uses a data set compiled by the Dutch Plant Protection Service (Plantenziektenkundige Dienst, PD). The data set contains the results of phytosanitary inspections of ornamental plant commodities (cut flowers, ornamental plants and materials for propagation) imported in the Netherlands from February 9th, 1998, to December 31st, 2001. There were 136,251 records in the data set. Each record represents a single shipment of an ornamental commodity from a single exporting country. At the moment of inspection, a single shipment may have consisted of smaller units - lots - that could be distinguished by e.g. a cultivar or producer (Jan Schans, PD, *personal communication*), but this information is not retained in the data set. Thus, a record of inspection of one shipment is the smallest unit for the numerical analyses presented here.

For every record in the data set, the following information was available: the name and the exporting country of an ornamental commodity; the shipment size- the total size (e.g. number of cut flower stems) of the individual lot(s) within a single data set record; the unique number of a Dutch importing company; the inspection report number; the date of inspection; the outcome of inspection ('rejected' or 'imported'); and the reasons of rejection of a shipment. The reasons of rejection could be phytosanitary– a pest was found in a shipment or non-phytosanitary– the absence or incomplete/incorrect filling in of the necessary documents (such as the phytosanitary certificate) or an inadequate quality of the commodity (e.g. wilted cut flowers). The data set was examined to make sure that each record is classified as 'rejected due to phytosanitary reasons', 'rejected due to non-phytosanitary reasons', or 'not rejected'.

In total, 881 shipments (0.65% of all shipments) were marked as rejected for import in the Netherlands in the period of 1998 to 2001. Of these shipments, 456 (0.33% of all shipments) were marked as rejected due to findings of pests and 425 shipments were marked as rejected due to other reasons. Pests that caused the rejection of a given shipment had to be of quarantine significance and mentioned in plant health directives of the EU (European Commission, 1976; European Council, 2000).

Upon a decision to reject a plant import, the general PD practice was to split the original shipment that had been found infested during import inspection, into an infested and a non-infested parts if such splitting was possible based on unique and objective criteria, such as supplier in the exporting country, variety, or other criteria (Jan Schans, PD, *personal communication*). If splitting had occurred, information on the infested and non-infested parts of a shipment was entered in the data set as two separate records. This practice could artificially affect a relationship, if extant, between the size of plant imports and the probability of rejection. We considered splitting possible if under the same inspection report number more than one record of the same commodity from the same exporting country as the infested record was present. Approximately 40% of records of rejected shipments were identified as possibly being formed by splitting the original shipments.

Statistical analyses on both the data set that included all the records and one that included only records for which splitting of rejected shipments was considered impossible because the corresponding inspection reports contained only one record of a single commodity from a single exporting country. The results were practically identical irrespective of which underlying data set was used. Therefore, all the results reported in this paper are based on the entire data set of import inspections.

6.2.2 Explanatory variables

The International Standard on Phytosanitary Measures (ISPM) No 23 'Guidelines for Inspection' issued by Secretariat of the International Plant Protection convention (IPPC) (IPPC, 2006d) was followed as a guidance for selecting relevant explanatory variables. The ISPM No 23 lists factors that may be considered when making a decision to use inspection as a phytosanitary measure. Based on this standard, we specified variables describing: (i) exporting country, (ii) commodity, (iii) importing company, (iv) shipment and (v) year and season of import. In addition, we specified a number of explanatory variables representing the economic and geographic characteristics of the exporting country using the data obtained from the Dutch Agricultural Economics Research Institute (Theuws et al., 2003). Table 1 presents the explanatory variables and their descriptive statistics.

Exporting country characteristics. The first eleven variables represent geographical regions and income classes of the exporting countries according to the World Bank classification (World Bank, 2006). The following three variables characterize the importance of agricultural exports to the exporting country: AGRTOT (the share of agricultural exports in total exports), CUT (the share of exports of cut flowers in agricultural exports) and PLANT (the share of export of potted plants in agricultural exports). These variables are included to test the hypothesis that the exporting country's agricultural specialization may influence the probability of rejecting a shipment.

Commodity characteristics. The binary variables DIANTHUS, CHRYS, FICUS and DENDROB represent the ornamental plants in genera *Dianthus*, *Chrysanthemum*, *Ficus* and *Dendrobium*, that from 1998 to 2001 collectively accounted for 68% of shipments rejected due to the presence of pests and 29% of shipments rejected on non-phytosanitary grounds. Furthermore, shipments of these ornamental commodities accounted for approximately a third of all inspected shipments (Table 1).

Importing company characteristics. The variables NSPECIES and D1000+ test whether shipments destined for Dutch companies importing, respectively, many different ornamental species or many shipments of ornamental species, have greater probabilities of being rejected. PHYTOM is a binary variable equal to one if the company that imported the shipment possessed the quality certificate 'Phytomark'. From 2000 to 2003, this certificate was conferred on Dutch companies that complied with a set of rules, representing good phytosanitary and quality

Table 1. Descriptive statistics of the explanatory variables, n=136,075

Variable	Description	Mean	Standard deviation
Variables related to the exporting country			
RMN[a]	situated in Middle East and North Africa	0.26	0.44
REU[a]	situated in Europe and Central Asia	0.07	0.26
REA[a]	situated in East Asia and Pacific	0.14	0.34
RLA[a]	situated in Latin America and the Caribbean	0.28	0.45
RNA[a]	situated in North America	0.02	0.15
RSA[a]	situated in South-East Asia	0.05	0.21
RSS[a]	situated in Sub-Saharan Africa	0.18	0.38
I1[ab]	is a low income country	0.18	0.38
I2[a]	is a middle low income country	0.41	0.49
I3[a]	is a middle high income country	0.10	0.30
I4[a]	is a high income country	0.32	0.47
AGRTOT	share of agricultural exports in total exports	27.1	22.9
CUT	share of cut flowers in agricultural exports[c]	61.3	58.4
PLANT	share of pot plants in agricultural exports[c]	14.7	15.2
Variables related to imported commodity			
DIANTHUS[a]	Dianthus (*Dianthus caryophyllus* L.)	0.17	0.37
CHRYS[a]	Chrysanthemum (*Chrysanthemum* L.)	0.07	0.25
FICUS[a]	Ficus (*Ficus* L.)	0.03	0.17
DENDROB[a]	Dendrobium (*Dendrobium* Sw.)	0.03	0.16
Variables related to importing company			
NSPECIES	the number of different ornamental species imported by a single importing company	83.32	78.52
D1000+[a]	importing company with volume of import greater than 1,000 shipments	0.58	0.49
PHYTOM[a]	importing company possessing the Phytomark certificate	0.11	0.31
Variables related to shipment			
LOG_SIZE	natural logarithm of shipment size	8.39	2.59
Variables representing season and year of import			
S1[a]	December, January or February	0.28	0.45
S2[a]	March, April or May	0.31	0.46
S3[a]	June, July or August	0.20	0.40
S4[a]	September, October or November	0.21	0.41
Y98[a]	Year 1998	0.21	0.41
Y99[a]	Year 1999	0.25	0.43
Y00[a]	Year 2000	0.27	0.44
Y01[a]	Year 2001	0.27	0.45

[a] Binary variable, equal to 1 if an record satisfies the property and 0 otherwise.
[b] Binary variables of income class do not sum up to one due to rounding
[c] Calculated as- cut flowers (pot plants)/overall agricultural exports*1000. The factor '1000' is used because in many countries the shares of cut flowers and pot plants in agricultural exports are negligible.

practices in horticultural production. Obtaining the certificate was difficult and costly. This may explain why the proportion of shipments imported by companies possessing the 'Phytomark' certificate was relatively low (Table 1). *Characteristics of a shipment*. LOG_SIZE is the natural logarithm of the number of units (e.g. of cut flowers, potted plants or cuttings) in a shipment. This variable is used to test whether the size of a shipment can be important in predicting the likelihood of rejecting a shipment.

Season and year of import. The last eight binary variables (Table 1) represent the season and year of import of a shipment. These variables are included in the model to test the hypothesis that the likelihood of rejecting shipments is significantly associated with seasons or years of import.

For 4,554 records (3.34% of the data set) the values for the variables representing export characteristics (AGRTOT, CUT and PLANT) were missing. Missing data mostly pertained to smaller exporting countries with limited data availability. We replaced the missing values by the averages of variables AGRTOT, CUT and PLANT calculated for the countries belonging to the same income class as the country for which information was unavailable. After replacement, 161 (0.12% of the data set) missing values were left; these values were omitted from the analysis.

6.2.3 The MNL model

Three mutually exclusive outcomes were defined as the response variable for import inspection (i) a shipment is accepted for import (ii) a shipment is rejected due to the presence of a pest and (iii) a shipment is rejected due to other reasons. The MNL model (Scott Long, 1997) predicts the probability of observing one of the above outcomes for the *i*th shipment of ornamental species with a given set of explanatory variables. For estimation purposes, the above outcomes were assigned values 0, 1 and 2, respectively. The probability to observe the *j*th (j=0, 1, 2) inspection outcome for the *i*th imported shipment is given by:

$$prob(Y_i = j | X_i) = \frac{\exp(\beta_j' X_i)}{\sum_{j=0}^{j=2} \exp(\beta_j' X_i)} \qquad j=0,1,2$$

where $\beta_j' X_i$ represents $\sum_k \beta_{kj} x_{ik}$, and β_{kj} are the k parameters to be estimated for j inspection outcomes and X_i is the vector of k explanatory variables.

Because the probabilities of alternative inspection outcomes should sum up to one, it is sufficient to estimate equations for two inspection outcomes. Likewise, parameter vectors β'_j need be estimated for two outcomes j only. One inspection outcome - shipment is not rejected (j = 0) - is thus dropped from estimation and represents the reference situation. The corresponding parameter vector is β'_0=0. Parameter estimates β_{kj} for the other two outcomes represent the change in the natural logarithm of odds of rejection due to pest or due to other reasons, relative to the reference outcome (shipment is not rejected), following a unit change in the independent variable x_k. Thus, the change in the odds of obtaining one of the two inspection outcomes versus the reference outcome is given by exp(β_{kj}). In general, a positive value of the estimated parameter implies that the probability of rejection due to pest or due to other reasons increases, while a negative value indicates the opposite.

The MNL model is estimated using maximum likelihood. A relevant measure of model fit is R^2_L (Menard, 2000) - a logistic regression analogue of a coefficient of determination in linear models. R^2_L is calculated as $1-\ln L(\mathrm{Full}) / \ln L(0)$, where lnL(Full) is the log-likelihood of a model with all explanatory variables while lnL(0) is the log-likelihood of a model with the intercept only. A greater value of the R^2_L generally indicates a better model fit. Due to the binary nature of the observations (0 or 1), the absolute magnitude of R^2_L measures used in logistic regression is considerably lower than of the R^2 in linear models (Cox and Wermuth, 1992).

6.2.4 Estimated models

We applied the same set of explanatory variables to estimate four models. The 'All-species' model included all records in the data set. The '4-species' model included records pertaining to four genera of ornamental plants: Dianthus, Chrysanthemum, Dendrobium and Ficus. The remaining two models, denoted 'Dianthus' and 'Chrysanthemum', included records on the respective genera of ornamental plants only. The rationale for distinguishing the above four models is the following. From the inspection policy perspective, it is preferable to have a general model that can be applied to all ornamental commodities (All-species model). However, it is *a priori* questionable whether regression coefficients are consistent across commodities. For instance, in one commodity there may be a systematic trend that shipments from Asia are less often rejected than those from Africa, whereas for another commodity, the trend could be reversed. Thus, it may occur that models applied to subsets of the data provide a better explanation of those data than an overall model. The parameterization of models with one, few or many ornamental commodities serves a purpose to explore the generality of parameter estimates in the MNL models as a tool in the prediction of likelihood of rejection in plant imports.

All models were estimated using the NOMREG procedure in SPSS 12.0 (SPSS Inc., Chicago, USA). Estimated equations for the 4-species and All-species models included all explanatory variables. In the Dianthus and Chrysanthemum models, we used the SPSS backward elimination procedure that sequentially eliminated non-significant variables at P=0.1 (χ^2 test), to select the best set of explanatory variables.

Only k-1 binary variables representing geographical region, income class, season and year of import, and individual ornamental commodities (in 4-species model) need to be estimated for each group of these variables (with k values) to avoid redundancy. One binary variable for each of these groups was omitted, creating thus a reference situation with which the obtained parameter estimates should be compared. In all the models, the reference situation represents a shipment imported in 1998 (Y1998), from a high-income country (I1), and imported in winter (S1). In addition, in the All-species model, there is also a reference region - Middle East and North Africa (RMN), and in the 4-species model- a reference commodity- *Ficus*.

Prior to estimation, we examined binary variables in all models for data separation (Albert and Anderson, 1984). Data separation occurs when an explanatory variable has no records pertaining to one or more categories of the dependent variable. If such a predictor is left in the model, its maximum likelihood estimate may not exist (Albert and Anderson, 1984). In the 4-species and Dianthus and Chrysanthemum models we detected a number of variables that suffered from data separation. We subsequently omitted the variables from the estimated equations, such that the data separation problem was solved.

6.2.5 Correlations between variables

We examined possible correlations between variables using PROC CORR procedure of SAS (SAS Institute Inc., Cary, NC, USA). Correlations between continuous variables were examined using Pearson correlation coefficients. Correlations between continuous and binary variables were examined using nonparameteric Kendall correlation coefficients. Associations between binary variables were tested using two-way contingency tables; null hypotheses of independence were explored using chi-square tests.

We found high and significant correlations between continuous variables AGRTOT, CUT and PLANT in data sets of all 4 estimated models. We omitted the variable PLANT from all estimated equations as it was highly correlated with the other two variables. Furthermore, we found high and significant (P<0.001) correlations between the variables AGRTOT and CUT and some of the binary variables representing geographical position and income class of an exporting county. We used these correlations for interpreting estimation results (Mila et al., 2003).

6.3 Results

6.3.1 4-species and All-species models

Likelihood ratio (LR) χ^2 statistics shows that the 4-species and All-species models were highly significant (P<0.001) (Table 2). According to R^2_L, the 4-species model fitted data better than the All-species model. This confirms the hypothesis that a model for predicting the probability of rejection has a better fit when it is based on data pertaining to a limited set of ornamental species rather than many.

The share of agricultural export in total exports is positively and significantly (P<0.05) associated with the likelihood of rejecting a shipment in the 4-species model. The share of cut flower export in agricultural exports is a highly significant (P<0.001) and negative predictor of the likelihood of rejection in the All-species model. Parameter estimates indicate that shipments coming from Europe or Latin America are significantly less likely to be rejected on phytosanitary grounds than shipments coming from other regions (4-species model) and the reference region (Middle East and North Africa, All-species model). Furthermore, parameter estimates of regional variables RNA (North America) and RSA (South Asia) are also significant (P<0.05) and negative in the All-species model. However, none of the regional variables in both models was significant in predicting the probability of rejecting shipments due to non-phytosanitary reasons.

Variables representing the income class of an exporting country did not show a significant association with the likelihood of rejecting shipments on phytosanitary grounds in the 4-species or All-species model. This lack of statistical significance is due to high correlations between variables representing the income class of exporting countries and the variables AGRTOT and CUT. For example, high-income countries (variable I4) tended to have a greater share of agricultural exports in total exports and lower shares of cut flower exports in agricultural exports. When the 4-species and All-species models were estimated without variables AGRTOT and CUT, most income variables became significantly associated with the likelihood of rejecting shipments on phytosanitary grounds. At the same time, positive parameter estimates of variables representing low (I2) and middle high (I3) income countries in the All-species model suggest that shipments coming from poorer countries are less likely to be rejected due to non-phytosanitary reasons than shipments coming from a high income (reference) country.

The variable NSPECIES was highly significant (P<0.001) and had a negative regression coefficient in both the 4-species and All-species models, indicating that shipments destined for Dutch companies importing a larger variety of ornamental species are *ceteris*

Table 2. Parameter estimates of the 4-species and All-species MNL models (with standard errors in parenthesis)

Independent variables	Estimated models[a]			
	4-species model		All-species model	
	Rejection due to pest	Rejection due to other reason	Rejection due to pest	Rejection due to other reason
Intercept	-3.096(0.474)***	-5.047(0.581)***	-3.069(0.309)***	-4.902(0.33)***
AGRTOT	0.029(0.011)*	0.026(0.013)*	0.007(0.006)	0.004(0.005)
CUT	-0.003(0.003)	-0.006(0.003)	-0.010(0.002)***	-0.006(0.002)***
REU	-1.545(0.517)*	-0.406(0.548)	-1.710(0.349)***	0.031(0.278)
REA	0.151(0.424)	-0.102(0.662)	-0.313(0.247)	-0.161(0.275)
RLA	-1.635(0.411)***	-0.261(0.545)	-1.085(0.252)***	0.179(0.266)
RNA			-1.455(0.438)***	-0.385(0.373)
RSA			-1.258(0.471)*	-0.005(0.350)
RSS	-0.823(0.582)	-0.055(0.739)	-0.432(0.346)	0.331(0.357)
I1	0.147(0.682)	-0.693(0.933)	-0.015(0.356)	-0.249(0.307)
I2	-0.152(0.273)	-0.189(0.414)	-0.369(0.195)	-0.679(0.208)*
I3	0.989(0.544)	0.177(0.684)	0.100(0.281)	-0.883(0.257)***
NSPECIES	-0.008(0.001)***	-0.001(0.002)	-0.007(0.001)***	0.000(0.001)
D1000+	1.349(0.156)***	0.218(0.238)	0.814(0.118)***	-0.593(0.149)***
LOG_SIZE	-0.404(0.023)***	-0.217(0.038)***	-0.319(0.018)***	-0.038(0.021)
PHYTOM	-0.923(0.353)*	0.187(0.334)	-0.665(0.261)*	-0.243(0.199)
DIANTHUS	1.785(0.354)***	1.218(0.427)*	2.595(0.161)***	0.406(0.165)*
CHRYS	0.735(0.385)	0.915(0.463)*	1.596(0.225)***	0.094(0.233)
FICUS			0.818(0.286)*	-0.006(0.313)
DENDROB	1.302(0.442)*	-0.395(0.833)	1.977(0.226)***	-0.868(0.530)
S2	0.548(0.157)***	-0.299(0.245)	0.489(0.127)***	-0.267(0.138)
S3	-0.239(0.244)	0.012(0.268)	-0.163(0.179)	0.195(0.139)
S4	0.538(0.182)*	0.005(0.252)	0.359(0.148)*	0.118(0.137)
Y99	-0.998(0.177)***	0.912(0.260)***	-0.597(0.137)***	0.718(0.146)***
Y00	-0.769(0.179)***	0.321(0.293)	-0.523(0.138)***	0.242(0.158)
Y01	0.026(0.149)	-0.284(0.346)	-0.129(0.127)	0.005(0.166)
Number of records	39,345	39,345	136,075	136,075
$\chi2$ statistic	693 (44 df)		1067 (50 df)	
R^2_L	0.130		0.090	

[a] Variables FICUS, I4, S1, Y98 (4-species model) and RMN, I4, S1, Y98 (All-species model) were omitted to avoid redundancy. Variables RSA and RNA (4-species model) model were removed due to data separation problem.

paribus less likely be rejected due to phytosanitary reasons. A positive value of the coefficient for D1000+ ($P<0.001$) suggests that shipments destined for importing companies with a large number of imported shipments have a higher probability of being rejected due to the presence of a pest. Given the high negative correlation found between NSPECIES and D1000+ (Kendall τ=-

0.55, $P<0.001$), the above findings suggest that companies with large volume of imported shipments specialize on import of fewer ornamental species that have greater likelihoods of bringing pests.

The variable LOG_SIZE (natural logarithm of shipment size) has a negative regression coefficient and is a highly significant ($P<0.001$) predictor of the probability of rejecting shipments due to phytosanitary reasons in both models. Moreover, this variable is a significant ($P<0.001$) predictor of the probability to reject shipments due to non-phytosanitary reasons for ornamental species included in the 4-species model. Possession of the Phytomark certificate by the importing company significantly ($P<0.05$) decreases the likelihood of rejecting shipments destined for this company on phytosanitary grounds in both the 4-species and All-species model. On the other hand, the results do not suggest that possession of Phytomark is significantly related to the likelihood of rejecting shipments on non-phytosanitary grounds. Parameter estimates of DIANTHUS and DENDROB (in the 4-species and All-species models) and CHRYS and FICUS (in the All-species model only) imply that plants in these genera are *ceteris paribus* significantly more likely to be rejected due to the presence of a pest than plants from other genera. The values of parameter estimates imply a considerable increase in the odds of rejecting shipments of these ornamental commodities due to phytosanitary reasons. For example, the odds of rejection increase with a factor of $e^{2.595} = 13.4$ for shipments of Dianthus (compared to non-Dianthus shipments) and with a factor of $e^{1.596} = 4.9$ for shipments of Chrysanthemum (compared to non-Chrysanthemum shipments).

Parameter estimates of the variables S2 and S4 suggest that shipments imported in spring or autumn are *ceteris paribus* more likely to be rejected due to the presence of a pest compared to shipments imported in winter (a reference season). We suggest that fluctuations in pest populations in exporting countries are a plausible explanation for this result. Finally, estimates of year variables in both models indicate that shipments imported in 1999 and 2000 had a significantly lower probability of rejection due to the presence of a pest compared to shipments imported in 1998.

6.3.2 Dianthus and Chrysanthemum models

Both models were highly significant ($P<0.001$) according to the LR χ^2 test statistic (Table 3). The fit of the Dianthus model was substantially better than that of the Chrysanthemum model, according to R^2_L. Only one regional variable, RMN (Middle East and North Africa), was significantly ($P<0.05$) and positively associated with the probability to reject shipments of Dianthus on phytosanitary and non-phytosanitary grounds. Shipments of Dianthus originating

Table 3 Parameter estimates of the Dianthus and Chrysanthemum MNL models (standard errors in parenthesis)

Independent variables	Estimated models[a]			
	Dianthus		Chrysanthemum	
	Rejection due to pest	Rejection due to other reason	Rejection due to pest	Rejection due to other reason
Intercept	-2.916(0.759)***	-3.075(0.806)***	-5.219(1.207)***	-8.310(1.402)***
AGRTOT			0.083(0.022)***	0.005(0.014)
CUT	0.001(0.005)	-0.017(0.003)***	0.015(0.007)*	0.006(0.006)
RMN	1.553(0.66)*	1.274(0.604)*		
RLA	-0.511(1.015)	2.134(0.755)*		
I1	3.292(0.614)***	0.892(0.609)	-3.510(1.259)*	3.404(1.405)*
I2	0.691(0.437)	-1.090(0.511)*	-0.946(0.877)	2.743(1.293)*
I3	3.126(1.001)*	-0.394(1.018)	1.604(0.931)	2.999(1.324)*
NSPECIES	-0.015(0.002)***	0.001(0.002)		
D1000+	1.815(0.232)***	-0.321(0.356)	0.380(0.395)	1.401(0.413)***
LOG_SIZE	-0.451(0.032)***	-0.236(0.061)***	-0.345(0.04)***	-0.193(0.053)***
S2	0.725(0.176)***	-0.416(0.3)		
S4	0.668(0.22)*	0.300(0.283)		
Y99	-1.597(0.232)***	1.185(0.289)***	-0.047(0.412)	1.315(0.339)***
Y00	-1.126(0.227)***	0.704(0.332)*		
Number of records	22,555	22,555	9,395	9,395
$\chi 2$ statistic	612 (26 df)		127 (16 df)	
R^2_L	0.180		0.130	

*P<0.05, ** P<0.01, *** P<0.001

[a] Only variables that were significant at 10% level (LR test) during backward elimination procedure are reported. Variables I4, Y98, S1 in both models were omitted to avoid redundancy. Prior to estimation, variables RSS, RSA, REA, RNA, PHYTOM (Dianthus model) and RSS, RSA, REA, RNA (Chrysanthemum model) were removed due to data separation problem.

from countries in Latin America are *ceteris paribus* more likely to be rejected due to non-phytosanitary reasons than shipments originating from other regions.

The results suggest that shipments of Dianthus imported from low and middle high income countries are more likely to be rejected on phytosanitary grounds than shipments imported from high-income countries. The impact and significance of estimated variables NSPECIES, D1000+, LOG_SIZE, S2 and S4 in the Dianthus model were very similar to their impact in the 4-species model.

Parameter estimates of AGRTOT (P<0.001) and CUT (P<0.05) suggest that shipments of Chrysanthemum coming from countries with relatively larger shares of, respectively, agricultural exports and exports of cut flowers are more likely to be rejected because of the presence of a pest. None of the regional variables in the Chrysanthemum model was statistically significant. Income variables, conversely, appeared significant (P<0.05) positive predictors of the probability of rejecting shipments of Chrysanthemum coming from lower income countries due to non-phytosanitary reasons. The probability of rejecting shipments of Chrysanthemum due to non-phytosanitary reasons is higher for larger importers, as indicated by variable D1000+ (P<0.001). The variable LOG_SIZE is a significant (P<0.001) negative predictor of the likelihood of rejecting shipments of Chrysanthemum on non-phytosanitary grounds.

Parameter estimates of the year variables indicate significant annual variability in the probability of rejecting shipments of Dianthus and Chrysanthemum due to both phytosanitary and non-phytosanitary reasons.

6.3.3 Comparison of models

The differences between the 4-species and All-species models were small compared to the differences between the Dianthus and Chrysanthemum models. The closeness of results of the former two models is mainly because the four ornamental species in the 4-species model accounted for most of the rejected shipments in the All-species model, and for a considerable proportion of inspected shipments in the overall data set. Thus, most statistically significant variables in the 4-species model were also significant in All-species model. However, the overall fit of the All-species model was still notably lower (R^2_L=0.090) than that of the 4-species model (R^2_L=0.130).

After backward elimination, a considerably larger number of significant variables remained in the Dianthus model than in the Chrysanthemum model. Most notably, none of the regional and seasonal variables that were significant in Dianthus model appeared in the estimated equation for Chrysanthemum. As a result, the fit of Dianthus model was substantially higher than that of Chrysanthemum model. In general, Dianthus and Chrysanthemum models showed a better fit to data than 4-species and All-species models. This suggests that independent variables are the best predictors of the likelihood of rejecting shipments of individual ornamental species.

Parameter estimates in the single species models suggest possible interpretations of results of multi-species models. Similarities of parameter estimates of variables NSPECIES, D1000+, LOG_SIZE, and seasonal and year variables, in Dianthus and 4-species models suggest that inclusion of records on Dianthus in the latter model to a large extent influenced the parameter estimates.

6.4 Discussion

This study shows that a multinomial logistic model can be used to predict the probability that an imported shipment of an ornamental species is rejected due to the presence of a pest or due to other reasons. Explanatory variables characterizing an imported shipment were significantly ($P<0.001$) associated with the likelihood of rejecting shipments in all the estimated models. The results of the 4-species and All-species models suggest the best risk factors to predict the likelihood of rejecting shipments due to the presence of a pest: (i) geographical regions of exporting countries, (ii) the size of the shipment, (iii) the ornamental plants in specific genera and (iv) variables representing the season and year of import. These factors are also relevant for predicting the likelihoods of rejecting shipments of individual ornamental commodities (Dianthus and Chrysanthemum) but there can be substantial variation among significant factors depending on particular commodity. Models representing individual ornamental species Dianthus and Chrysanthemum showed the best fit to data. With addition of records on other ornamental species, the fit of models deteriorated while the realm of possible application enlarged. The decrease in explanatory power with increasing diversity of commodities is likely because many different and perhaps conflicting explanatory factors may influence likelihoods of rejecting shipments of ornamental species included in multi-species models. Thus, the MNL regression is best to be applied in single species models for which the impact of specific factors can best be singled out.

Because MNL models have not been applied before in a phytosanitary context, it is impossible to directly compare the results of this study with other studies. Our results though support earlier findings (Frey and Mani, 1992) that likelihoods of rejecting shipments on phytosanitary grounds vary significantly between ornamental plants in different genera.

The results indicate that likelihoods of rejecting imported shipments are significantly associated with certain regions of the world (e. g. Middle East and North Africa). However, these results should not be taken to imply that shipments imported from all countries situated in a given region pose the same risk. In the present case, most rejected shipments from the Middle East and North Africa were associated with Israel, which was also the largest exporting country to the Netherlands in the period of 1998 to 2001. The impact of a certain country can be investigated by including a relevant binary variable in the estimated equations. We made such a pathway analysis for Dianthus and Chrysanthemum (not reported). The results indicate that shipments coming from certain countries have significantly higher probabilities of being rejected due to the presence of a pest. However, introduction of country variables may increase the likelihood of the data separation problem, because of a significantly smaller number of records pertaining to a single country and, thus, a greater likelihood that available records do not fall within all the categories of the dependent variable. Data separation did not allow testing the impacts of some regional variables in the 4-species model and of most of the regional variables in the Dianthus and Chrysanthemum models.

The results suggest significant seasonality in the likelihood of rejecting of shipments due to phytosanitary reasons, confirming earlier work (Frey, 1993; McCullough et al., 2006).

Other studies (Frey, 1993) found seasonality in pest interceptions in relation to the intended use of ornamental commodities (e.g. cuttings and potted plants). Although we were unable to test this finding because our data did not specify the intended use of ornamental commodities, the results indicate that seasonality can be significant for some ornamental species (Dianthus) and not significant for others (Chrysanthemum).

The results further suggest that bigger shipments are less likely to be rejected due to the presence of a pest, *ceteris paribus*. This result was robust to alternative options for dealing with uncertainties in the available data set with respect to the consequences of the practice of splitting of infested records in the data set (see Materials and Methods). This finding thus indicates that bigger shipments are less likely to be infested with a pest. There are several reasons to explain such a phenomenon. For instance, exporters have greater incentive to carefully check and assure the phytosanitary quality of bigger, more valuable, shipments. Next, it may be that commodities that have high phytosanitary quality- e.g. propagating materials (Roozen and Cevat, 1999) - are imported in bigger shipments. This finding may also – in part – reflect difficulty to obtain a random and representative sample from a large shipment, even if officially, tailgate methods of inspection that target only the most accessible units of a shipment (Venette et al., 2002), are not applied (Jan Schans, PD, *personal communication*). The more clustered a sample is taken, the smaller is the probability that a pest – if present – is detected (Binns et al., 2000). The actual reason for lower probability of pest infestation in larger shipments deserves further study. For proper investigation of the probability of rejecting shipments in relation to their size, it is necessary that the size of a shipment is recorded prior to any splitting (if it is to occur). This need, although perhaps obvious from a viewpoint of predicting the probability of rejecting a shipment, must be less obvious to inspecting agencies that value the size of what is actually rejected more than the size of what initially is imported. We communicated this finding to the Dutch PD.

In all the estimated models, only a few explanatory variables were significantly associated with the likelihood of rejecting shipments due to non-phytosanitary reasons. In part, this may be due to combining into a single inspection outcome so different reasons for rejecting shipments as the absence (incomplete/incorrect filling in) of the phytosanitary certificate and rejection on quality grounds. Various factors, currently not included in the estimated models, may be related to likelihoods of rejecting shipments due to the above reasons. For example, the absence of a phytosanitary certificate indicates a general problem of organization of export inspection while the low quality of an imported commodity may be related to e.g. poor transportation conditions.

The impacts of explanatory variables can be taken into account when designing import inspection schemes. Purely on qualitative grounds, inspection can be more (respectively, less) focused on commodities or shipments that are indicated to have higher (respectively, lower) likelihoods of being rejected. For example, the results of the All-species and 4-species models suggest that the inspection frequency of shipments destined for importers that have a Phytomark certificate can in general be reduced. On the other hand, a lower frequency of inspection of Chrysanthemum shipments on the basis of possession of a Phytomark certificate by an importing company would not be justified because the relevant variable was eliminated as being insignificant from the estimated model for Chrysanthemum. Furthermore, the inspection can be focused more on Dutch companies that have a large number of imported shipments but a low variety of imported species. Finally, seasonality in the likelihood of rejecting shipments suggests that inspection of (all or specific) ornamental species may be more intensive in autumn and spring and less intensive in other seasons. The results can also be used to directly calculate the probabilities of rejecting shipments on phytosanitary grounds. This can be useful for example in risk assessment models and in models of resource allocation for import inspection (Surkov et al., 2007a).

The results reported in this study remained consistent after the All-species version of the MNL model was fitted to the data set of import inspections of ornamental commodities in the Netherlands from 2003 to 2005 (not reported). The set of explanatory variables was similar to one used in this study except variables representing agricultural export characteristics, Phytomark certificate and variables for specific ornamental commodities. However, we were able to specify a variable for the intended use of an ornamental commodity (a cut flower or a non-cut flower). We found that shipments of cut flowers were significantly more likely to be rejected on phytosanitary grounds than shipments of non-cut flowers.

This study showed the importance of collecting in inspection databases additional data that can be useful for analyses and prediction of pest interceptions, e.g. data on the intended use of commodities, the size of the imported shipment and information related to the importing company. Most importantly, inspection databases should include both positive and negative pest interceptions. Only in this case the MNL model can be identified. Yet, until recently, in some countries (e.g. the United States) only positive pest interceptions have been recorded (McCullough et al., 2006).

In summary, this study demonstrated that the MNL model allows estimating the impact of factors that may influence the decisions to inspect or not inspect particular commodities, commodity pathways or commodity shipments. In this way, the MNL model can support the inspection decisions of the inspecting agencies. The application of MNL or similar models can be considerably facilitated if the inspecting agencies collect the data related to pest interceptions not only for record-keeping purposes but also with the view of using this data for analysis, prediction and management.

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Chapter 7 General Discussion

7.1 Introduction

Phytosanitary inspection is a major barrier against introductions of quarantine plant pests that may be associated with imported commodities, but in most importing nations the available resources are limited. This thesis has developed concepts and empirical results that may help increase the efficacy of import inspections. Chapter 2 analysed the optimal allocation of resources for import inspection under the maximum acceptable pest damage constraint. Chapters 2, 3 and 4 developed the optimal inspection policy under the inspection capacity constraint. The unconstrained allocation of inspection effort was analysed in Chapter 4. Using the framework of previous chapters, in Chapter 5 the EU 'reduced checks' import inspection policy was analysed. In Chapter 6, an empirical framework for the analysis of factors explaining the probability of rejecting the imported shipments due to phytosanitary or quality reasons was developed.

This chapter critically discusses the methodological issues related to modelling the optimal import inspection policies (section 7.2), discusses the data issues (section 7.3), reviews the main findings of this thesis (section 7.4), discusses how the findings of the thesis can be implemented (section 7.5), and presents main conclusions (section 7.6).

7.2 Methodological issues

7.2.1 The objectives of import inspection

The objective of any quarantine inspection agency can be defined as minimization of phytosanitary risks. How risk is defined is an empirical matter and may vary among inspecting agencies. In this thesis, the optimal inspection policies were analysed under various assumptions on how phytosanitary risks stemming from international trade are perceived by the inspecting agencies. In Chapter 2, risk was represented by the likelihood of introduction of *any* pest species through imported propagating materials. In Chapters 2 through 5, the objective function of the inspecting agencies included both likelihoods and outcomes i.e. the economic cost, of pest introduction. However, irrespective of how risk is defined, under the optimal inspection policy more resources are allocated to pathways where the greatest marginal reduction in total risk can be achieved. Yet, the allocation of inspection effort will be different if the likelihood *and* the cost of pest introduction are taken into account compared to the case when only the likelihood is selected as an objective function (Chapter 5).

Arguably, in allocating their resources the inspecting agencies wish to reach first-best outcomes. However, in reality there are constraints that prevent the achievement of the first-best outcomes. Substantial evidence suggests that the lack of resources is the major constraint facing inspecting agencies worldwide (e.g. Everett, 2000; National Research Council of the United States, 2002; Simberloff, 2006; U.S. Office of Technology Assessment, 1993). Thus, the main emphasis in Chapters 2 through 4 was on developing conceptual and empirical frameworks for the inspection policies under the resource constraints.

The resource (capacity) constraint essentially represents the inability of the inspecting agency to provide the optimal unconstrained allocation of inspection effort for a given volume of imported commodities at a given place and date. The persistence of the capacity constraint is largely due to the lack of qualified personnel (Simberloff, 2006). However the capacity constraint essentially represents the lack of monetary resources. For example, a monetary value can always be attached to a certain number of available inspectors. In the empirical applications of Chapters 2 through 4 of this thesis, the monetary (budget) constraint was thus imposed as the most flexible representation of the inspection capacity.

7.2.2 Modelling the actions of the inspecting agency

This thesis focused on border inspection as the only quarantine measure applied to imported commodities. Thus, the measures of the inspecting agency were modelled to influence the probability of pest entry only and not the probability of pest establishment (see equation 1 in Chapter 3). This assumption realistically reflects inspection practices of products destined for final consumption, which constitute the bulk of the fresh horticultural imports in most importing countries. Products for consumption are usually inspected only once because the likelihoods of pest establishment related to these products are relatively small (Roozen and Cevat, 1999). On the other hand, some products, for example propagating materials, go directly into the production chain and represent therefore a greater phytosanitary risk. Because of that, in the Netherlands, the PD conducts repetitive inspections of nurseries that import propagating materials (Roozen and Cevat, 1999). By doing so, the PD aims at reducing the probability of pest establishment. In this thesis, phytosanitary inspection after import was not modelled because this would require the development of a more complex bio-economic framework to account for the spatial aspects of spread of pest species after initial entry. This requires additional data on the spread characteristics of the pest species in the question and data on the flows of commodities- pest vectors- in the Netherlands. Most of these data are not available. Modelling the allocation of inspection effort at the border *and* in the production chain could be the focus of future research efforts. In this case, different stages in the import and production chain of a commodity would compete for the available inspection budget. The stage, in which the inspection is relatively more effective, would then obtain relatively more of the available resources.

Because import inspection is the only quarantine measure applied in this thesis, the costs of pest introductions are unaffected by import inspections. Potentially, the agency may influence the costs of pest introduction through measures applied to eradicate pest outbreaks or limit their size or through extra research costs to develop e.g. better pest management practices. The agency would then bear some of the costs of pest introduction. In the empirical applications of Chapters 3 and 4, producers were assumed to bear all the costs of outbreaks of *B. tabaci*, *T. palmi* and *L. huidobrensis* through higher crop protection costs and yield losses. Thus, the agency's costs were assumed zero in this case. Eradication or containment of new pest species or the ones with large social, environmental and economic impacts may only be possible with the contribution of the public agency (Myers et al., 1998). In these cases, it is more appropriate to explicitly model the costs borne by the agency. Furthermore, the assumption that producers bear all the costs of outbreaks may be relaxed to some extent if the government compensates some of the costs incurred with outbreaks.

The actions of the inspecting agency are largely determined by its risk attitude that determines its risk-aversion toward phytosanitary risks. The more risk averse a particular agency is, the more conservative approaches it takes and the more conservative assumptions it makes to manage the import phytosanitary risks. In the empirical applications of Chapters 3 and 4, the probabilities of pest introductions were assumed positive for all trade pathways of chrysanthemum cuttings, despite no historical findings of some pest species in some of the pathways. This assumes a risk-averse agency. Alternatively, a risk-neutral agency could assume zero probabilities of pest introduction through particular pathways. The risk-aversion of the agency is also reflected in assumptions on the efficacy of import inspection, in particular in the error probability of inspection (Chapters 2 through 4). A more risk averse agency will use a lower confidence level in parameterisation of the efficacy of import inspection. Furthermore, the agency may be concerned with uncertainties related to phytosanitary risks (e.g. uncertainty in the potential impact of a pest on a given crop) and may attempt to reduce it (e.g. by collecting additional data) or to apply phytosanitary measures taking into account the existing uncertainties (e.g., by choosing inspection policy based on a range of probabilities of pest introduction through all the pathways, including non-zero probabilities for 'safe' pathways).

The model for allocation of inspection efforts in Chapters 2 through 4 is static and lacks intertemporal aspects. These aspects are important because allocation of a budget in a current year influences the intertemporal budget allocation and the future costs of pest introduction. This is because a given pest species may fail to establish in a period t and so its introduction will be delayed at least until period $t+1$. This implies that the costs of pest introduction are not realised in period t; thus, the budget allocation in future periods depends on the success of budget allocation in previous periods. To account for such intertemporal effects, a richer dynamic model of budget allocation should be developed. It could be based on dynamic programming models used for intertemporal allocation of resources for biodiversity conservation (e.g. Wilson et al., 2006).

7.2.3 Modelling the costs of pest introduction

The conceptual and empirical frameworks of Chapters 2 through 4 assumed that the inspecting agency's efforts do not influence the supply of an imported commodity on domestic market. One might argue that inspection measures *could* influence the supply through detention of infested commodities at the border, thereby reducing the supply on the internal market and possibly increasing the prices. However, for this to occur, the proportion of infested commodities should be relatively high and import should represent a substantial share of the total supply of a given commodity on the importing country's market. Although import volumes of certain products may be large, high proportions of infested commodities are unlikely to be the case in reality because this is against exporting countries' interests. The available evidence suggests that proportions of infestation of most commercial products are very low (e.g. Paarlberg and Lee, 1998; Wearing et al., 2001). The analysis of import inspection data of chrysanthemum cuttings (Chapter 3) and cut flowers (Chapter 5) in the Netherlands supports this finding. Of course, occasionally, the proportion of pest infestation can be relatively high. For example Frey (1993) and Childers and Rodriguez (2005), contrary to findings in this thesis, reported high infestation rates of cuttings and ornamental plants in Switzerland and the US, respectively. Yet, their findings may be specific to certain exporting countries and reflect the properties of specific commodities.

The costs of pest introduction may affect only a few producers or the entire society. This depends on the size of pest outbreaks and their impacts on prices of affected crops. In Chapter 3, the costs of pest introduction were assumed to involve only the producers of the affected crops in the Netherlands. Thus, implicitly, the price in the Netherlands was assumed to reflect the world price and hence changes in supply of the affected crops did not influence the price in the Netherlands. In Chapter 4, the costs of pest introduction were calculated in a partial equilibrium model as changes in social welfare of producers and consumers of the affected crops. In this framework, the supply curves in the Netherlands were upward-sloping and the reduction in supply of affected producers was translated in the increased crop price for non-affected producers.

Calculation of the costs of pest introduction as a reduction in the gross margins of affected producers is relatively simple and requires little data. Modelling the costs of pest introduction as the change in the social welfare is more correct from the economic point of view (Hoagland and Jin, 2006; Paarlberg et al., 2003), but this requires additional data and inevitably involves additional uncertainties (e.g. on the elasticities of excess supply and demand). Thus, the choice between appropriate frameworks to calculate the costs of pest introduction should weigh these considerations. In some cases, depending on the elasticities of supply and demand, the estimates of pest cost under both approaches will be approximately equal. The choice of the framework may also depend on the crop and the pest species.

In the partial equilibrium framework of Chapter 4, some potentially relevant pest costs were not considered. Firstly, substitution effects of two types are likely to arise for the affected crops. The first type of substitution is due to demand shifts to consumption of other crops that become relatively cheaper than the ones whose supply is affected by pest outbreaks (for example, greater consumption of leaf vegetables instead of tomatoes, or roses instead of chrysanthemums). The second effect, that may mitigate the first one, is the substitution between the more expensive Dutch vegetables with the cheaper import substitutes. Modelling the latter effect requires specification of the partial equilibrium model with a two-way trade. A two-way trade model could allow for variable imports- which were fixed in Chapter 4- to account for reaction of producers in other countries to changes in supply in the Netherlands. Furthermore, spill-over effects of pest introduction for other sectors of the economy, e.g. transport, were ignored in the partial equilibrium model. These effects may be important especially when there is a large decrease in the supply of the affected crops in the Netherlands. However, accounting for these effects is data-demanding and was outside the scope of this thesis.

Chapter 4 showed that export losses may have a dramatic impact on the overall costs of introduction of a pest species and should thus be taken into account whenever possible. Inclusion of export losses in the estimate of the costs of pest introduction depends on how likely export bans are to be imposed in particular export markets. However, the estimated economic costs of introduction of *T. palmi* were based on the assumption that the extent of pest outbreaks in the Netherlands was too low to induce imposition of export bans on the Netherlands horticultural products and thus did not include potential export losses. Inclusion of these losses in the estimate of costs of introduction of *T. palmi* would not have changed the pattern of budget allocation because *T. palmi* already had higher costs of introduction compared to *B. tabaci* and *L. huidobrensis*.

7.2.4 Uncertainty in model parameters

The conceptual and empirical frameworks of Chapters 2 through 4 assumed that the inspecting agency is able to estimate the probabilities and the costs of pest introduction. Thus, this approach considers the expected costs of pest introduction. Expected costs of pest introduction should also account for *uncertainty* in model parameters (Lichtenberg and Zilberman, 1988). Uncertainty may exist with respect to the range of crops that may be affected by a particular pest species, the impact of a particular pest species on a specific crop or probabilities of outbreaks of different sizes. As long as the mean impacts of pest introduction are properly estimated and are high relative to uncertainty impacts, the estimated costs of pest introduction should give correct representation of the expected costs of pest introduction. Nonetheless, the impacts of uncertainty may be substantial. To deal with the uncertainty in model parameters one could invest in reducing it by e.g. collecting additional data. Reducing uncertainty impacts would make the allocation of resources more focused, but collection of additional data is costly. Alternatively, the inspection measures could be applied so as to take into account the uncertainty in some of the parameters, e.g. assuming a positive probability of pest introduction through each of the pathways. However, this could lead to overspending of the available resources (Lichtenberg, 2006).

7.3 Data

To estimate the probability of pest introduction into a given importing country, one needs data on the probability of pest entry and on the probability of pest establishment. The probability of introduction can realistically be estimated even for the large number of pest species given the quantitative data on import volumes and numbers of pest interceptions at the borders of importing countries. Estimation of the probability of establishment, given introduction has occurred, requires substantially more data, for example the data on the probability of pest transmission and spread in the production chains and environment of an importing country. Given a broad range of pest species that may be associated with commodities imported into a given country, it is very difficult if not impossible to obtain data on the probabilities of establishment of all the pest species. Thus, in Chapters 3 and 4 of the thesis, the probability of pest establishment was assumed constant and equal to 0.1 for all pest species. In reality, this probability is likely to differ for various pest species depending on their biological characteristics and the characteristics of the environment.

With the probability of pest establishment assumed constant, estimation of the probability of pest entry is crucial. The probability of pest entry was estimated based on the Dutch PD database of import inspections. The PD database is unique because both positive and negative pest interceptions are recorded, enabling estimation of the proportions of pest interceptions. From recent studies that have analysed interceptions of invasive species (Brockerhoff et al., 2006; Dobbs and Brodel, 2004; Haack, 2001; McCullough et al., 2006; Roques and Auger-Rozenberg, 2006; Stanaway et al., 2003; Work et al., 2005), it follows that in most importing countries only the positive pest interceptions are recorded. Based on these data one can estimate the numbers of pest interceptions, which are very useful to determine the range of pest species associated with imported commodities and to monitor trends in arrival of (potential) pest organisms. However, it is the frequency (rate) of pest interceptions that conveys the most important *management* information, based on which the resource allocation decisions should be made. Therefore, as suggested in Chapter 6, it is very important to record both positive *and* negative cases of pest interceptions. Because this has been done in the Netherlands, it was possible in this thesis to estimate the probabilities of pest entry as applied in Chapters 2, 3 and 4 and apply the MNL model in Chapter 6. Agencies in other countries should invest in recording all inspection results because the marginal costs of doing this should be rather small but the marginal benefits in collecting data for scientific analysis and optimisation are large. The recording procedures can be further facilitated through a computerized information exchange between importers and the inspection service; in the Netherlands this is done via the CLIENT system (PD, 2007).

Equally important is to select variables to record in inspection databases. The analysis in Chapter 6 shows that variables describing an importing company, the intended use of the commodity and the size of an imported shipment were highly significant in explaining the likelihood of rejecting shipments imported in the Netherlands due to phytosanitary reasons. Recording this information in inspection databases adds extra possibilities for analyses and management of import pest risks. For example, the inspection intensity of a certain commodity may be increased for importers with higher frequencies of historical pest interceptions. Moreover, based on this additional data, the inspection services may work closer with importers to reduce the incidence of quarantine pests and diseases in imported commodities. In the end, these additional data make the inspection policy more effective by allowing to select those commodities, pathways or shipments which are *ceteris paribus* more likely to bring the associated pest species.

The quality of information recorded in inspection databases is extremely important. It is necessary to verify that inspection databases contain all pest interceptions within a specified period and all pest species and commodities are correctly identified taxonomically. This is important because (mis)identification of a pest species affects the estimate of risk associated with a commodity or a pathway and hence the respective inspection policies.

Also, the quality of the recorded information is important because it is subsequently used for analysis and decision-making. The PD databases of import inspections provided a wealth of information but substantial effort was required to make them usable for the analysis in this thesis, especially in Chapters 5 and Chapter 6 (see the Appendix). The PD databases have not been compiled for research and analysis but they may and actually *should be* used for this purpose, as was concluded in Chapter 6. One of the key issues in organizing the database is what information should be collected in a single database record. A single record in the PD databases represented one or *more* lots of a single ornamental commodity from a single exporting country (see the Appendix). It was impossible to conclude how many lots were collected under one record; this may potentially influence the results of the statistical analysis of the database. A related issue is how the information on the rejected and non-rejected lots is recorded in the databases. Ideally, the database should be organised on a single lot basis (see the Appendix).

This is especially pertinent because the EU Directive 2000/29 prescribes inspection of every lot in multi-lot consignments. Recording information on a single lot basis would allow avoiding ambiguities in data analyses.

7.4 Main results

This thesis developed theoretical and empirical frameworks that can be used for the analysis and evaluation of the import inspection policies. From a theoretical perspective, in the absence of capacity constraints, the inspecting agencies should allocate their resources so as to equalize the marginal costs of inspection with the marginal benefits – i.e. reduced damages from pest introductions (Chapter 4). If capacity constraints are binding, the optimal allocation of inspection resources should lead to equalization of the marginal costs of pest introduction across risky import pathways (Chapters 3 and 4).

The empirical results of Chapters 2 through 4 suggest that *ceteris paribus* greater inspection effort should be allocated to pathways whose inspection yields a greater marginal reduction in the probability (if the costs of introduction are the same across pathways) or the expected costs of pest introduction. The empirical analysis of the inspection policy of Chrysanthemum cuttings imported in the Netherlands (Chapters 3 and 4) shows that although import inspection greatly reduces the expected costs of pest introduction, a current allocation of inspection effort can be improved in most cases to yield lower expected costs of pest introduction. Further, the analysis of the inspection policy under the binding budget constraint revealed a high shadow value of import inspection, *viz.* 18 euros in Chapter 3 and 8 euros in Chapter 4 for every euro of the available inspection budget. Thus, investment in inspection generates high returns in the form of reduced expected costs of pest introduction. However the returns from inspection may vary significantly depending on the value of the expected costs of pest introduction. This indicates that costs and likelihoods of pest introduction require careful estimation. Furthermore, the return to inspection is reduced if infestations are less likely to be detected, for example when clustering of infested units occurs in imported lots. The results of Chapter 4 show that the unconstrained allocation of inspection effort with lower total costs of pest introduction can be attained at small cost when there are fixed inspection costs, such as a call out fee. The results in this Chapter also show that export losses arising after establishment of a pest species may be very high and dramatically influence the costs of introduction of a particular pest species.

The low proportions of pest interceptions in the Netherlands confirmed the selection of genera of cut flowers for 'reduced checks' in the EU in 2005 and 2006 (Chapter 5). However, the hypothetical example in Chapter 5 suggests that the expected costs of pest introduction into the EU could be further decreased compared to 'reduced checks'. Because currently the potential costs of pest introduction through a given commodity are not included in calculating the frequencies of reduced checks, Chapter 5 suggests that doing so can help reduce the expected costs of pest introduction in the EU. Chapter 6 showed that a prediction of the probability of rejection of imported lots due to phytosanitary or non-phytosanitary reasons can be made based on the historical data on import inspections. The results showed that the size of an imported shipment, the season of import, the geographical region, the characteristics of the importing company and the type of an importing commodity are all important variables that influence the likelihood of rejecting imported shipment due to quarantine pests.

7.5 Implementation of the findings in this thesis

The models for budget allocation developed in Chapters 2 through 4 were applied to a well-defined set of commodities imported in the Netherlands. These models can generally be applied to a single commodity or range of commodities imported into a given country. To implement the models, one has to 1) determine the range of potential pests species that may be associated with a given commodity or commodities, 2) estimate the costs and/or likelihoods of introduction of these pest species through this commodity, and 3) parameterise the efficacy of import inspections. All these steps require quantitative data which are hard to obtain in most countries. To determine the range of potential pest species that can be associated with a commodity one may analyse historical data of pest interceptions and use the relevant literature. The likelihoods of pest introduction may be difficult to estimate, especially the likelihood of pest establishment after entry. The efficacy of import inspection can be realistically parameterised through observing actual inspections and determining the true proportion of infestation both for rejected and accepted lots. Perhaps, the most difficult challenge lies with estimating the economic costs of introduction from a given pest species, because the economic impacts may be highly uncertain and the available economic data are scarce. Therefore, the efforts to implement the model are substantial and are most likely to be warranted only for important commodities imported in large volumes and commodities with a relatively small number of the associated pest species. The insights in the optimal conduct of import inspection are equally applicable to export phytosanitary inspections.

The MNL model developed in Chapter 6 can be applied to analyse import inspection data in other countries. The model can also be applied for export inspections. The implementation of this model requires recoding of positive and negative pest interceptions in inspection databases.

7.6 Conclusions

The main conclusions of this thesis can be summarized as follows:

- Modelling the costs and benefits of import inspection gives insight in the characteristics of optimal strategies. The results of analysis can be used to critically evaluate current practices in import inspection and search for possible improvements (Chapters 2-5);
- In this evaluation, both the input from stakeholders and experts' knowledge should play an important role because the practical wisdom and interests of stakeholders were only rudimentarily accounted for in the theoretical analyses;
- Under a binding budget constraint representing current situation in the Netherlands, the marginal benefits of import inspection are high. Expanding the available budget for inspection of chrysanthemum cuttings imported in the Netherlands with one euro decreases the expected costs of pest introduction with 18 euros (Chapter 3);
- In the presence of fixed inspection costs, an unconstrained allocation of inspection effort can be achieved relatively cheaply from the current, capacity constrained, inspection effort. Quantitative results of the analysis are sensitive to the expected costs of pest introduction and the assumed efficacy of import inspection (Chapter 4). These aspects warrant empirical study to consolidate the results obtained here;
- The application of 'reduced checks' in the EU is justified for most genera of cut flowers. The inclusion of the economic impacts from potential pest introduction through a given commodity in calculating the frequencies of reduced checks can further improve the reduced checks system (Chapter 5);
- The logistic model is a useful tool for predicting the likelihoods of rejecting imported commodities due to phytosanitary reasons. The size of an imported shipment, the season of import, the intended use of commodities, the presence of quality certificates with an importer of a shipment and the characteristics of an importer are important factors explaining the likelihoods of rejecting imported commodities due to the presence of quarantine pests (Chapter 6);
- Results in this thesis indicate that scientifically based cost-benefit analysis can highlight opportunities for major improvements of the profitability of import inspection as a tool in the mitigation of risks from invasions of plant pests. Sound data-recording procedures by plant protection agencies, including negative inspection results, provide crucial base material for conducting those analyses and should be a priority for any national or international agency responsible for plant health.

Appendix Description of the databases of import inspections

In this thesis, databases of import phytosanitary inspections of products imported in the Netherlands are extensively used. These databases are maintained and compiled by the Dutch Plant Protection Service (PD). This Appendix describes these databases in more detail, documents how they were analysed in various chapters of this thesis and gives recommendations with respect to data recording procedures in the PD.

General description of import phytosanitary inspections in the Netherlands

The process of filling in the databases is related to the conduct of import phytosanitary inspections. Import inspection is initiated when the PD receives a request for inspection from a Dutch importer. The PD inspector goes to the *importer location*- e.g. storage rooms in flower auctions or the importer's premises- and inspects all commodities present at the same date at the importer's premise. This event is defined as one *inspection visit*. All commodities present at importer's location have to be accompanied by the *phytosanitary certificate* (PC). PCs should give the scientific and common name of the commodity, its country of origin and contain special remarks, e.g. whether a particular commodity underwent a special treatment (e.g. fumigation) prior to export, when this is required by the EU plant health regulations (IPPC, 2006b). A commodity cannot be accepted for import without a properly completed PC. According to the EU Directive 2000/29, a single PC should cover a single *consignment*. Consignment is 'a quantity of goods being covered by a single document required for customs formalities or for other formalities, such as a single PC or a single alternative document or mark; a consignment may be composed of one or more lots'. *Lot* is defined as 'a number of units of a single commodity, identifiable by its homogeneity of composition, origin, etc. forming part of a consignment'. All single lots within a consignment must be mentioned in a PC. If not, this would imply that the contents of a consignment is not accurately described in a PC and could serve as a basis for rejecting this consignment for import (IPPC, 2006a, article 2.2). Therefore, at the importer's location during inspection visit there may be one or more single lots of one or more commodities comprising one or more imported consignments. Commodities in the same consignment may originate from different countries but usually they originate from the same country.

During the inspection visit, the PD inspector has to visually examine a sample from every lot present at the importer's location. The inspector should record the results of this examination in the *inspection report* that is compiled for every inspection visit. Thus, inspection reports contain the results of import inspection of all commodities during inspection visit. Inspection reports are a basis for filling in the PD electronic databases of import inspections.

Databases of import inspections

In this thesis, databases of inspections of commodities imported in the Netherlands during two periods - 1998 to 2001 and 2003 to 2005 - were used. Henceforth, the former database is referred to 98/01 database and the latter as 03/05 database. Both databases were compiled based on inspection reports and they contain similar information; however, there are also differences in the information contained in the databases.

Both databases represent electronic tables in which *records* (rows) contain information (in columns) on inspection of a single commodity from a single country of origin. Although the actual phytosanitary inspection had to be conducted for every imported lot, records in the databases contain information on inspection of one *or more* lots of a single commodity from a single country of origin (Jan Schans, PD, *personal communication*). At the moment of inspection, lots could be distinguished by more detailed commodity characteristics - e.g. the producer in the country of origin, commodity cultivar or colour of cut flowers. However, in the inspection report, an inspector may have compressed information of different lots in one record as long as all lots in this record are of the same commodity from the same country of origin. Thus, a record of inspection of a single commodity from a single country of origin is the smallest unit for analysis of the database; information on other lots' characteristics (producer, etc.) is not reported in the databases. Likewise, whether a given record contains information on one or more lots of a given commodity from a given country of origin is not indicated.

The information in the above paragraph is fully pertinent to 98/01 database. The 03/05 database was filled in later years when data recording procedures were adjusted because of the introduction of 'reduced checks' in the EU. In addition, the PD implemented the CLIENT system that allowed for a computerized exchange of information between Dutch importers and the PD. These factors contributed to improvements of the data recording procedure of import inspection and made significantly *more likely* that inspection results were recorded at a *single lot level* compared to the 98/01 database (Jan Schans, PD, *personal communication*). However, despite expected improvements in the data recording procedure, it is still unknown whether a given record in the 03/05 database gives information on one *or more* lots.

Both databases included the following information for every record of inspection: the date of inspection, the name of the ornamental commodity (at the level of genus), the country of origin, the unique number of the Dutch company that imported the ornamental commodity, the inspection report number, the result of inspection and reasons for rejection (if applicable). In addition, the 03/05 database included information on the PC number(s) and whether or not an inspected commodity was a cut flower.

Issues related to the use of the databases in the paper

98/01 database

Data from this database were used in Chapters 2, 3, 4 and 6 of the thesis. In all these chapters, the unit of analysis was a single database record, which was referred to as 'consignment'- in Chapter 2, 'lot'- in Chapters 3 and 4, and 'shipment' in Chapter 6. In general, using the 98/01 database, an implicit assumption was that a single record in the database was equivalent to a single lot of an ornamental commodity from a given exporting country. This assumption may not always have been met, because, as indicated in the previous section, one record could represent more than one lot. However, since in the database there was no evidence that the number of single lots within a given record was *actually* greater than one, the assumption that one record represented a single lot is supported.

In Chapters 3 and 4 data on interceptions of quarantine pests species, associated with chrysanthemum cuttings imported in the Netherlands, were analysed. There was a lack of consistency between the two main databases used in this analysis: the 98/01 database and the pest diagnostic database for 1998-2000 (PD Diagnostic Department, 1998-2000). Specifically, in the 98/01 database, sometimes the pest species was reported incompletely, or, in rare cases, the name of a pest species was not reported at all. As a result, a substantial effort was required to match the information in these databases and calculate the number of interceptions of quarantine pest species.

In Chapter 6, the 98/01 database was used to analyse the likelihood of rejecting shipments due to phytosanitary and non-phytosanitary reasons, using the MNL model. The results reported in this Chapter correspond to the use of the full 98/01 database. However, as mentioned in Discussion to this Chapter, additional analysis was performed to test the robustness of the finding that larger shipments were less likely to be rejected due to phytosanitary reasons. The PD indicated that this finding was possibly due to splitting of rejected lots after import inspection, which could contribute to rejected lots being smaller than not rejected ones (Jan Schans, PD, *personal communication*). To check this possibility, an additional analysis was performed to select records in the 98/01 database for which splitting of lots seemed *logically* impossible based on the information available in the database. To select such records, inspection report numbers were analysed for every record in the database.

The reasoning for using the inspection report number as a relevant selection criterion is the following. The inspection report contains records of inspection of all commodities present at an inspection location during an inspection visit. Thus, different records in the database having the same inspection report number indicate that lots under these records were inspected at the same time, inspection location, and that they were covered by the same PC(s) and were originally parts of the same consignment(s). If any splitting of lots took place, then according to the database it was only possible if there were *at least* two records of the same ornamental species from the same country of origin under the same inspection report number and one of the records was marked as rejected. In this case, logically, the rejected record and the accepted record represent lots that *could* initially be parts of a single lot. Case 1 in Table 1 illustrates this situation using a simplified example; it shows that the rejected lot (third line) could have been related to any of the two accepted lots mentioned under the same inspection report number (ZZZ in this case), as a result of splitting of their parent lot. A similar reasoning applies to records marked as rejected due to non-phytosanitary reasons. However, in cases that there were *two or more* records of rejection of the same commodity from the same importing country under the same inspection report number, splitting of records was considered impossible (case 2 in Table 1). The rationale for this assumption is that *a priori* there seems to be no logical reason for forming more than one infested lot from an original lot, which was found to contain pest specimens. Thus, in these cases it must have been that records of rejected lots *before* and *after* import inspection were the same and thus no splitting should have taken place.

Following this reasoning, the database was split into two parts: one containing records for which splitting was considered possible and one for which splitting was considered impossible. The former part included all records pertaining to inspection reports with possible splitting. Thus, also records of other ornamental commodities but present under the same inspection report number as the ornamental commodity for which splitting was judged possible, were included in the sample with possible splitting. Then, the MNL model was applied to both parts of the database. No appreciable differences were found

Table 1 An example of records in the 98/01 database

Ornamental commodity	Country of origin	Inspection report number	Status (rejected or accepted)
Case 1			
Rose	A	ZZZ	Accepted
Rose	A	ZZZ	Accepted
Rose	A	ZZZ	Rejected
Case 2			
Rose	A	ZZZ	Rejected
Rose	A	ZZZ	Accepted
Rose	A	ZZZ	Rejected

in the signs and significance of parameter estimates among the results based on the full 98/01 database and results based on the sub-sample of the database for which splitting of records seemed impossible. Hence, the finding that bigger shipments were less likely to be rejected on phytosanitary grounds was not an artefact of the data, i.e. it was not caused by the possible splitting of records.

03/05 database

The 03/05 database was used in Chapter 5 of the thesis. The first part of this Chapter analyses the percentages of interceptions of harmful organisms during import inspections of cut flowers in the Netherlands. The following explains how the numbers of rejected and inspected consignments in the database were calculated.

To count the numbers of consignments, it was necessary to count the number of PCs that accompanied the consignments. An implicit assumption is that one consignment has one PC. There were some peculiarities related to how PC numbers in the 03/05 database were reported. Assumptions made to count the number of PCs in these special cases are reported below.

- If a few PC numbers separated by slashes '\' were reported for a given record in the database, then each number was counted as representing a separate consignment
- For some records, only the iso-code of an exporting country (e.g. KE for Kenya) was present instead of the full PC number. To calculate the number of consignments in these cases, the inspection report number was used. For example, two records of the same ornamental commodity from the same country of origin falling under the same inspection report number, one of which had a PC number such as KE123546 and another simply KE, were considered as parts of one consignment.
- Some records under the same inspection report number had the following PC numbers (Table 2):

Table 2 Examples of the reporting the PC numbers in the 03/05 database

Inspection report number	PC number
Case 1	
ZZZ	KE123456
ZZZ	KE123456/123457
Case 2	
ZZZ	KE123456/123457
ZZZ	KE123456/123457

In Case 1, there are only two PCs for the purpose of calculating their numbers. Similarly, in Case 2, there are just two PCs (the order of their mentioning in two records is reversed).

Recommendations

The above analysis of the PD databases suggests a number of improvements that would facilitate scientific analysis of the data.

1) The data recording procedures could be significantly improved. Ideally, data in different databases (e.g. the database of import inspections and the database with diagnostic results) must be easily traceable to each other. This can be done by for example assigning a unique number to samples sent to diagnostic laboratory from a given lot and including this unique ID number in all databases.
2) Efforts are required to make sure that unambiguous information is recorded in databases, e.g. the exact scientific names of detected pest species, the phytosanitary certificate number of an imported lot, and the scientific names of plants. Useful additional information about imported lots could be recorded, e.g. the intended use of commodities (e.g. potted plants, cut flowers, propagating materials), the names of importing and exporting companies.
3) The databases should be organized so as to allow prompt extraction and analysis of information. The records in the databases should be organized accordingly. A preferred unit of recording is a single lot.
4) If infested lots are being split into infested and non-infested parts, the information on the characteristics of the initial lot, i.e. prior to any splitting, should be recorded in the database. A unique ID number consisting of e.g. the PC number of the initial lot plus extra identifying characters can be given to every lot originating from the initial one.
5) Because reduced checks in the EU are calculated at the consignment level (and if recording the information at the lot level proves impossible), it is necessary that the PCs' numbers are accurately reported in the inspection databases.

All the measures outlined above can significantly improve the usefulness of inspection databases, facilitate their analysis and strengthen the reliability, credibility and applicability of the results of analysis.

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Summary

Growth and liberalization of world trade have increased the risks of spreading of quarantine plant pests. Import inspection of incoming commodities is a major tool for prevention of pest introductions related to world trade, but inspection capacities are limited. The main objective of this thesis is to provide conceptual insights and quantitative results of analysis that may help optimize import phytosanitary inspection in view of binding capacity constraints.

The thesis starts with a discussion of the objectives and constraints of import inspecting agencies in the theoretical part of **Chapter 2**. Two possible situations are identified and analysed. In the first situation, the inspecting agency wants to find the minimum cost to maintain a specified level of risk of introduction of quarantine pests. The second situation refers to the case when the inspecting Agency wants to minimize the risks of introduction of quarantine pests while operating under a capacity (budget) constraint. Because in reality inspection capacities are limited, the empirical application in Chapter 2 focuses on the situation when the available capacity is constrained. The inspecting agency's objective in this application is to minimize the total number of lots of infested propagating materials pertaining to six different ornamental commodities imported in the Netherlands through nine pathways. A pathway is defined as the commodity-exporting country combination. Agency's objective represents the case when the data on the economic costs of pest introduction are not available and when only the likelihood of infestation of a single unit of propagating materials is known. The numerical results suggest that *ceteris paribus* more resources should be allocated to pathways with larger proportion of infested lots. Furthermore, within single pathways, bigger lots should receive longer inspection times since they may bring a greater number of infested plant materials.

Chapter 3 analyses the optimal allocation of inspection resources under capacity constraint when risk of pest introduction is represented as the expected costs of introduction of quarantine pests through trade pathways. The theoretical analysis shows that to minimize the expected costs of pest introduction under a given inspection capacity, the inspection effort should be allocated so as to equalize the marginal costs of pest introduction across import pathways. An empirical application focuses on finding the optimal allocation of inspection effort for chrysanthemum cuttings (CCs) imported in the Netherlands from six countries. The likelihoods and costs of introduction in the Netherlands of three quarantine pest species - *Bemisia tabaci* (tobacco whitefly), *Liriomyza huidobrensis* (Serpentine leaf miner) and *Thrips palmi* (palm thrips) - through imported CCs were estimated. The costs of introduction were estimated as a reduction in revenues of affected producers of susceptible crops due to yield reductions and increased crop protection costs. In this analysis it is assumed that pest outbreaks do not affect the prices in the Netherlands. In the absence of import inspection, the total

estimated costs of pest introduction through the six pathways were 4.4 mln euros. An optimally allocated inspection budget reduced the expected costs of pest introduction to 0.6 mln euros. The numerical results suggest that *ceteris paribus* greater inspection effort should be allocated to pathways whose inspection yields a greater reduction in the expected costs of pest introduction, i.e. pathways with more costly pests and/or with higher proportions of infested lots. The results suggest that under a binding capacity constraint, import inspection has high benefits. In particular, it is found that, depending on the initial inspection capacity, every euro added to the available inspection budget, reduced the expected costs of pest introduction with 18 to 49 euros.

Chapter 4 extended the work in chapters 2 and 3 by providing conceptual and empirical insights into the 1) the unconstrained allocation of inspection effort that follows from minimisation of the sum of the total costs of pest introduction plus the inspection costs and, 2) the constrained allocation that minimizes the total costs of pest introduction under the limited inspection capacity. In this chapter, the costs of pest introduction are given by the sum of the welfare losses for producers and consumers of crops affected by pest outbreaks. As in Chapter 3, the empirical application in Chapter 4 focused on finding the optimal allocation of resources for inspection of CCs imported in the Netherlands. Furthermore, in Chapter 4 the costs of pest introduction were calculated using a partial equilibrium model that assumed two markets- the Netherlands and the rest of the world, linked through excess demand equations. Thus, potential price effects of pest introduction in the Netherlands were taken into account. The costs of pest introduction obtained using a partial equilibrium model in the absence of inspection were equal to 2.2 mln euros, i.e. lower than the costs calculated in Chapter 3. This is because losses for producers were partially compensated by the increased prices stemming from reductions in supply of the affected crops. A constrained budget allocation of 88 thousand euros reduced the expected costs of pest introduction to 0.4 mln euros. In the scenario without capacity constraint, the allocated budget is 125 thousand euros, while pest costs are negligible The results suggest that pests costs can be greatly reduced through a 42% increase in the current – constrained - inspection budget. The presence of fixed inspection costs explains this result. It is suggested that before the decision to expand current inspection capacity is made, a careful estimation of the costs of pest introduction and proper parameterisation of the efficacy of import inspection is required. The sensitivity analyses further indicated that if some countries impose export bans on the Netherlands horticultural products if *T. palmi* established in the country, the estimated costs of pest introduction would increase dramatically, adding to the value and importance of import inspection.

Chapter 5 provided an empirical and a theoretical analysis of the recently introduced EU policy of 'reduced checks' with respect to imported cut flowers. Empirically, the chapter analysed whether rates of pest interceptions in the Netherlands supported the application of reduced checks for certain genera of cut flowers imported in the EU. This analysis revealed low rates of pest interceptions associated with most genera of cut flowers and thus supported their selection for reduced checks. Furthermore, the chapter discussed whether the reduced checks system is actually an *optimal* system. Using a hypothetical example and stochastic simulations, the expected costs of pest introduction under the reduced checks and a theoretically optimal system of inspections developed in Chapters 2 through 4 of this thesis were compared. The results showed that the expected costs of pest introduction into the EU could be further decreased compared to 'reduced checks'. It is suggested that accounting for possible economic impacts of harmful organisms in determining the frequencies of reduced checks could improve the current system.

With limited resources available for import inspections, insight into factors that determine the probability of rejecting certain commodities for import due to the presence of quarantine pests could increase the efficacy of inspection. In **Chapter 6**, a multinomial logistic (MNL) regression model was applied to data on import inspections of ornamental plant commodities in the Netherlands from 1998 to 2001 to investigate whether it is possible to predict the probability that a shipment will be (i) accepted for import (ii) rejected for import because of detected pests or (iii) rejected due to other reasons. The MNL model was fit to data pertaining to all ornamental commodities in the dataset, to a subset of four ornamental commodities and to specific ornamental commodities. The models for specific commodities and for the set of four ornamental commodities showed a better fit to data than the model for all ornamental commodities. The results showed that variables characterizing the imported shipment's region of origin, the shipment's size, the company that imported the shipment, and season and year of import, were significant in most of the estimated models. The results suggest that the MNL model can be helpful for better targeting of resources for import inspection.

The **Appendix** to the thesis provided a discussion of the databases used in this thesis and gives recommendations toward improving the data-recording procedures in databases of inspection agencies with a view towards scientific analysis and design of optimal import inspection policies. Finally, **Chapter 7** reviewed the main results of previous chapters, provided their critical discussions and presented general conclusions. The main conclusions of this thesis can be summarized as follows:

- Modelling the costs and benefits of import inspection gives insight in the characteristics of optimal strategies. The results of analysis can be used to critically evaluate current practices in import inspection and search for possible improvements (Chapters 2-5);
- In this evaluation, both the input from stakeholders and experts' knowledge should play an important role because the practical wisdom and interests of stakeholders were only rudimentarily accounted for in the theoretical analyses;

- *Ceteris paribus m*ore inspection resources should be allocated to pathways, whose inspection yields a greater reduction in the expected costs (or likelihoods, when the costs are equal) of pest introduction for every euro of the available budget (Chapters 2, 3, and 4);
- Under a binding budget constraint, the marginal benefits of import inspection are high. Expanding the available budget for inspection of chrysanthemum cuttings imported in the Netherlands with one euro decreases the expected costs of pest introduction with 18 euros (Chapter 3);
- In the presence of fixed inspection costs, an unconstrained allocation of inspection effort can be achieved relatively cheaply from the current, capacity constrained, inspection efforts. Quantitative results of the analysis are sensitive to the expected costs of pest introduction and the assumed efficacy of import inspection (Chapter 4). These aspects warrant empirical study to consolidate the results obtained here;
- The application of 'reduced checks' in the EU is justified for most genera of cut flowers. Including the economic impacts from potential pest introduction through a given commodity in calculating the frequencies of reduced checks can further improve the reduced checks system (Chapter 5);
- The logistic model is a useful tool for predicting the likelihoods of rejecting imported commodities due to phytosanitary reasons. The size of an imported shipment, the season of import, the intended use of commodities, the presence of quality certificates with an importer of a shipment and the characteristics of an importer are important factors explaining the likelihoods of rejecting imported commodities due to the presence of quarantine pests (Chapter 6);
- Results in this thesis indicate that scientifically based cost-benefit analysis can highlight opportunities for major improvements of the profitability of import inspection as a tool in the mitigation of risks from invasions of plant pests. Sound data-recording procedures by plant protection agencies, including negative inspection results, are crucial for conducting those analyses and should be a priority for any national of international agency responsible for plant health.

Samenvatting

Nederland is een grote importeur van landbouwproducten, en door de groei en liberalisering van de wereld handel wordt het risico op introductie van quarantaine organismen in Nederland steeds groter. Quarantaine organismen (kortweg Q-organismen) zijn organismen die volgens internationale verdragen niet in een land aanwezig mogen zijn. Als een Q-organisme wél aanwezig is, dan is het land verplicht om maatregelen te nemen die de prevalentie van het betreffende organisme zoveel mogelijk beperken of verminderen. Deze maatregelen zijn echter kostbaar. Bovendien kan aanwezigheid van een quarantaine-organisme in een land leiden tot verminderde internationale vraag en export. Het voorkomen van import van Q-organismen is daarom van groot economisch belang. Importinspectie wordt gezien als een effectief middel om import van Q-organismen te voorkomen en daarmee alle kosten die aanwezigheid van een Q-organisme met zich meebrengt. In dit proefschrift worden inzichten en kwantitatieve modellen ontwikkeld die kunnen helpen om importinspectie zo effectief en efficiënt mogelijk in te richten. Dit is van belang omdat inspectie kosten met zich meebrengt, en omdat er een beperkte inspectiecapaciteit is, bijvoorbeeld door de beperkte beschikbaarheid van deskundige inspecteurs.

In **hoofdstuk 2** wordt een theoretisch kader ontwikkeld om een optimale strategie voor importinspectie af te leiden, gegeven beperkingen in budget of capaciteit. Er worden in de theorievorming twee situaties onderscheiden. In de eerste situatie probeert de inspectie-autoriteit tegen minimale kosten een bepaalde kans op invasie van Q-organismen te realiseren. Minimale inspectiekosten zijn dan het doel, en een maximumkans op invasie wordt gehanteerd als randvoorwaarde. In de tweede situatie probeert de inspectie-autoriteit bij een gegeven budget (of capaciteit) de kans op invasie te minimaliseren. In deze situatie hebben de inspectiekosten de rol van randvoorwaarde en is het doel een minimale kans op invasie. De tweede situatie sluit dicht aan bij de praktijk en wordt daarom nader uitgewerkt in een voorbeeld. In het voorbeeld worden zes verschillende producten geïmporteerd via negen zogenaamde ’pathways’. Een pathway is een combinatie van een geïmporteerd product en een land van herkomst. Het voorbeeld illustreert een theoretisch resultaat, namelijk dat de meeste inspectiecapaciteit moet worden ingezet voor de inspectie van de pathways met de hoogste fractie partijen die geïnfesteerd zijn met Q-organismen. Theoretisch is de capaciteits- of budget-allocatie optimaal als de marginale verlaging van de kans op invasie per eenheid extra geïnvesteerd budget of capaciteit gelijk is voor alle pathways. De bemonsteringintensiteit moet groter zijn voor grotere partijen omdat een grote geïnfesteerde partij een grotere kans geeft op succesvolle vestiging van een Q-organisme, indien de partij wordt doorgelaten bij inspectie, dan een kleine partij.

In **hoofdstuk 3** worden de kosten van invasie ook in beschouwing genomen. Deze zijn afhankelijk van het Q-organisme, de breedte van zijn waardplantreeks, en de productiewaarde van de aangetaste gewassen. Volgens de theorievorming van hoofdstuk 3 is de optimale allocatie van inspectiecapaciteit díe allocatie waarbij de verlaging van marginale kosten van plaag-invasie per eenheid extra capaciteit gelijk is voor alle pathways. Dit resultaat ligt in het verlengde van het theoretische resultaat dat verkregen werd in hoofdstuk 2. De theorie wordt geïllustreerd aan de hand van de import van chrysantenstekken. Deze worden in Nederland geïmporteerd om te worden doorgeteeld tot snijbloemen. Er zijn in het voorbeeld zes landen van herkomst. Met deze stekken kunnen drie verschillende Q-organismen worden versleept: (1) tabakswittevlieg (*Bemisia tabaci*), (2) mineervlieg (*Liriomyza huidobrensis*), en (3) tropische trips (*Thrips palmi*). De kosten van invasie van deze drie insecten in Nederland werden gekwantificeerd op basis van inschattingen van de grootte van verwachte uitbraken, de kosten van bestrijding en uitroeiing, en de kosten van gewasschade. In de afwezigheid van import inspectie werden de verwachte integrale kosten van invasie van deze drie organismen via deze zes pathways geschat op 4.4 miljoen euro per jaar. Een optimaal gealloceerde inspectie reduceerde deze verwachte kosten tot 0.6 miljoen euro. De theoretische analyse in dit hoofdstuk laat zien dat er meer inspectiecapaciteit moet worden toegewezen aan pathways naarmate de fractie geïnfesteerde partijen groter is, en naarmate de Q-organismen die in de pathway kunnen voorkomen een grotere potentiële economische impact hebben. Een belangrijk resultaat van het numerieke voorbeeld is de inschatting van de marginale baten van verhoging van inspectie-inspanning in verschillende pathways. Per euro extra besteed budget werden in verschillende pathways de verwachte kosten van plaaginvasie met 18 tot 49 euro verlaagd. Dit resultaat geeft aan dat de inspectiecapaciteit beperkend is. Dit wordt verder geanalyseerd in hoofdstuk 4.

Het theoretische raamwerk van de hoofdstukken 2 en 3 wordt in **hoofdstuk 4** verder uitgebouwd door toevoeging van een partieel evenwichtsmodel. Dit model veronderstelt het bestaan van twee markten, Nederland en de rest van de wereld. Indien zich in Nederland een Q-organisme vestigt, dan heeft dit gevolgen voor het aanbod en de prijs van bepaalde landbouwproducten. Via internationale handel worden vraag, aanbod en prijs op elkaar afgestemd. Met dit complexe theoretische kader wordt getracht een bredere vraag te beantwoorden, namelijk, bij welk budget van importinspectie zijn de som van inspectiekosten en de kosten van plaaginvasie minimaal? Ook wordt de vraag gesteld welke allocatie van inspectiebudget, gegeven een bepaald totaal budget, optimaal is. Net als in hoofdstuk 3 worden de theoretische resultaten geïllustreerd met een toepassing op de import van chrysantenstekken. De totale kosten van plaaginvasie in afwezigheid van inspectie werden in dit raamwerk berekend op 2.2 miljoen euro, de helft van de kosten berekend via het raamwerk van hoofdstuk 3. De lagere kosten van plaaginvasie zijn het gevolg van een hogere prijs voor producenten die voortkomt uit de verlaging van het aanbod van aangetaste gewassen. Een vast inspectiebudget van 88 duizend euro verlaagde de verwachte kosten van plaaginvasie tot 0.4 miljoen euro. In het scenario waarin de kosten van inspectie volledig werden vrijgelaten, en het model zelf het optimale budget mocht 'zoeken' kwam het inspectiebudget uit op 125 duizend euro en waren de kosten van plaaginvasie verwaarloosbaar klein. Dit resultaat geeft aan dat een verhoging van capaciteit zal leiden tot een vermindering van totale kosten. Een voorzichtige interpretatie en consolidatie van dit resultaat, in interactie met stakeholders, zal nodig zijn alvorens er beleidsmatige consequenties aan kunnen worden verbonden. Zo is er bijvoorbeeld nog weinig kwantitatieve informatie beschikbaar over de efficiëntie van bemonstering in importpartijen. Ook zou een meer gedetailleerde benadering gekozen kunnen worden om de kosten van plaaginvasie te berekenen. Gevoeligheidsanalyses geven aan dat de geschatte kosten van plaaginvasie nog belangrijk toenemen als rekening gehouden wordt met een reductie in de vraag naar Nederlands product als zich in Nederland een Q-organisme, bijvoorbeeld *Thrips palmi*, zou vestigen. Importinspectie wordt dan nog waardevoller.

In **hoofdstuk 5** worden inspectiedata uit de praktijk van de import van snijbloemen, in combinatie met het raamwerk uit voorafgaande hoofdstukken, gebruikt om het recente EU-beleid van 'reduced checks' op kostenefficiëntie te onderzoeken. De resultaten geven aan dat de kans op infestatie in de pathways die zich gekwalificeerd hebben voor reduced checks inderdaad voldoet aan de maatstaven die gelden om voor reduced checks in aanmerking te komen. Echter, het systeem van reduced checks legt het wat betreft kostenefficiëntie af tegen een theoretisch optimaal systeem. Dit komt doordat in een optimaal systeem niet alleen de fractie partijen die geïnspecteerd wordt flexibel is en afhangt van de pathway, maar bovendien de monstergrootte per partij. In het systeem van reduced checks ligt deze monstergrootte vast, en is alleen de fractie partijen die geïnspecteerd wordt geflexibiliseerd; in het optimale systeem kan iedere pathway een andere monstergrootte hebben, al naar gelang het risico op infestatie en de verwachte kosten bij invasie van de plagen die in een bepaalde pathway voorkomen. De analyses geven aan dat met flexibilisering van de monstergrootte een efficiëntiewinst is te halen. Deze grotere efficiëntie kan ingezet worden voor reductie van de kosten van inspectie of om de meest risicovolle pathways intensiever te inspecteren. Analyses in dit proefschrift geven aan dat de tweede optie op nationaal niveau winstgevender is.

Hoofdstuk 6 behandelt een opzet om te komen tot een voorspelling van de kans op infestatie binnen een pathway. Sommige pathways hebben historisch gezien een veel hogere kans op infestatie, d.w.z. ze hebben een grotere fractie partijen waarin een Q-organisme aanwezig is, en in dit hoofdstuk wordt geprobeerd om uit deze data een voorspellend model af te leiden dat op basis van kenmerken van een geïmporteerde partij de kans op infestatie berekent. Voor deze analyse werd gebruik gemaakt van een multinomiaal logistisch regressiemodel, waarin een groot aantal verklarende variabelen werd meegenomen, en waarin voor iedere partij drie uitkomsten mogelijk waren: (*i*) toegelaten voor import; (*ii*) niet toegelaten voor import wegens aanwezigheid van een Q-organisme; en (*iii*) niet toegelaten voor import wegens kwaliteitsgebreken. Parameters van dit model werden afgeleid uit historische data van importinspecties door de Nederlandse Plantenziektenkundige Dienst. Er werd een model afgeleid voor alle geïmporteerde plantproducten, voor een subset van vier belangrijke siergewassen; en voor elk van deze vier soorten siergewassen afzonderlijk. In deze modellen hadden de volgende variabelen een significante invloed: de regio van herkomst, de grootte van de geïmporteerde partij, kenmerken van de importeur zoals een keurmerk, jaar en jaargetij. De modellen voor een specifiek product hadden de grootste verklarende waarde.

In de **Appendix** wordt ingegaan op de kwaliteit van de data die gebruikt werden voor de gerapporteerde analyses en worden aanbevelingen gedaan om de datavastlegging in de toekomst te verbeteren zodat wetenschappelijke analyse van deze gegevens en ontwerp van optimale inspectie zo goed mogelijk worden gefaciliteerd en ondersteund.

In **hoofdstuk 7** wordt een discussie gevoerd over de belangrijkste resultaten van deze studie. De voornaamste conclusies zijn:

- Het modelleren van de kosten en baten van importinspectie geeft inzicht in de kenmerken van optimale strategieën. De resultaten van analyse kunnen gebruikt worden om de bestaande importinspectie kritisch te evalueren en te zoeken naar mogelijke verbeteringen (hoofdstuk 2-5);
- Bij deze evaluatie moet participatie van stakeholders en inbreng van ervaringsdeskundigen een belangrijke rol spelen. Immers, de aanwezige ervaringskennis en belangen van stakeholders zijn slechts rudimentair verdisconteerd in de gebruikte data en theoretische analysemodellen (hoofdstuk 7);
- Volgens de theorie moet voor een optimaal resultaat de inspectiecapaciteit dáár worden ingezet waar per geinvesteerde euro de verwachte kosten van plaaginvasie maximaal worden teruggedrongen. In de optimale oplossing zijn de marginale opbrengsten van extra budget of capaciteit in alle pathways gelijk;
- Onder een beperkend inspectiebudget, overeenkomend met een realistische schatting voor de situatie in Nederland, zijn de marginale baten van importinspectie hoog. Bijvoorbeeld, per extra euro besteed aan de inspectie van chrysanten kunnen de verwachte kosten van plaaginvasie met minimaal 18 euro worden teruggedrongen (hoofdstuk 3);
- Een inspectiecapaciteit die optimaal is, vanuit het oogpunt van reductie van totale kosten van plaaginvasie plus inspectie, is aanmerkelijk groter dan de huidige inspectiecapaciteit (hoofdstuk 4). De analyses geven aan dat op nationaal niveau de extra kosten van een verruiming van inspectiecapaciteit ruimschoots worden terugverdiend door een reductie in kosten van plaaginvasie. De kwantitatieve resultaten zijn echter gevoelig voor onzekerheden in de gehanteerde ramingen van de kosten van plaaginvasie en voor de

efficiëntie van het bemonsteringproces. Het is daarom noodzakelijk om de resultaten te verifiëren en consolideren in empirische studies naar de belangrijkste aannames in de modellen (hoofdstuk 7);

- De meeste in Nederland geïmporteerde partijen van snijbloemen hebben zo'n lage kans op plaaginfestatie dat het systeem van reduced checks gerechtvaardigd is. Analyses geven aan dat een verbetering in de vaststelling van reduced checks mogelijk is door rekening te houden met plaag- en pathway-specifieke verwachte kosten van plaaginvasie, en door de monstergrootte te flexibiliseren; d.w.z. grote monsters in pathways met grote partijen, of een hoge kans op infestatie met plagen met een groot potentieel economisch effect;
- Het logistische model kan een hulpmiddel zijn om de kans op infestatie per partij te berekenen op basis van kenmerken van de partij. In deze modellen hadden de volgende variabelen een significante invloed: de regio van herkomst, de grootte van de geïmporteerde partij, kenmerken van de importeur zoals een keurmerk, jaar en jaargetij;
- Wetenschappelijke analyses kunnen helpen bij de identificatie van mogelijkheden om de winstgevendheid van importinspecties te verbeteren. Om zulke analyses uit te voeren zijn betrouwbare databases nodig welke gebaseerd zijn op goede procedures om de resultaten van importinspectie vast te leggen. Het is bijvoorbeeld essentieel dat negatieve inspectieresultaten (niets gevonden) worden geregistreerd. Goede procedures en betrouwbare databases zouden een prioriteit moeten zijn voor iedere nationale plantenziektenkundige dienst. Daarmee leggen deze diensten niet alleen hun acties vast maar verzamelen ze tegelijkertijd het materiaal op basis waarvan in de toekomst de effectiviteit en efficiëntie van inspectie kan worden verbeterd.

Краткий Автореферат

Рост и либерализация мировой торговли значительно увеличили риски распространения карантинных вредителей растений. Инспекция импортируемой продукции является важным инструментом предотвращения интродукции вредителей связанных с мировой торговлей, однако доступные мощности для проведения инспекций во многих странах мира ограничены. Основной целью данной диссертации является разработка концептуальных основ и количественных приложений, которые могут способствовать оптимизации импортных фитосанитарных инспекций при ограниченности ресурсов.

В теоретической части **второй главы** диссертации обсуждаются возможные цели (объектные функции) карантинных (инспекционных) служб в мире, а также ограничения, препятствующие достижению этих целей. Определены и проанализированы два возможные случая. В первом случае целью карантинной службы является нахождение минимума затрат для поддержания определенного уровня риска интродукции карантинных вредителей. Во втором случае карантинная служба желает минимизировать риски интродукции карантинных вредителей при наличии ресурсных (бюджетных) ограничений на мощности, доступные для инспекции. Так как в действительности ресурсы для инспекций ограничены, эмпирическое приложение второй главы диссертации концентрируется на случае ограниченности ресурсов. Целью карантинной службы в данном приложении является минимизация общего числа зараженных карантинными вредителями партий саженцев, относящихся к шести различным видам декоративной продукции, импортируемой в Нидерланды через девять «направлений». «Направление» представляет собой комбинацию, состоящую из страны-экспортера и определенного вида декоративной продукции. Избранная объектная функция представляет ситуацию, когда данные об экономических последствиях от интродукции карантинных вредителей недоступны, а известны только вероятности заражения партий саженцев. Количественные результаты свидетельствуют, что при тождественных условиях больше ресурсов должно быть распределено к «направлениям» с большим количеством зараженных партий. Также, внутри определенного «направления», партии большего размера должны быть инспектированы в течение более длительного времени, т.к. такие партии могут содержать большее количество пораженных саженцев.

В **Главе 3** анализируется оптимальное распределение ресурсов при ресурсных ограничениях, когда риск от интродукции вредителей представлен в виде ожидаемых экономических потерь от интродукции карантинных вредителей через торговые направления. Теоретический анализ в данной главе показывает, что для минимизации ожидаемых экономических потерь от интродукции вредителей при заданном уровне инспекционных ресурсов, последние должны быть распределены так, чтобы уравнять предельные издержки от интродукции вредителей между торговыми направлениями. Эмпирическое приложение в этой главе рассматривает оптимальное распределение ресурсов для инспекции саженцев хризантем, импортируемых в Нидерланды из шести стран. Были оценены вероятности и экономические потери от интродукции трех карантинных вредителей – *Bemisia tabaci* (Белокрылка табачная), *Thrips palmi* (Пальмовый трипс) и *Liriomyza huidobrensis* (Южноамериканский листовой минер) в Нидерланды через импортированные саженцы хризантем. Экономические потери от интродукции вредителей были подсчитаны как уменьшение выручки от реализации продукции из-за снижения урожайности и увеличения затрат на защиту растений у фермеров-производителей культур, восприимчивых к перечисленным выше вредителям. При подсчете экономических потерь было предположено, что массовое появление вредителей не оказывает воздействия на цены в Нидерландах. При отсутствии импортной инспекции, общие ожидаемые потери от интродукции вышеуказанных вредителей через шесть направлений оценены в 4.4 миллиона евро. Оптимально распределенные инспекционные ресурсы уменьшили ожидаемые потери от вредителей до 0.6 миллиона евро. Результаты показывают, что при одинаковых условиях больше инспекционных ресурсов должно быть распределено к «направлениям», где происходит наибольшее уменьшение ожидаемых экономических потерь от интродукции вредителей, т.е. к «направлениям» с более опасными вредителями и(или) пропорцией зараженных партий. Результаты свидетельствуют, что при ограниченных ресурсах импортная инспекция приносит высокую отдачу. В частности, обнаружено, что в зависимости от первоначального количества инспекционных мощностей, один евро добавленный к имеющимся ресурсам, уменьшает ожидаемые потери от интродукции вредителей от 18 до 49 евро.

Глава 4 расширила анализ глав 2 и 3, представив концептуальные и эмпирические подходы к: 1) распределению инспекционных ресурсов, которое минимизирует сумму общих экономических потерь от интродукции вредителей и затрат на проведение инспекции и 2) распределению ограниченного количества ресурсов для инспекции, минимизирующее общие экономические потери от интродукции вредителей. В этой главе, экономические потери от интродукции вредителей представлены суммой потерь производителей и потребителей сельскохозяйственных культур, подверженных вспышкам вредителей. Подобно анализу в Главе 3, эмпирический анализ Главы 4 рассматривает оптимальное распределение ресурсов для инспекции саженцев хризантем, импортируемых в Нидерланды. Однако в Главе 4, экономические потери от интродукции вредителей были подсчитаны с использованием модели частичного рыночного равновесия, в которой было предположено существование двух рынков- Нидерландов и всего остального мира, связанных между собой уравнениями избыточного спроса. Таким образом, были приняты во внимание возможные ценовые эффекты вспышек вредителей в Нидерландах. Потери от интродукции вредителей, подсчитанные в модели частичного равновесия, в отсутствие импортных инспекций, составили 2.2 миллиона евро, т.е. ниже чем потери, подсчитанные в Главе 3. Это является результатом того, что экономические потери производителей были частично компенсированы возросшими ценами из-за сокращения рыночного предложения культур, подвергшихся воздействию вспышек вредителей. Распределение доступных для импортной инспекции ресурсов в объеме 88 тысяч евро уменьшило ожидаемые потери от интродукции вредителей до 0.4 миллиона евро. При отсутствии ресурсных ограничений стоимость импортных инспекций равна 125 тысячам евро, в то время как ожидаемые потери от интродукции вредителей крайне несущественны. Результаты показали, что потери от интродукции вредителей могут быть значительно уменьшены за счет 42-процентного увеличения текущего- ограниченного- бюджета на проведение импортных инспекций. Объясняет этот результат наличие элемента постоянных затрат при проведении импортных инспекций. Указано, что до принятия решения об увеличении текущего бюджета на проведение инспекций, необходимо тщательно подсчитать потери от интродукции вредителей и правильно оценить количественные параметры, характеризующие эффективность импортной инспекции. Анализ чувствительности результатов показал, что если некоторые страны запретят экспорт определенных видов сельскохозяйственной продукции из Нидерландов в случае, если *T. palmi* распространится в Нидерландах, то оцененные потери от интродукции вредителей значительно бы увеличились. В этом случае значимость импортной инспекции значительно возрастает.

В **Главе 5** проведен теоретический и эмпирический анализ недавно введенной в действие системы упрощенных проверок для фитосанитарного досмотра цветов на срезку, импортируемых в Европейский Союз (ЕС). Эмпирически в Главе 5 было проанализировано, подкрепляет ли процент обнаруженых карантинных вредителей при инспекции импортных цветов на срезку в Нидерландах целесообразность применения упрощенных проверок для определенных родов цветов на срезку, импортируемых в ЕС. Данный анализ показал низкий процент обнаружения вредителей в партиях большинства родов цветов и, таким образом, подтвердил выбор этих родов цветов для упрощенных проверок. В этой же главе было рассмотрено, является ли система упрошенных проверок *оптимальной* системой. Используя гипотетический пример и стохастические симуляции, сравнивались ожидаемые потери от интродукции вредителей при применении упрощенных проверок и при применении оптимальной системы импортных инспекций, разработанной в главах 2-4 данной диссертации. Результаты показали, что ожидаемые потери от интродукции вредителей в ЕС могут быть уменьшены по сравнению с потерями при применении упрощенных проверок. Заключено, что включение возможных экономических потерь в расчет частот инспекций может улучшить существующую систему проверок со сниженными частотами.

При ограниченности ресурсов для проведения импортных инспекций, анализ факторов, влияющих на вероятность запрещения определенной продукции к импорту в страну из-за присутствия карантинных вредителей, может повысить эффективность импортных инспекций. В **Главе 6**, была применена мультиномиальная логистическая (МЛ) регрессионная модель к результатам импортных инспекций декоративной растениеводческой продукции в Нидерландах за период 1998-2001 гг. Исследовался вопрос, возможно ли предсказать вероятность того, что партия определенной продукции будет 1) разрешена к импорту, 2) запрещена к импорту из-за присутствия вредителей, или 3) запрещена к импорту из-за других причин. МЛ модель была применена к результатам инспекций, относящимся ко всем видам растениеводческой продукции в базе данных, к перечню из четырех видов растениеводческой продукции, а также к отдельным видам растениеводческой продукции. МЛ модели, примененные к результатам инспекций, относящимся к перечню из четырех видов растениеводческой продукции, а также к отдельным видам растениеводческой продукции, показали более высокое статистическое соответствие данным, чем модели, примененные к результатам инспекций, относящимся ко всем видам растениеводческой продукции в базе данных. Результаты показали, что переменные, характеризующие регион происхождения партии растениеводческой продукции, размер партии, компанию-импортера продукции, время года и год импорта продукции, были статистически существенны в большинстве оцененных моделей. В целом, результаты данной главы указывают на то, что МЛ модель может способствовать более целенаправленному распределению ресурсов для импортных инспекций.

В **Приложении** к данной диссертации обсуждаются аспекты использования баз данных в диссертации и даются рекомендации к улучшению процедур, используемых для заполнения электронных баз данных карантинных служб. Эти рекомендации направлены на создание условий для научного анализа результатов, а также оптимизацию импортных инспекций. Наконец, в **Главе 7** критически обсуждаются основные результаты, полученные в предыдущих главах, и представлены основные выводы работы. Основные выводы данной диссертации:

- Моделирование затрат и доходов от проведения импортных инспекций позволяет рассмотреть характеристики оптимальных стратегий. Результаты анализа могут быть использованы для критической оценки существующей практики импортных инспекций и поиска возможных улучшений (Главы 2-5);
- При проведении вышеуказанной оценки, важную роль должны играть мнения всех заинтересованных сторон, а также экспертные оценки, т. к. в теоретическом анализе

данной работы интересы заинтересованных сторон и практический опыт были лишь ограниченно приняты во внимание;

- При тождественных условиях больше ресурсов должно быть распределено для инспекции тех торговых направлений, где ожидается наибольшее уменьшение в ожидаемых потерях (либо в вероятностях интродукции, если данные об экономических потерях отсутствуют) от интродукции карантинных вредителей на каждый евро доступного бюджета (Главы 2-4);
- При наличии ресурсных ограничений предельная отдача от импортных инспекций высокая. Увеличение бюджета для инспекции саженцев хризантем, импортируемых в Нидерланды, на один евро ведет к снижению ожидаемых потерь от интродукции вредителей на 18 евро (Глава 3);
- При наличии элемента постоянных затрат при проведении инспекций, результат, достигаемый при распределении ресурсов *без наличия* ресурсных ограничений, может быть достигнут со сравнительно небольшими издержками с текущих, ресурсно-ограниченных уровней инспекций. Полученные количественные результаты, показывающие распределение ресурсов, чувствительны к величине ожидаемых потерь от интродукции вредителей и к параметрам, характеризующим эффективность импортных инспекций (Глава 4). Эти аспекты заслуживают дальнейшего эмпирического исследования для консолидации результатов, полученных в данной работе;
- Применение системы проверок со «сниженными частотами» в ЕС оправданно для большинства родов цветов на срезку, импортируемых в ЕС. Включение возможных экономических потерь от интродукции вредителей в расчет частот сниженных фитосанитарных проверок определенных видов растениеводческой продукции может повысить эффективность системы проверок со сниженными частотами (Глава 5);
- Логистическая регрессионная модель является полезным инструментом для прогнозирования вероятности запрещения определенных видов продукции к импорту из-за наличия фитосанитарных проблем. Размер импортной партии, сезон импорта, способ использования продукции (например, как саженцы или для конечного потребления), наличие сертификатов качества у компании-импортера, а также характеристики компании-импортера являются существенными факторами, объясняющими вероятность запрещения продукции к импорту из-за присутствия карантинных вредителей (Глава 6);
- Результаты данной диссертации показали, что научно-обоснованный анализ затрат и доходов предоставляет возможность для существенного повышения отдачи от импортных инспекций, как средства для снижения рисков интродукции вредителей растений. Формирование электронных баз данных карантинных служб, включающее

запись негативных результатов инспекций (т.е. тех, при которых вредители не обнаружены), является необходимым условием для проведения вышеупомянутого научного анализа и должно являться приоритетом для национальных и международных служб, ответственных за защиту растений.

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Curriculum Vitae

Ilya Vladimirovich Surkov was born in April 21st 1978 in Omsk, Russia. In 1995 he entered Omsk State Agrarian University (OmSAU), to follow specialization 'Accounting and Auditing'. He graduated from OmSAU in 2000 with distinction. In 2000-2001 Ilya was a PhD student at the department of General Economic Theory at OmSAU. In 2001-2003 under the EU Tempus project Ilya was an MSc student at Wageningen University, following specialization 'Agricultural Economics and Management'. From March 2003 until May 2007 he was working on his PhD dissertation entitled "Optimising Import Phytosanitary Inspection" at Business Economics Group of Wageningen University. During this period he followed the educational programs of the Mansholt Graduate School of Wageningen University and of the Netherlands Network of Quantitative Economics, both of which he completed in 2007.

Автобиография

Илья Владимирович Сурков родился 21-го Апреля 1978 г. в г. Омске. В 1995 г. он поступил в Омский Государственный Аграрный Университет (ОмГАУ) на специальность «Бухгалтерский Учет и Аудит». Илья закончил ОмГАУ в 2000 г. с отличием. В 2000-2001 гг. он учился в аспирантуре ОмГАУ на кафедре «Общей экономической теории». В 2001-2003 гг. в рамках проекта «Темпус-Тасис» Европейского Союза Илья обучался в магистратуре Университета г. Вагенинген, Нидерланды, по специальности «Экономика и Управление Сельским Хозяйством». С марта 2003 г. по май 2007 г. Илья обучался в аспирантуре на кафедре «Экономика Бизнеса» Университета г. Вагенинген. Тема его докторской диссертации: «Оптимизация импортного фитосанитарного контроля». В период работы над диссертацией Илья посещал курсы аспирантской школы им. Мансхолта Университета г. Вагенинген, а также Нидерландской Школы Математической Экономики и получил дипломы этих школ в 2007 г.

Completed Training and Supervision Plan

Name of the course	Department/Institute	Year	Credits*
Courses:			
Models in agricultural economics	Wageningen University	2002	5
Econometrics II	Wageningen University	2002	3
Research Methodology	MG3S	2003	2
Scientific Writing	Language centre, Wageningen University	2003	1.5
Mansholt Introduction course	MG3S	2003	1
Bayesian Methods in Theory and Practice	MG3S	2003	2
Food-Safety Risk Analysis	MG3S	2003	3
Applied General Equilibrium Models	Netherlands Network of Quantitative Economics (NAKE), Utrecht	2003	2
Micro I	Tilburg University	2003	4
Experimental Economics	NAKE, Utrecht	2004	2
Natural Resource Economics	NAKE, Utrecht	2004	2
Supply Chain Economics	MG3S	2004	2
Macro I	Tilburg University	2004	4
Bayesian Statistics	NAKE, Utrecht	2004	2
Behavioural Economics	NAKE, Utrecht	2006	4
Presentations:			3
Agricultural Economics Society's Annual conference, Nottingham, UK		2005	
American Agricultural Economics Association's Annual conference, Long Beach, USA		2006	
European Plant Protection Organisation's Conference on Computer Methods in Plant Protection		2006	
Mansholt Multidisciplinary Seminar, Wageningen		2007	
TOTAL (min. 20 credits)			42.5

*1 credit is equivalent to 40 hours of course work (1 credit = 1.4ECTS)

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