An empirical model of optimal import phytosanitary inspection

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Abstract This paper presents an empirical model of optimal budget allocation for import inspection of imported commodities. In this model, the budget constrained inspecting Agency wants to minimize the expected pest costs related to import trade pathways. The model is applied to the problem of budget allocation for inspection of chrysanthemum cuttings imported to the Netherlands. The numerical results imply that under a budget constraint, resources should be first allocated for inspection of pathways with the greatest expected pest costs. Pathways with lower expected pest costs should receive less or no resources. Thus, the inspecting Agency has to trade off risks between inspected and non-inspected pathways.

Inspection of imported commodities is a key element of the quarantine policy of most importing countries worldwide. In many cases, import inspection is a last barrier where harmful pests and diseases can be intercepted. The efficacy of import inspection in preventing the entry of pests and diseases is therefore a crucial condition for the overall success of quarantine policies. Commercial commodities inspected for presence of pests and diseases typically include agricultural, horticultural and forestry products because they pose the largest risks of carrying harmful pests and diseases. 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 2002).

Agencies responsible for conducting inspections have to operate under a constant pressure from increasing volumes of imported commodities that require inspection. At the same time, resources available for import inspection are generally limited. It can be said that capabilities of inspecting agencies in many counties are constantly lagging behind ever-increasing volumes of import. Evidence from the US and New Zealand suggests that even in wealthy and advanced- in relation to import quarantine- countries, only a limited share of the entire volume of imported commodities may be inspected (Everett 2000; National Research Council 2002).This evidence is even more striking given that in most countries the costs of inspections (inspection fees) are paid by importers of commodities.

The problem of optimizing the allocation of available resources for import inspections is therefore very pressing. Despite its importance, researchers paid little attention to this issue. Most studies focused on a general analysis of the optimal policies to prevent biological invasions[1] (Horan et al. 2002; Jensen 2002; Leung et al. 2002; Olson and Roy 2005; Perrings 2005) yet with a limited attention devoted to import inspection as the main instrument of prevention. Only recently, a number of studies including papers of Batabyal and Beladi (2006), Batabyal et al. (2005) and Batabyal and Nijkamp (2005) have explicitly focused on analyzes of import inspection policies. These papers used a framework of the queuing theory to analyze

[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).

theoretically the properties of inspection regimes of ships that may bring biological invaders in their cargo. In these papers the inspecting agency had virtually no budget constraint. This enabled Batabyal et al. (2005) to conclude that the inspecting agency should select the inspection regime depending on whether the reduction in the inspection costs or the costs of biological damages is the inspecting agency's priority. However, given a strong aversion of most importing countries to incursions of harmful pests and diseases, it is unlikely that reduction of inspection costs is a realistic inspecting agency's objective (also because the costs of inspections are born by importers of commodities).

This paper presents an empirical model of budget allocation for import inspection of imported commodities. The purpose of this model is to show how the inspecting agency in a given importing country should allocate its limited budget to minimize the phytosanitary risks[2] stemming from international trade. The model is applied to the problem of budget allocation for import inspection of chrysanthemum cuttings imported to the Netherlands. The contribution of this paper is twofold. Firstly, it presents a novel conceptual framework of constrained budget allocation for import inspection of commodities that may bring harmful plant pests. Secondly, the developed empirical model can be used for decision support in actual quarantine policy-making.

The remainder of the paper is organized as follows. Next section presents the conceptual framework. Then, the empirical application, data, and results are presented. The final section presents concluding remarks.

Conceptual framework

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 g be the pathway index and assume that there are G (g=1,…,G) pathways. Assume that each of the G pathways may serve as a potential vector for k (k=0,…,κ,…,K) quarantine pests. Assume further that $k \in [0, \kappa]$ pests are already

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[2] By "risk" we mean the potential damage that a given pest may cause in the importing country. Throughout the article we use terms "risk" and "pest cost (damages)" interchangeably.

established in H. As a result, the economic costs associated with the incursion[3] of the kth pest, d_k, may vary depending on whether this pest is already established in H or not. If the pest is already established, then the economic costs due to a new incursion are restricted to the premises where the new incursions occur and may have limited spillover effects for the economy or trade. Incursion of a new pest in H may involve both direct costs for the affected stakeholders (e.g. growers of affected crops) and indirect costs for the relevant sectors in the economy. Indirect costs may include e.g. higher production costs due to larger application of pesticides and lost profits due to possible trade restrictions. Further, we assume that d_k is given by the present value of all the costs associated with the incursion of a given pest, given the distinction between established and non-established pests introduced above.

Assume that the incursion of the kth pest is possible via Q pathways, where Q is a non-empty subset of G, i.e. $Q \subseteq G$. The probability of the incursion of a pest, p_{qk}, is the product of the probability of establishment and the probability of introduction, i.e.:

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

where $s_{qk}(h_k)$ and $u_{qk}(V_q, \gamma_{qk}, \alpha_{qk})$ are the probabilities of the kth pest establishment and introduction from the qth pathway, respectively. $s_{qk}(\cdot)$ depends on the conditions for survival existing for the kth 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 qth pathway, V_q, and the proportion of import infested with the kth pest, γ_{qk}. Also, the probability of introduction 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 incursion p_{qk} is independent of incursions via other pathways. This implies that the success of the incursion via the qth pathway does not depend on the success of the incursion via other pathways. This assumption requires that p_{qk}'s are small for $\forall\ q,k$.

[3] Essential terminology used in the paper is presented in the Appendix.

In the absence of any preventive quarantine measures, the present value of economic costs of all k pests associated with the qth pathway is given by the sum of their economic costs d_k weighted by the respective probabilities of incursion p_{qk} , i.e.

$$(2) \qquad D_q = p_{q1}d_1 + p_{q2}d_2 + ... + p_{qk}d_k = \sum_k p_{qk}d_k \ .$$

Equation (2) implies that, other things being equal, pathways with a larger number of pests (higher k), more dangerous pests (higher d) or higher probabilities of incursion (higher p) will have higher quarantine risks, as defined by D_q. 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 number of pests associated with a given pathway is a result of the interplay of the commodity factor (i.e. how suitable is the commodity as a host for the pest) and the country factor (i.e. whether the conditions in a certain exporting country are suitable for certain pests). Hence, identical commodities coming from different countries may have different pest ranges; as a result, quarantine risks 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 lower p_{qk}'s and, thus, lower quarantine risks.

We assume that the Agency aims at minimizing the expected pest costs from all pathways and import inspection of incoming commodities is the only preventive measure applied by the Agency. 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 optimally 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 budget b_q allocated for inspection of the lots coming along the qth pathway and a stochastic and unobservable variable Ω_{qk}. The latter variable captures the variation in the error probability of detection of different pests. Furthermore, Ω_{qk} accounts for specific characteristics of different 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 packing, etc).

The problem of the Agency is to choose α_{qk} as a function of the budget 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. This assumption states that the probability of an inspection error decreases when larger budget is allocated for a pathway; however, the marginal effect of extra budget is decreasing. Thus, the marginal productivity of inspection is decreasing.

Furthermore, we assume that $\frac{\partial u_{qk}}{\partial b_q} < 0, \frac{\partial^2 u_{qk}}{\partial b_q^2} \geq 0$ $\forall$ q,k, i.e. u_{qk} is also a convex function of the pathway budget[4]. Finally, given the assumed convexity of u_{qk} in b_q and treating the probability of pest establishment s_{qk} as constant, the overall probability of the kth pest incursion, p_{qk}, (see equation 1) is a convex function of the budget 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 incursion. This is in line with a common assumption that prevention efforts have diminishing effects on the probability of an environmental risk (Barrett and Segerson 1997). In the following, we will write the probability of pest incursion as a function of allocated budget, 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:

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[4]Specifically, for these assumptions to hold 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 $\frac{\partial^2 u_{qk}}{\partial b_q^2} = \frac{\partial^2 u_{qk}}{\partial \alpha_{qk}^2} \left(\frac{\partial \alpha_{qk}}{\partial b_q} \right)^2 + \frac{\partial u_{qk}}{\partial \alpha_{qk}} \frac{\partial^2 \alpha_{qk}}{\partial b_q^2} \geq 0$, respectively. These conditions have required signs, given the assumptions on α_{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 introduction is an increasing function of the inspection error, are satisfied.

(3) $$D_q(b_q) = p_{q1}(b_q)d_1 + p_{q2}(b_q)d_2 + ... + p_{qk}(b_q)d_k = \sum_k p_{qk}(b_q)d_k \,.$$

The Agency wants to minimize the expected costs of pest incursion from all *Q* pathways subject to the available budget constraint, *B*. Mathematically, the Agency's problem reads as follows:

(4) $$\text{Minimize } \sum_q D_q(b_q)$$

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

After conversion of the budget constraint into "≥" form, the Lagrangean *L* of the Agency's problem becomes:

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

where λ is the Lagrange multiplier, representing the marginal (shadow) value of the budget constraint. The Kuhn-Tucker optimality conditions for (5) (Chiang 1984) are given by:

(6) $$\frac{\partial L}{\partial b_q} = \frac{\partial D_q(b_q)}{\partial b_q} + \lambda \geq 0\,,\ b_q \geq 0 \text{ and } b_q(\frac{\partial D_q(b_q)}{\partial b_q} + \lambda) = 0 \qquad \forall\ q$$

and

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

The interpretation of optimal conditions is intuitive. Condition (6) implies that the optimal pathway budgets b_q should be allocated such that the marginal pest costs are equalized for all pathways that receive a positive budget, i.e. $\frac{\partial D_q(b_q)}{\partial b_q} = -\lambda\ \forall\ q$ with $b_q>0$. Condition (7) means that the budget constraint should be satisfied with equality in order to have $\lambda>0$. If the constraint is not satisfied with equality, then λ should optimally be zero. This means that a (small) change in the value of the constraint *B* will not change the optimal solution.

An empirical application

Setup

We apply the conceptual framework to inspections of cuttings of chrysanthemum (*Dendranthema grandiflora*) imported in the Netherlands. Generally, cuttings are a propagation material that goes directly to the production chain; because of that, their associated risk of introduction and spreading of harmful organisms is greater than of e.g. cut flowers which are destined for consumer market (Roozen and Cevat 1999). In view of the high phytosanitary risk, the EU Directive 2000/29 (European Commission 2000) prescribes that every lot of propagating materials should be inspected at import.

Inspection of chrysanthemum cuttings occupies a significant share of the overall inspection workload of the Dutch Plant Protection Service (Plantenziektenkundige Dienst, henceforth PD). For example, during 1998-2001, approximately 5.3% of all lots with ornamental products (including cut flowers, potted plants, and propagation materials) inspected at the Dutch border were lots consisting partially or entirely of chrysanthemum cuttings. In total, these lots originated from 28 countries. We selected the six largest countries with a combined share of export of approximately 95%, both in terms of volume and the number of imported lots (see table 1).

<Table 1 here>

Thus, there are six pathways (q=6) in the numerical model. The pathways were labeled from A to F[5]. Next, we defined pest species that are associated with these pathways. For that, we analyzed data on interceptions of harmful organisms during import inspections of chrysanthemum cuttings 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 which have a quarantine status for the Netherlands[6]. The rationale for restricting our application to quarantine pests was based on the premise that quarantine pests imply greater economic losses (due to potential implications for export) than organisms that

[5] We used letter codes instead of real names of the exporting countries due to confidentiality reasons.

[6] The quarantine pests for the Netherlands are listed in EU directive 2000/29/EC (European Commission 2000).

do not have this status[7]. According to the dataset (see table 1), three quarantine pests were intercepted in lots coming from the selected pathways in the period 1998-2001: *Thrips palmi* (palm thrips), *Bemisia tabaci* (tobacco whitefly) and *Liriomyza huidobrensis* (serpentine leaf miner). Of these pests only *Thrips 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 incursion we took the difference in pest statuses into account. We assumed that costs of incursion of *Bemisia tabaci* and *Liriomyza huidobrensis* pertain only to the year of the actual incursion; in contrast, costs of incursion of *Thrips palmi* are assumed to extend for a 10-year horizon. The yearly costs of pest incursions were estimated by summing the monetary damages borne by growers of the susceptible crops across affected growers. For *Thrips palmi*, the yearly costs were discounted and summed over the 10-years time horizon. For simplicity we ignored the indirect costs of *Thrips palmi* such as losses due to export restrictions. The Appendix gives more detail on estimation of costs of pest incursion.

Empirical model

The empirical model is constructed such as to represent the actual inspection activities of the PD. Since the PD charges for each extra minute of inspection, the length of inspection, denoted l (l=0,..,L), in minute intervals is the choice variable in the model. Thus the Agency needs to choose l to:

(9) $$\text{Minimize } T = \sum_q \sum_k p_{qk} d_k$$

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

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

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

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

with q=A, B, C, D, E, F and k=*Bemisia tabaci*, *Liriomyza huidobrensis, Thrips palmi*.

[7] In fact, a mere classification of the pest as "quarantine" implies that it has an economic importance for the relevant area. This directly follows from the definition of the "quarantine pest".

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} represents 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.

p_{qk} is given by the following expression:

(10) $$p_{qk} = 1 - \prod_l (1 - \gamma_{qk} n_q \varepsilon_{ql} \alpha_l),$$

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 all pathways the model has to choose combinations of the inspection error α_l per inspected lot and the proportion of lots inspected with a given length ε_{ql} that minimize the total expected pest costs (equation (9)). 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 are inspected (i.e. α_l=1 $\forall$ n_q), then inspection has no impact on the probability of pest incursion p_{qk} (see equation (10)). The probability of the kth pest incursion is calculated as the product 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. This is of course a simplification, because the probability of incursion is defined solely by the probability of introduction of a given pest, ignoring the probability of pest establishment after introduction. Unfortunately, we do not have detailed data to estimate the probability of pest establishment for pests in the model.

Data

First, we show how the error probability of import inspection α_l, the inspection length l and inspection cost c_l are related in the model. 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, sample size s is adjusted 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 detection threshold p_t (Venette, Moon and Hutchison 2002). The relevant formula is given by Kuno (1991):

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

Equation (11) implies that s is decreasing in α, that is a higher inspection error is associated with a smaller sample. s 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%[8]. With p_t fixed, equation (11) can be solved for different α's.

Next, we relate the costs of inspection to sample size. Obviously, larger samples require more inspection time and are therefore more costly. We assume that during each minute, the inspector may examine a fixed sample of 60 cuttings. We limit the maximum length of inspection to 20 minutes, assuming that inspection beyond this time is impractical. Feasible inspection lengths and the associated sample sizes are shown in columns 1 and 2 of table 2. Column 3 gives the cost of inspection of a given length, based on PD inspection tariffs. The PD tariff includes a fixed 'base tariff' charged for each inspection and a 'per minute tariff' charged for each extra minute of inspection (PD 2006). The last column of table 2 gives the error probability α_l calculated for each sample size l using equation (11).

<Table 2 here>

Table 3 presents the parameter values for the model.

<Table 3 here>

The expected number of lots per pathway was taken at the average yearly level of import based on 1998-2001 data. The proportion of lots infested with a given pest (γ_{qk}) was calculated as a ratio of the number of lots found infested with a given pest during import inspections and the total number of lots imported along the given pathway (see table 1). If a given pest had no record of interceptions for a given

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[8] The same detection threshold level is set in New Zealand for inspection of imported nursery stock (Biosecurity New Zealand 2006). In general, detection threshold may vary depending on the commodity, pest or the preferences of the Agency. For example, in the U.S. the detection threshold is set at 10% irrespective of the commodity (U.S. Department of Agriculture 1998).

pathway, then γ_{qk} was assumed zero. As a result, only four pathways (A, B, D and E) have $\gamma_{qk}>0$ for at most one pest per pathway.

It remains to specify the costs of pest incursion d_k and the value of the budget constraint, *B*. The estimated costs of *Bemisia tabaci*, *Liriomyza huidobrensis* and *Thrips palmi* incursion are equal to 0.28, 1.66 and 40.44 mln euros, respectively (see the Appendix for more detail). The budget constraint was set to 88,000 euros to represent inspection of all lots with at least 5 minutes (1,665 lots *52.91 euros/lot). This is assumed to replicate the current inspection policy when each lot has to be inspected. Thus, in the first scenario ("fixed allocation"), all lots from all pathways are inspected for 5 minutes (hence no optimization is taking place). In the second scenario ("optimal allocation"), the model optimally allocates available budget. In the third ("small budget") and fourth ("large budget") scenarios, respectively, we tightened and relaxed the budget constraint of the "optimal allocation" scenario with 50% to represent the situation when the budget is small or large.

Results

Table 4 shows the expected costs of pest incursion under various inspection scenarios.

<Table 4 about here>

The first row of table 4 presents the expected pest cost in the case of no import inspection. The values are obtained by a straightforward multiplication of the probabilities of incursion ($n_q\gamma_{qk}$) of a given pest and the associated costs of incursion d_k, when α_l=1. The greatest pest costs are associated with pathways A and B; pathways D and E have significantly smaller expected costs of pest incursion. This reflects the fact that more costly pests are historically associated with pathways A and B (see table 3). No pest costs are expected from pathways C and F because no quarantine organisms were intercepted along these pathways. As a result, under all scenarios, no budget (and hence no inspections) is allocated for pathways C and F. In general, table 4 shows that whenever inspection is applied, the expected pest costs are considerably reduced. However, the reduction in expected pest cost under the "fixed allocation" scenario is significantly smaller than in other scenarios in which budget is allocated optimally. This difference arises because under optimal allocation of budget, almost entire budget is allocated for pathways with greater expected pest costs (i.e. A and B) and a significantly smaller share of budget is allocated for pathways D and E.

To see the mechanism behind budget allocation, consider figure 1 that shows the allocation of inspection time for the "small budget" scenario. The height of the bar in each of the inspection length categories indicates the share of lots of a given pathway inspected in this category. One can see that pathways C, E and F received zero budgets; this is indicated by the bars in the "0 minutes" inspection category. Lots along pathways A and B should be inspected with 15 and 20 minutes, respectively. Only a small share of lots from pathway D should be inspected with 7 minutes while the remaining, larger share of lots, should remain uninspected. Thus, lots following along pathways with more damaging pests (pathways A and B) received longer inspection time compared to lots following along pathways with less damaging pests (pathway D). In general, under budgets of different sizes, the model always allocates budget first to more risky pathways and the remainder of the budget goes to less risky pathways. Also, lots following along at least one pathway (pathway D in this case) are inspected in two inspection categories- to exactly satisfy the budget constraint.

<Figure 1 here>

The results in table 4 also imply that a decrease in the inspection budget has more influence on the expected pest costs than the equivalent increase. This is a consequence of the decreasing marginal efficacy of budget: the greater is the budget the lower the marginal pest cost as a function of budget is and vice versa. This observation is supported if we compare the shadow values of the budget constraint, λ, obtained under various scenarios. In the "optimal allocation" scenario, λ was equal to -3.7 euros, implying that a 1 euro increase in budget would decrease the expected pest costs from all (inspected) pathways with this amount. Under the "small budget" scenario, λ increased to -4.1 euros while in "large budget" scenario λ was virtually zero implying that the budget was in fact excessive. In the latter case the Agency could significantly decrease the inspection budget with only a moderate increase in the expected pest costs.

Sensitivity analysis

The numerical results obtained thus far largely reflect our assumption of zero proportion of infestation γ_{qk} for pathways C and F, both of which had no historical records of pest interceptions. Because by construction the expected pest costs associated with these pathways automatically equaled to zero, the model did not allocate any budget for these two pathways. However the assumption above ignores the possibility that some pests may still be associated with a given pathway. Pests may have had been present in the imported lots but were simply not detected. Therefore, it is important to include the possibility that some pests may have been associated with certain pathways in the model.

To allow the possibility that some of the pests may be associated with certain pathways we modified the dataset as follows. For pathways with no records of pests interceptions in the PD database we used the EPPO pests sheets (EPPO 2006) to determine whether *Thrips palmi*, *Bemisia tabaci* and *Liriomyza Huidobrensis* were present (in other words, established) in a given exporting country (pathway). If it turned out that a given pest species was present in an exporting country, we calculated the proportion of infestation for a given pathway using the formula of Couey and Chew (1986):

(12) $$\gamma_{qk} = 1-(1-0.95)^{1/n},$$

where n was the historical number of imported lots (from table 1). Equation (12) calculates γ_{qk} as the upper limit of the 95% confidence interval that contains the true proportion of infestation. Using equation (12) we calculated γ_{qk} for nine pathways in total. For five exporting countries (pathways) in which a given pest was not present according to the EPPO pest sheets, we maintained the assumption that γ_{qk}=0. Finally, for the remaining four pathways we kept the estimated proportions of infestation as the ratio of infested and non-infested lots. Table 5 presents the modified data on proportions of infestation for model pathways.

<Table 5 here>

Using the modified data on proportions of infestation and making no other changes, we run the same set of scenarios as for the original dataset. Table 6 presents the expected pest costs for different scenarios.

<Table 6 here>

Table 6 reveals that modification of the data implied a major increase in the expected pest costs. The expected pest costs are now associated with all six pathways, because at least one of the pests is associated with each of the pathways. The greatest pest costs are associated with pathways C and D reflecting relatively high calculated (based on equation (12)) proportions of infestation with *Thrips palmi* (see table 5). The expected pest costs from all the pathways were almost 8 times greater than those reported in table 5.

The modification in data, on the other hand, has not influenced the qualitative results of applying import inspections under various scenarios. As before, the "optimal allocation" scenario resulted in a significantly lower expected pest cost compared to the "fixed allocation" scenario. This is because in the former scenario the model allocated most budget for pathways with greatest expected pest costs (i.e. pathways C, D and B). The remainder of the budget went to pathways with significantly lower expected pest costs (pathways A, E and F). Lots following along pathways with greater expected pest costs should also be inspected with more time, as figure 2 suggests.

<Figure 2 here>

The results of allocation of the inspection time presented in figure 2 show very different patterns compared to figure 1. According to figure 2, all lots coming along pathways B, C, D and F should be inspected. Some of the lots coming along pathways E should be inspected too. And none of the lots coming along pathway A should be inspected. These results contrast with results shown in figure 1, in which all lots coming along pathway A should be fully inspected. In the model based on the modified data, the allocation of budget occurred at the expense of not inspecting lots coming along pathway A that *a priori* implied comparatively small expected pest cost (table 6); at the same time, of all pathways, the largest number of lots (600, see table 3) is expected from pathway A.

Therefore, the significant differences in observed results underscore the importance of assumptions underlying the estimation of the proportion of infestation.

Concluding remarks

This paper presented an empirical model of optimal budget allocation for inspection of commodities that may carry harmful plant pests. The underlying conceptual model implies that with a binding budget constraint, the optimal policy is to allocate resources such as to equalize the marginal pest costs across risky pathways. In this way, the total expected pest cost are minimized.

The model was applied to inspection of chrysanthemum cuttings imported to the Netherlands. In general, the numerical results demonstrate that import inspection greatly reduces the expected pest costs. However, for a given budget, the policy of inspecting all lots with the same time is inferior compared to situation when the model chooses the optimal allocation. The essential mechanism behind this result is that under the optimal allocation a larger budget is allocated for inspection of pathways where the largest reduction in pest costs can be expected per each euro invested. Also, the results imply that lots following along pathways with greater expected pest costs should be inspected for a longer time, minimizing thus the probability of not detecting harmful pests. At the same time, pathways with *a priori* lower expected pest costs should receive smaller or zero budget, depending on the size of the total budget. These findings are consistent with Horan et al. (2002) who noted that it is optimal to devote more resources to confront (quarantine) events that are considered more likely and to allocate fewer or no resources to confronting events that are considered less likely. It is obvious that the Agency should be prepared to bear some risks in this case due to no inspection of some pathways.

Sensitivity analysis suggests that the numerical results are highly dependent on the expected pest costs associated with different pathways. Thus, for the model to produce reliable results, it is very important to have proper estimates of all the necessary quantitative data including the economic costs and the probabilities of pest incursion.

Overall, the presented model represents a novel contribution in the field of the economics of quarantine protection. Furthermore, the numerical results of the model make clear implications for inspecting or not inspecting lots coming along different import pathways.

Appendix

Terminology

Throughout the paper the following terminology is used (starred definitions are adopted from FAO (2005):

Quarantine pest*- A pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled

Pest introduction- entry of the pest in the importing country and survival during border quarantine procedures

Pest establishment- the establishment of a permanent pest population in the importing country, after which the economic costs are incurred

Pest incursion- pest introduction resulting into pest establishment

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

Estimation of pest costs

To estimate the economic costs of pests selected for the model we used the following approach (partially adopted from Temple et al. (2000) and Macleod et al. (2004)). First, we defined the range of crops that are at risk of *Bemisia tabaci*, *Liriomyza huidobrensis* and *Thrips palmi* in the Netherlands. The selection of susceptible crops was based on literature (mainly EPPO (2006); also see literature references to tables A1 and A2) and interviews with Dutch experts. Next, 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 defined as the difference between the revenue and variable costs. Gross margins were calculated using data on Dutch horticulture from PPO Applied Plant Research (2004). Further, we determined scenarios that captured various extents of the outbreaks. The extent of an outbreak means the percentage of growers affected by yearly outbreaks. Scenarios included low (1%), medium (5%) and high (15%) percentage of growers affected by the outbreaks. The number of affected growers was multiplied with estimated costs of an outbreak per grower, giving the total yearly costs of a given pest for growers of a given crop. The costs were summed over growers of different crops to give the total yearly pest costs per scenario. This number was multiplied with the probability of each scenario occurring, estimated by experts. Finally, the expected pest costs per scenario were summed over all the scenarios to yield the total yearly expected pests costs.

The quantitative assumptions of the impact of an outbreak of *Bemisia tabaci* and *Thrips palmi* on the affected grower of vegetable crops are summarized in table A1. Table A2 presents similar assumptions for the ornamental crops. Assumed impacts differ for vegetable and ornamental crops because stricter requirements are applied for visual quality of ornamental crops. (The loss in yield of ornamental crops if the outbreak occurs during harvest can be very large.) The range of assumed ornamental crops affected by different pests: *Bemisia tabaci* (Begonia, Gerbera, Poinsettia); *Liriomyza huidobrensis* (cut and pot chrysanthemum); because *Thrips palmi* is highly polyphagous, we assume that any grower of ornamentals can be affected and hence we calculated losses based on the gross margin for an average Dutch grower of ornamental crop.

Given the assumed impacts of pests on relevant crops, table A3 presents estimated yearly costs of incursion for different pests (detailed calculations are available upon request). Because *Bemisia tabaci* and *Liriomyza huidobrensis* are present in the Netherlands, no future impacts are calculated for these pests. For *Thrips palmi* the present value of costs was calculated by discounting (r=0.05) the yearly pest costs over the chosen time horizon (t=10) and summing them over. The present value of costs is equal to 40,443,798 euros.

<Tables A1, A2, A3 here>

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Table 1. Imported 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 for import, due to findings of:							
Thrips palmi	-	1	-	-	-	-	1
Bemisia tabaci	3	-	-	-	-	-	3
Liriomyza huidobrensis	-	-	-	1	1	-	2
Non quarantine pests	3	3	3	6	1	1	17
Total rejected lots	6	4	3	7	2	1	23

Table 2. 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' tariff)*, 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

Note: 'base tariff' - 44.36 euros, 'per minute' tariff- 1.71 euros. Source: (PD 2006).

Table 3. Parameter Values for the Model

Parameter	Pathway					
	A	B	C	D	E	F
Expected number of lots (n_q)	600	200	155	250	300	160
Proportion of lots (γ_{qk}) infested with:						
Bemisia tabaci	0.0013	0.0000	0.0000	0.0000	0.0000	0.0000
Thrips palmi	0.0000	0.0012	0.0000	0.0000	0.0000	0.0000
Liriomyza huidobrensis	0.0000	0.0000	0.0000	0.0009	0.0008	0.0000

Table 4. Expected Costs of Pest Incursion under Various Model Scenarios (in 1,000 Euros)

Scenario	Expected pest costs per pathway				Total pest costs
	A	B	D	E	
No inspection	1,294	9,460	65	68	10,887
"Fixed allocation"	288	2,103	14	15	2,420
"Optimal allocation"	11	23	5	15	54
Small budget	14	23	60	68	165
Large budget	3	23	0.2	0.2	27

Table 5. Modified Proportion of Infestation γ_{qk} for Pathways in the Model

Pest species	Pathway					
	A	B	C	D	E	F
B.tabaci	**0.0013**	<u>0.0030</u>	<u>0.0050</u>	<u>0.0030</u>	<u>0.0020</u>	<u>0.0040</u>
T.palmi	0.0000	**0.0012**	<u>0.0190</u>	<u>0.0030</u>	0.0000	0.0000
L.huidobrensis	0.0000	<u>0.0040</u>	<u>0.0050</u>	**0.0009**	**0.0008**	0.0000

Note: values in bold represent historical proportions of interceptions; underlined values are calculated using equation 12 (see the main text); the remaining values are equal to zero because a given pest is not present in the exporting country according to EPPO pest sheets (EPPO 2006).

Table 6. Expected Costs of Pest Incursion under Various Model Scenarios Based Modified Proportions of Infestation γ_{qk} (in 1,000 Euros)

Scenario	Expected pest costs per pathway						Total pest costs
	A	B	C	D	E	F	
No inspection	1,294	10,813	33,042	29,462	1,276	1,126	77,015
"Fixed allocation"	288	2,404	7,345	6,549	283	250	17,120
"Optimal allocation"	859	36	80	72	61	31	1,138
Small budget	1,294	88	81	97	1,039	63	2,662
Large budget	3	26	81	71	3	8	188

Table A1. Assumed Impact of an Outbreak of *Bemisia tabaci* and *Thrips palmi* on Vegetable Crops, %

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

Note: [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 A2. Assumed Impact of a Pest Outbreak 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]

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

Table A3. Expected Yearly Costs of Pest Incursion in the Netherlands, Euros

Pest species	Scenario		
	Low	Medium	High
Bemisia tabaci			
Cost of incursion	1,222,272	6,934,572	27,418,461
Subjective probability	0.96	0.03	0.01
Expected cost per scenario	1,173,381	208,037	274,185
Expected yearly costs	1,655,603		
Thrips palmi			
Cost of incursion	4,126,074	21,243,784	63,931,205
Subjective probability	0.96	0.03	0.01
Expected cost per scenario	3,961,031	637,314	639,312
Expected yearly costs	5,237,657		
Liriomyza huidobrensis			
Cost of incursion	217,384	1,141,266	3,423,798
Subjective probability	0.96	0.03	0.01
Expected cost per scenario	208,689	34,238	34,238
Expected yearly costs	277,165		

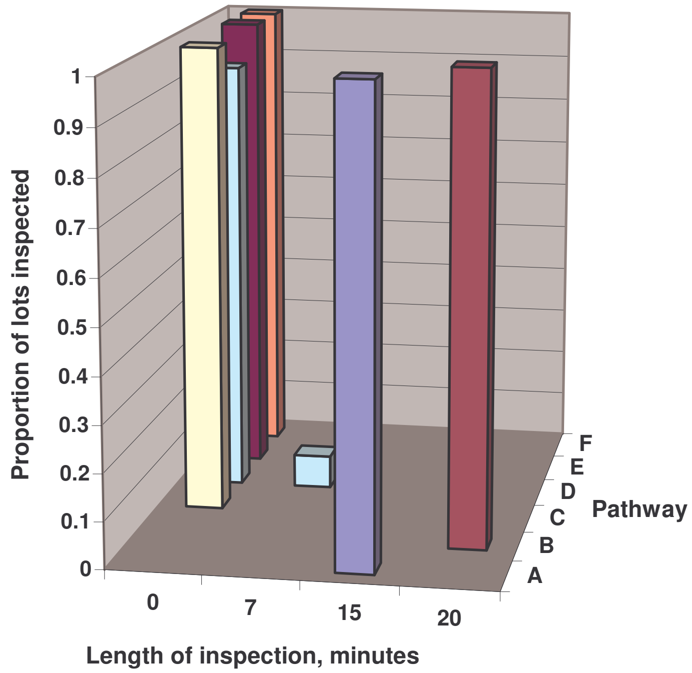

Figure 1. Inspection lengths for model pathways ("small budget" scernario)

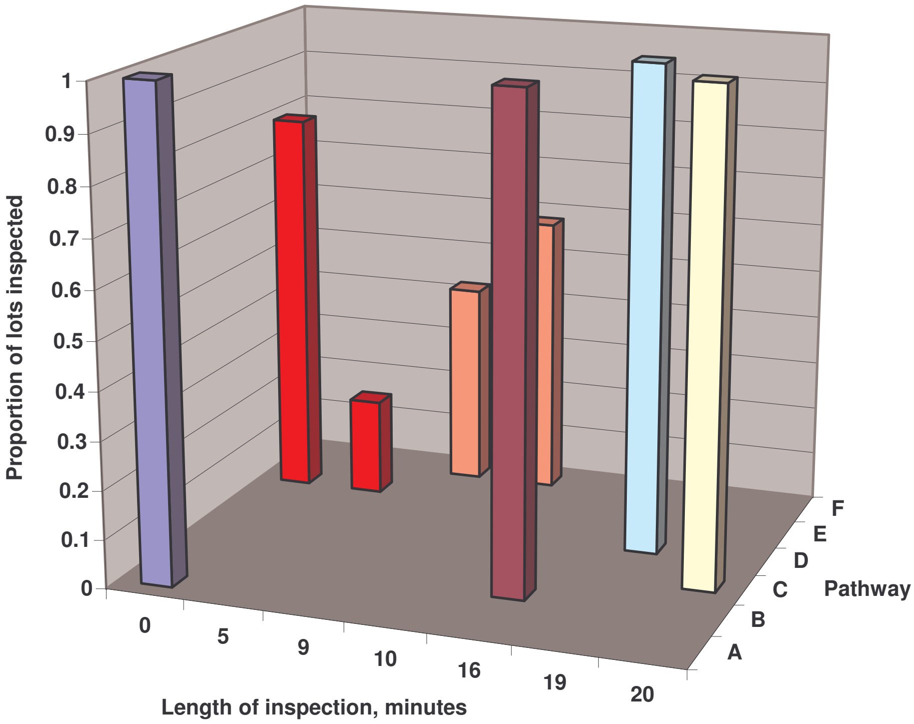

Figure 2. Allocation of inspection time for model pathways based on modified data on historical proportion of infestation ("small budget" scenario)