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Introduction of Quarantine Pests Related to International Trade and Design of an Optimal Phytosanitary Inspection Policy

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Abstract
Quarantine pests and diseases represent a significant threat to agricultural and horticultural production worldwide. Currently, it is recognised that international trade in agricultural products, and especially in plants and plant materials, is a major vector facilitating the spread of quarantine organisms. To provide an adequate level of phytosanitary protection, the responsible agencies should allocate their limited resources in the best way, so that phytosanitary risks associated with imported products are minimised. This is however a challenging task given the constantly growing volumes of imported products, their broad assortment, and large number of exporting countries.

This paper suggests an optimization framework that can be used for designing an optimal import inspection policy. In the first part of the paper the optimisation problems of the quarantine agency under the risk and budget constraints, respectively, are discussed. The conditions for the optimal allocation of the Agency's resources are derived. In this part of the paper the concept of acceptable level of risk (ALOR) and its implications for the problem of the inspecting agency are also discussed.

In the second part of the paper, two quantitative models for optimal allocation of resources for inspecting ornamental plants' imports to the Netherlands are presented. In the first - 'base' – model, the available budget is allocated to minimize the expected damage from pest introduction. In the second model the available budget is distributed proportionally to the expected risk from each commodity. Both models produce results in terms of the budget and inspection times to be allocated per each commodity. Though the base model yields higher reduction of the total expected damage, the results of the 'proportional damage' model are more consistent with risk minimisation objective. More precise data will facilitate the further development of the model and its potential application in the actual quarantine decision-making. To the best of authors'

knowledge both the setup and the results of the presented models represent a novel contribution in the field of economics of quarantine protection.

1 Introduction

World trade is widely recognised as the main vector for the movement and spread of quarantine pests (Bright, 1999; Jenkins, 2000). Pests may be unintentionally introduced directly with imported products, and also as 'hitch-hikers' on the containers' packaging material (Bright, 1999). The costs associated with introduction and establishment of an exotic quarantine pest, i.e. previously not present in a given country, can be very high. For example, it has been estimated that the presence of Mediterranean fruit fly - one of the most notorious quarantine pests worldwide - would result in yearly costs over $1 billion for the horticultural industry in California (Mumford, 2002). Similar estimates for New Zealand range between 100 and 130 mln US$ (Whyte, 1998).

It is therefore crucial- especially for countries with significant agricultural and horticultural activities as well as for those oriented on export of agri- and horticultural products - to have quarantine procedures that minimize the risks related to potential introduction of quarantine pests. Accordingly, phytosanitary inspection of imported products at the border of the importing country occupies an important place in quarantine practices as it is in most cases the only barrier where quarantine pests can be detected. Currently, the efficacy of the import inspection in maintaining an adequate level of phytosanitary protection is complicated due to a number of reasons. First, in most of large importing countries the inflow of commodities that need to be inspected is very large. In fact, it turns out that even in the wealthiest countries the complete inspection of incoming flows is virtually impossible. For example, in the United States the quarantine agency[1] has resources to inspect only 2% of incoming shipments (National Research Council, 2002). Likewise, in New Zealand not more than 18% out of annually arriving 300,000 shipping containers can be inspected (Hayden by Everett, 2000).

Furthermore, international agricultural trade continues to grow, not only volume-wise, but also in terms of more countries involved in trading activities as a result of trade liberalization. These two phenomena imply that more quarantine pests can be expected to accompany the import of agricultural products (Jenkins, 2000). The assortment of imported commodities with inherently different phytosanitary risks (e.g. due to different biological characteristics of an underlying commodity) may be also very broad. As a result, different inspection strategies may be required to inspect different commodities.

[1] Animal and Plant Health Inspection Service (APHIS)

Overall, available budgets can be seen as the most important- and most limiting- factor influencing the effectiveness of import phytosanitary inspections and, therefore, the phytosanitary risk that any importing country is exposed to. In most countries the quarantine budgets are quite tight (Saphores and Shogren, 2005). Therefore, it is also true that "perfect screening, detection, and control are technically impossible and will remain so for the foreseeable future" (US Office of Technology Assessment, 1993). The available resources should nevertheless be allocated in a way that provides the maximum attainable level of phytosanitary protection (Gray *et al.*, 1998).

The purpose of this paper is to develop an optimization framework that can be used for designing of an optimal, i.e. risk minimising, inspection policy taking into account the budget constraint of the quarantine agency (hereafter, Agency). This paper contributes to the literature on strategies to control biological invasions (Horan *et al.*, 2002; Saphores and Shogren, 2005). Similar to these studies the problem of the Agency is analysed from the perspective of the allocation of resources aiming at reducing expected damage related to pest establishment. Next, this paper contributes to the literature on economics of quarantine and SPS Agreement[2] (Anderson *et al.*, 2001) because the problem of the Agency is constructed as risk minimisation taking the acceptable level of risk (ALOR) established by a given importing country into account. The final contribution of this paper is that a quantitative model for optimal allocation of available resources for inspection of heterogeneous imported commodities is presented. Two alternative model specifications are considered: a 'base' model and a 'proportional damage' model. In the latter, the available inspection budget is allocated proportionally to the contribution of each commodity's risk to the total risk from all commodities.

The application in this paper focuses on ornamental plants. This choice is dictated by two circumstances. Firstly, ornamental species may serve as vectors for many quarantine pests. For example, numerous ornamental species are listed as potential hosts for different quarantine pests in Annex II of the EU directive 2000/29/EC (European Commission, 2000). Secondly, ornamentals are usually imported in a broad assortment and/or from a large number of exporting countries. Therefore, the number of possible country-species combinations (henceforth, referred to as 'pathways') with different phytosanitary risks may be very large. Hence, ornamentals seem ideal for purposes of the model in the paper. Data for the quantitative part of the model pertain to the Dutch import inspection data of ornamental commodities.

The paper is structured as follows. Section 2 discusses the general problem of the Agency in the light of ALOR. Two alternative model specifications for the optimal inspection of imported commodities are presented in Section 3. Specifically, subsection 3.1 outlines a theoretical 'base' model and subsection 3.2 presents a 'proportional damage' model. The models

[2] Agreement on the Application of Sanitary and Phytosanitary Measures (WTO, 1995).

are parameterised in subsection 3.3. The description of data and of specifics of solution algorithm can be found in Section 4. Results are discussed in section 5. Discussion and directions of future research are presented in Section 6.

2 Pest introduction, import inspection and the acceptable level of risk

The task of the Agency in any importing country is to minimize the risk of pest introduction related to imports of a given commodity. Obviously, phytosanitary risk (as any other risk) cannot be avoided completely unless all import is banned. Therefore, a certain maximum or 'benchmark' level of risk that can be accepted by the Agency should be established. This benchmark risk can be regarded as guidance for the Agency in establishing appropriate protecting measures but also as a justification of the applied measures in trade disputes (for example, when an exporting countries claims that quarantine measures are trade restrictive). Throughout the paper, this level of risk is called 'acceptable level of risk' (or simply ALOR). Note that the defined ALOR is close to the definition of the 'appropriate level of protection' (or ALOP) in the parlance of the World Trade Organisation (WTO). Specifically, ALOP is defined as "the level of protection deemed appropriate by the Member establishing a...phytosanitary measure to protect human, animal or plant life or health within its territory" (WTO, 1995). It may seem that the distinction between these definitions can be made (in fact ALOR implies ALOP), though in the literature there is a tendency to use these terms interchangeably (e.g. Snape and Orden, 2001). For the purposes of this paper the definition of ALOR is used.

How ALOR should be expressed is, however, not specified. Hence, the Agency in every country is free to choose any measure that expresses the country's ALOR. International Standards on Phytosanitary Measures may provide guidance in this respect. Specifically, ALOR can be expressed as (article 3.1 of FAO, 2001):

- reference to existing phytosanitary requirements
- indexed to estimated economic losses
- expressed on a scale of risk tolerance
- compared with the level of risk accepted by other countries.

It is clear that to be comparable, the established ALOR and risks posed by different commodities should be expressed on an equivalent basis. In the literature it has been proposed to define risk (and ALOR as well) as the product of the economic impact of a pest and the probability of pest introduction[3] (Bigsby, 2001). Such definition of risk gives rise to the application of the so-called 'iso-risk framework' (Bigsby and Crequer, 1998). In this framework, the risk represented by a

[3] Such approach of defining risk can be also encountered in a conventional risk literature (Kaplan and Garrick, 1981).

given commodity is calculated as the product of the probability that a quarantine pest associated with this commodity will be introduced (or, in the worst case, become established) in the importing country and the magnitude of the related damage. The locus of all probability-damage combinations between which the Agency is indifferent gives an iso-risk curve depicted on Figure 1.

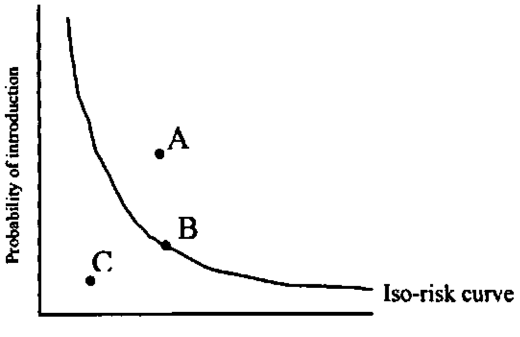

Figure 1 ALOR in the iso-risk framework

Source: adopted from (Gascoine, 2001)

Black circles on Figure 1 denote different phytosanitary risks related to imports of, say, three different commodities A, B, and C. Note that ALOR (i.e. iso-risk curve) is set in terms of risk *per commodity*, but not for the *total risk* (from all three commodities). Therefore, all risks above the curve will not be accepted. As a result, commodities B and C would be allowed for import as the risks they pose are within the country's ALOR. And conversely, import of the commodity A would not be permitted unless additional quarantine measures to decrease risk below or equal to ALOR are applied.

It is important to note that iso-risk approach implicitly implies that ALOR is established per individual pest. In reality, a particular commodity may host a variety of quarantine pests, each with different probability-impact combinations. As a result, the application of the iso-risk approach for establishing ALOR may become troublesome[4].

When more than one pest may be brought in with a given commodity, it is more appropriate to establish ALOR on a per commodity basis. In this case, the overall risk posed by a given commodity will be compared with ALOR expressed by some monetary value. The commodity risk will be calculated by summing risks (i.e. expected damages) over all pests (Bigsby, 2001):

[4] Though ALOR may still be established in terms of the risk associated with the most damaging pest (Rodriguez *et al.*, 2001).

$$E(D_j) = \sum_{k=1}^{K} p_k d_k \qquad (1)$$

where $E(D_j)$ is the expected damage related to import of the *j*th commodity, p_k is the probability of establishment of the *k*th pest (k=1,…,K), and d_k is the damage associated with the *k*th pest. Consider the damage due to pest d_k more closely. In general, the costs related with pest establishment include direct costs of the eradication campaign (the loss of destroyed or damaged host crop, the costs of chemicals applied, labour costs, quarantine costs, etc.) and the indirect costs related to the impact of a pest on other crops and future impacts of a pest (FAO, 2001). The latter include among other impacts the possible loss of export markets (due to trade restrictions) and higher production costs. Therefore, taking into account future economic losses associated with the the *k*th pest, d_k in equation 1 can be written as $d_k = d^m_k + d^f_k$ i.e. as the function of direct (or momentarily) costs d^m_k and the flow of future discounted damages d^f_k calculated as follows:

$$d_k^f = \int_0^T d_t^k e^{-rt} dt \qquad (2)$$

where d^k_t stands for the annual future damage due to pest, T is the appropriately chosen time horizon and r is the discount rate. Thus, d_k represents the present value of all economic damages related to pest establishment.

For the purpose of setting the ALOR at a level that allows evaluating risk for a given period, d_k should be expressed per unit of a time interval. If the yearly interval is chosen, then equation 1 can be re-defined as follows:

$$E(D_j) = \sum_{k=1}^{K} p_k^a d_k^a \qquad (3)$$

where p_k^a and d_k^a denote the per year probability of the *k*th pest establishment and the associated economic damages, respectively. The superscripts 'a' are mnemonic from "annual".

ALOR established on a 'per commodity' basis implies that irrespective of the number and the volume of commodities imported within a given year, they would be allowed for import provided that their individual risks are lower or equal to ALOR, or $E(D_j) \le ALOR$. However, when the number and/or the volume of imported commodities are large, pest establishment in a given year may become very likely. It is therefore more appropriate to define ALOR for the *total volume of commodities* imported by a given country. In this case the Agency determines "the maximum expected value (of risk) that will be accepted, aggregated over all commodities imported during a particular period" (Bigsby, 2001). The risk, i.e. the annual expected damage ($E(TD^a)$) from the total volume of commodities imported by a given country can be calculated as follows:

$$E(TD^a) = \sum_i \sum_j \sum_k p_k^a d_k^a . \qquad (4)$$

Hence, damage is summed over k pests associated with i (i=1,...,I) commodities imported from j (j=1,...,J) exporting countries. Provided that $E(TD^a) \leq ALOR$, all commodities will be imported.

It is obvious that to apply the iso-risk framework, ALOR itself should be set at a certain monetary level (as the iso-curve line is drawn in the expected damage space- see Figure 1). However, thus far, no country-WTO member was reported to announce its ALOR (Gascoine, 2001), at least officially. One of the reasons is that many countries consider ALOR as a very sensitive issue and are not prepared to announce it officially (Wilson, 2000; Gascoine, 2001). Another reason is that it may be difficult to calculate the reasonable value for ALOR given that interests of many stakeholders should be accounted for and quantified. However, it may be difficult to quantify the impacts of a particular pest for all interested parties. Furthermore, to estimate the expected damage posed by each imported commodity unambiguously, quantitative estimates of the probability of pest establishment and the associated damage are necessary. But it may be difficult or even impossible to estimate exactly the economic impact of a given pest (or pests), and/or assess the likelihood of the pest establishment because of the uncertainty surrounding pest risks and general lack of data (Rodriguez *et al.*, 2001). Even if estimates of the expected damage are obtained, they might be ambiguous or incomplete, undermining thus the application of the iso-risk approach.

Alternatively, the Agency may use the probability of establishment itself as the risk threshold. In this case, if the probability of pest establishment exceeds a certain threshold level, the import of the corresponding commodity may not be allowed. This approach (henceforth referred to as 'probabilistic') implicitly assumes that introduction of *any* quarantine pest will lead to a major outbreak, with high and unacceptable economic consequences. Similarly to the iso-risk approach, ALOR in the probabilistic approach can be expressed on the 'per commodity' or 'total volume' basis. Figure 2 demonstrates the case when ALOR is set per commodity.

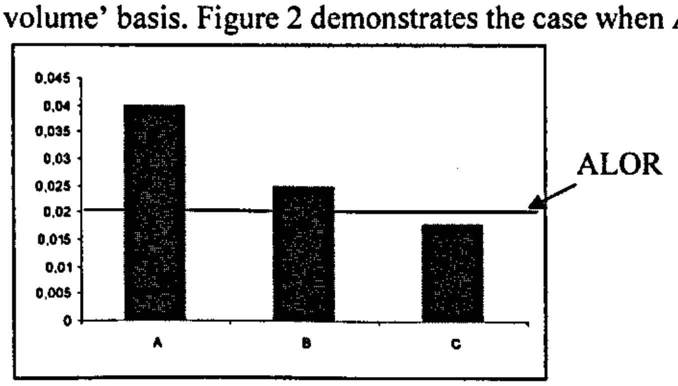

Figure 2 Annual probability of pest establishment as ALOR

In Figure 2, ALOR is arbitrarily set equal to 0.02. Thus, if ALOR is set per annum, the probability of pest establishment associated with import of a given commodity should not exceed 2% per year. It can be seen that risk posed by import of commodity C is within the acceptable limit, while import of commodities A and B involves a high risk of pest establishment.

The extension of the 'per commodity' based ALOR to the 'total volume' based ALOR is straightforward. The sum of probabilities of pest establishment for all three commodities should be lower or equal to 2%. A visual inspection of Figure 2 reveals that the combined probability of pest establishment will be far higher than 2%. Statistical independence between risks posed by different commodities is assumed here (in reality this may not be the case; for example commodities coming from the same exporting country are exposed to the similar pests' range and possibly similar production and quarantine conditions).

In short, it can be said that though most studies agree that ALOR should be defined on the 'expected value of risk' basis, in reality it may be difficult to settle ALOR purely on these grounds. Therefore, a probabilistic approach to define ALOR can be used[5]. This approach has of course a drawback of not taking the economic impact of pests associated with different commodities into account; on the other hand, less data are required.

Before concluding this section, two important points that have implications for the forthcoming model should be made. Firstly, ALOR clearly represents the risk attitude of the Agency. The lower it is set the more risk-averse the Agency is. Secondly, all quarantine procedures, including import inspection, are performed at the level that guarantees that ALOR of the country is maintained. For the conduct of import inspection this implies that a random sample of a representative size is taken for visual examination from the import consignment. The size of a sample is such as to guarantee the required level of confidence that a consignment is free from quarantine pests given the consignment size and the detection threshold of the inspection (FAO, 2004). The detection threshold is the minimum infestation level in a consignment that can be detected with a given confidence level. So, this threshold may serve as a proxy for the maximum risk (i.e. maximum infestation level) that a given country is prepared to take. Therefore, when the Agency is not budget constrained, all consignments of imported commodities will be inspected with a given level of confidence and ALOR will thus be obeyed. This can be seen from Figure 1: all commodities will be inspected and those with risks higher than ALOR (commodity A) will be discarded (at a certain confidence level). As in reality the quarantine budgets are not unlimited, the inspection decisions should take this into account. The next section presents a model of

[5] Note that discussion here is limited to approaches that eventually should yield quantitative estimates of ALOR. Of course, qualitative approaches can be also used. For example, in Australia ALOR is loosely defined at a 'negligibly low level' (Gascoine, 2001).

import inspection under budget constraint.

3 The model of optimal import inspection

3.1 Theoretical conditions for optimal allocation of inspection resources

Consider an importing country *H* (for *h*ome) that imports *j* agricultural (j= 1,...,J) commodities from *i* (i=1,...,I) exporting countries. To be more specific, assume that these commodities are ornamental plants. The average size of a random consignment of the *j*th ornamental commodity is m_j and the number of consignments imported annually is n_j. So, the total volume of import V_j of the *j*th commodity is equal to $V_j = m_j n_j$. At the border of *H*, import inspection of incoming consignments of ornamentals takes place. Assume that import inspection is the *only* quarantine measure applied for all commodities. The inspection is oriented at commodities rather than pests, so it is not pest specific. Import inspection involves taking a random sample for visual examination from every consignment. The size of the sample is such that at the confidence level α it is assured that the proportion of infestation in a consignment does not exceed p_{max} and the latter is a maximum allowed level of infestation in a consignment. Thus, there is a probability of at least 1-α that a pest is not detected. If at least one specimen of quarantine pest *k* is found in a sample, the entire consignment is discarded. If no pests are found, the consignment is cleared for import. After import, plants can be sold immediately (e.g. cut flowers) or used as production inputs (e.g. propagation materials) by growers in the home country. In both cases there is a probability that pest from the consignment may successfully escape into the natural environment (for example, from the grower's premise or with cut flowers thrown outside after the end of their vase-life). If a pest escapes into environment, there is a probability that it will establish a viable population and will become endemic in the home country[6]. Denote the combination of factors that determine the probability that a pest survives after import and establish a viable population in the importing country as a single factor γ (assumed not pest specific and for all types of ornamental commodities). Thus, γ absorbs all factors that influence pest survival after import inspection (climate and host suitability, host availability, probability to be not detected by a grower, etc. (Wearing *et al.*, 2001)).

The Agency has an annual budget *B* that can be spent for inspections. As inspections are

[6] Hence, it is assumed that the eradication campaign against the pest will not be fully effective or too costly to undertake.

oriented on commodities, then for inspection of the jth commodity from ith exporting country a share of $b_{ij} \geq 0$ of the total budget can be allocated.

Consider first the problem of the Agency when the budget constraint is not active.

Minimize $E(C) = \sum_i \sum_j b_{ij}$

subject to $\sum_i \sum_j p_{ij}(b_{ij}) \leq ALOR$

The first-order conditions (FOCs) are given by:

$$1 - \varphi \frac{\partial p_{ij}(b_{ij})}{\partial b_{ij}} = 0 \quad \Rightarrow \quad \frac{1}{\varphi} = p'_{ij}(b_{ij}) \quad \text{all } ij$$

$$ALOR = \sum_i \sum_j p_{ij}(b_{ij}),$$

where $E(C)$ denotes the total costs related to inspection of imported commodities, $p_{ij}(b_{ij})$ is the probability of pest establishment as a function of the inspection budget, and φ is the Langrange multiplier associated with the constraint. FOC implies that in the optimum, the reduction of the risk due to increase in the inspection budget for the ijth pathway, should be equal across all budgets. Note that ALOR is set as the maximum probability of pest establishment which is accepted by the Agency. Alternatively, the constraint could be set with ALOR expressed at some monetary value, and the risk per pathway as $p_{ij}(b_{ij}) * d_j$ i.e. as the expected damage per pathway.

When the budget constraint comes to force, the constrained minimisation problem of the Agency can be written as follows:

$$\text{Minimize } E(TD) = \sum_i \sum_j p_{ij}(b_{ij}) d_j \tag{5}$$

subject to[7] $\sum_i \sum_j b_{ij} \leq B$

and $b_{ij} \geq 0$

where $E(TD)$ is the *per year* total expected damage due to import of commodities (superscripts for the yearly damage (equation 4) are omitted for simplicity). Thus, the objective of the Agency is to minimise the expected yearly damage due to pests subject to the Agency's yearly budget constraint. Note that the problem is formulated in terms of the expected damage minimisation. Note also that the objective function is changed compared to equation 4 in Section 2 because inspection is not pest-specific. However, the possible impact from pests d_j is made commodity

[7] Alternatively, the budget constraint could be written as two constraints: a 'commodity constraint', i.e. $b_1 + b_2 + \ldots + b_j \leq \beta_j$ and a 'country constraint' $\beta_1 + \beta_2 + \ldots + \beta_i \leq B$.

specific. Therefore, this parameter captures that some commodities may host larger number (or more dangerous) pests and that potential negative impacts may differ between commodities.

Parameter $p_{ij}(b_{ij})$ makes the link between the inspection efforts of the Agency and the probability that a given pest may become established in the *home* country explicit. Here it is assumed that $\frac{\partial p_{ij}(b_{ij})}{\partial b_{ij}} < 0$ and $\frac{\partial p_{ij}^{2}(b_{ij})}{\partial b_{ij}^{2}} > 0$ (following Barrett and Segerson, 1997). So, a higher budget decreases the probability that a pest may become established; the efficacy of additional budgets is however decreasing with higher budgets. Note that when $b_{ij}=0$, then the probability of pest establishment p_{ij} will be entirely determined by factor γ (conditional that a pest is imported to H).

The first order conditions for the Agency's problem are:

$$\frac{\partial L}{\partial b_{ij}} = \frac{\partial p_{ij}(b_{ij})}{\partial b_{ij}} d_i - \lambda = 0 \quad \text{or} \quad \frac{\partial p_{ij}(b_{ij})}{\partial b_{ij}} d_i = \lambda, \qquad \forall\, i,j \qquad \textbf{(FOC1)}$$

$$\frac{\partial L}{\partial \lambda} = B - \sum_i \sum_j b_{ij} = 0 \quad \text{or} \quad B = \sum_i \sum_j b_{ij} \qquad \textbf{(FOC2)}$$

where L is the Lagrangean of the problem.

FOC1 implies that in the optimum, marginal benefits (reduced expected damage) should be equal to the shadow price of the total budget. Moreover, marginal benefits should be equal across budgets. FOC2 simply insures that the budgets are fully used. These results are in parallel to findings of the literature on strategies to control biological invasions (Horan *et al.*, 2002; Saphores and Shogren, 2005). Henceforth, this model will be referred to as the 'base model'.

3.2 A 'proportional damage' model of budget allocation

It is interesting to compare the budget allocation decisions of the model above with the model where budget is allocated according to some rule. In the literature it has been proposed that the quarantine measures should be in proportion to the extent of (pest) risk presented (Mumford, 2002). If such rule is adopted, then budgetary resources should be allocated in proportion to the contribution of each pathway to the total risk represented by all pathways. Hence, if $\omega_{ij} = p_{ij} d_{ij} / E(TD)$ represents the contribution of the ijth pathway in the total risk (E(TD) is defined as in previous subsection), then the budget per each pathways will be a function of omega too, i.e. $b_{ij}(\omega_{ij})$. The problem of the Agency will be then defined as follows:

Minimize $E(TD) = \sum_i \sum_j p_{ij}(b_{ij}) d_j$

subject to $\sum_i \sum_j b_{ij}\omega_{ij} \le B$,

where the modified FOCs are as follows:

$$\frac{\partial p_{ij}(b_{ij})}{\partial b_{ij}} d_i = \omega_{ij}\lambda \text{ and } B = \sum_i \sum_j b_{ij}\omega_{ij}.$$

As can be seen, the shadow price of each budget will be different and determined by the contribution of the underlying pathway into the total risk. This means that the changes in the budgets for pathways with large risks will influence the total risk more than changes in the budgets for pathways with moderate or small risks. Henceforth, this model is referred to as 'proportional damage' model.

In the optimal solutions of both 'base' and 'proportional damage' models, the individual budgets b_{ij} are calculated such that the overall risk is minimized and total budget *B* is fully used. *How* individual budgets b_{ij} should be spent, must be specified additionally. This specification has important implications for the overall results of the models, because if the information about the distribution of the budget b_{ij} in a particular way is known a priori, then the optimal solution in the model may be influenced by this information.

For both models, it is assumed that a given budget b_{ij} can be distributed between all consignments passing via *ij*th pathway. Moreover, consignments can be inspected with more time (and, thereby, with larger samples) if the risk posed by the pathway is sufficient to justify such allocation (see the next subsection for more detail). It should be noted that the assumptions concerning budget distribution depend on the actual inspection procedure used by a given Agency and the general assumptions behind the models. Given the assumption that visual inspection is the only available policy in the current model, the above assumption that consignments can be inspected with more time seems appropriate.

Concluding this subsection, it should be said that the imposed budget constraint implies that in the optimum not all consignments with ornamental commodities may be inspected (of course, had there been no budget constraint, all consignments would be inspected). Thus, it can be expected that ALOR of the home country may be exceeded. But it is also important to bear in mind that pest establishment in the absence of import inspection in a given period is not certain to occur; in fact, the probability of this may be very low. The proportion of infestation in a particular exporting country can be extremely small and/or the volumes of import may be also small. Thus, in theory, no inspection *per se* may be needed and, still, the home country's ALOR will be maintained.

3.3 Empirical model for optimal phytosanitary inspection

In the preceding subsection the solution approach and the characteristics of the optimal solution were laid out. To solve the problem empirically, a few important relationships between key variables should be set. At this stage it is also important to make an explicit link between the model and actual inspection routines. Thus, where relevant, the Dutch inspection regulations for ornamental commodities are discussed.

Recall that in the objective function of the Agency the probability of pest establishment is the variable that Agency may influence (the economic impact remains constant). It is thus necessary to set a formula that describes the probability of pest establishment. The annual probability of *a* pest establishment resulting from import of the commodity *j* from the country i can be calculated as follows

$$\Pr ob(est \mid p_{\inf}^{ij}) = 1 - (1 - (1 - \alpha) p_{\inf}^{ij} \gamma)^{V_{ij}} \quad (6)$$

where $p_{\inf}^{ij}$ is the proportion of infestation in the exporting country, γ is the probability of pest survival in the home country after import, V_{ij} is the expected volume of import, and α is the probability that a pest is not detected during import inspection. Note that equation 6 without (1-α) term calculates the probability of a pest establishment in the country when no import inspection is in place. In the previous sentence the article 'a' in front of 'pest' was italicized because of the assumption that inspection is not pest specific and thus the risk of *a* random quarantine pest is being modelled. Thus, equation 5 can be estimated provided that necessary data are available (see section 4).

Next, it is important to establish a link between the efficacy of import inspection, the time required for inspection, and the costs of inspection. As was already mentioned, the efficacy (i.e. the confidence level) $\alpha \in (0,1)$ of the import inspection depends on the sample size *s* taken from the consignment and the maximum allowable infestation level in a consignment p_{max}. A commonly used formula for calculating the sample size based on the required α and p_{max} is the following (Kuno, 1991)

$$s = \frac{\log \alpha}{\log(1 - p_{\max})} \quad (7)$$

Thus, the sample size is increasing in α and decreasing in p_{max} (i.e. one should sample more to achieve higher confidence level and sample less when maximum allowable infestation is higher). As an example, when p_{max}=0.5% (a common threshold level in quarantine practice) and α=0.95, approximately 570 plants should be sampled, irrespective of the consignment's size. In Table 1 equation 5 is solved for 1-α (ignore the rest of the table for the moment).

Table 1 Relation between sample size, confidence level, time of inspection and sample costs

Sample size, units	1-α	Time of inspection, minutes	Inspection costs ('15 minutes' fee + 'call out' fee)*, euros
0	1,0000	0	0
300	0,2223	15	61.61
570	0,0574	30	83.28
825	0,0160	45	104.95
1065	0,0048	60	126.62
1260	0,0018	75	148.29
1434	0,0008	90	169.96
1587	0,0004	105	191.63

*callout fee- 39.94 euros, "15 minutes" fee- 21.67 euros.

Source: http://www9.minlnv.nl/pls/portal30/docs/folder/minlnv/lnv/uitvoering/ud_pd/tarieven/ (Dutch Plant Protection Service)

Taking samples is costly, however. It is costly with respect to both time and money. In the Netherlands the structure of the tariff for import inspection provides a clear indication of the possible relationship between the time spent for inspection, the size of the sample taken, and the costs of inspection. Specifically, import tariff consists of a fixed tariff per visit to the location of import inspection (*call out fee*) and variable tariff for each 15 minutes the inspector spends for taking samples. A logical conclusion can be made that the longer the inspector stays on the import location site the more samples can be taken. And exactly this relationship can be used as the basis for formulating the necessary relationship. It is assumed that to sample the first 300 plants 15 minutes are required. Therefore, to achieve the required 95% confidence level, the inspector would have to inspect ~570 plants for 30 minutes (or inspect ~1 plant per 3 seconds). Later, due to the law of diminishing returns, less plants can be inspected per time unit[8] (see Table 1). The sampling curve is therefore concave in time. The associated 'per 15 minutes' costs are also presented in Table 1. The possible inspection times range between zero and 105 minutes. Though the last values in the range (i.e. 90 and 105 minutes) guarantee a virtual quarantine safety of a consignment of almost any size (given p_{max}), the use of these inspection times is hardly practical. Nevertheless, for completeness, these values are included in the table.

4 Data and solution algorithm

4.1 Data

The model finds solutions for budget allocation for the following pathways: Kenya (chrysanthemum, dianthus and rose), Israel (chrysanthemum, dianthus and impatiens) and Costa Rica (chrysanthemum, yucca and dracaena). The chosen commodities constitute a representative selection among commodities imported to the Netherlands both in terms of their volumes and the

[8] An opposite effect, of course, is the reduced marginal productivity of the inspector. This effect is assumed to be negligible.

phytosanitary risks posed, i.e. commodities with relatively high (chrysanthemum, dianthus, dracaena) and relatively low phytosanitary risks are represented (rose, impatiens, yucca).

Data for the model came from the results of import inspections of ornamentals imported to the Netherlands during 1998-2001 (see Table 2). The proportion of infestation $p_{\inf}^{ij}$ in the exporting country was estimated as follows. If no pests were found during import inspection, the upper 95% $p_{\inf}^{ij}$ was estimated using formula $\alpha = 1-(1-p_{\inf}^{ij})^{N_{ij}}$ (Couey and Chew, 1986). When pests were found during import inspection, the estimation approach was different. Unfortunately, from the available data it was not possible to deduce the proportion of infestation in the infested consignment. Only the fact that it had been infested was known. Thus, at first, the number of infested plants in one consignment had to be estimated. Pert(0.005,0.1,0.2) distribution was used (Vose, 2000) to estimate the proportion of infestation in the infested consignment, where the respective parameters represent the minimum, most likely and maximum values. In this distribution the most likely value receives four times higher weight than minimum and maximum values. The choice of values is based on the assumption that infestation level in a given consignment was low. This is because each consignment passes via export inspection before export, so the infestation level in the consignment when it is inspected by inspectors of the importing country should be relatively small. Next, the estimated mean values for $p_{\inf}^{ij}$ were multiplied with the consignment size. The obtained number of infested plants was summed over all infested consignments. This number was then used as parameter a in Beta(a+1,b-a+1) distribution, where b is equal to the total number of plants imported during 1998-2001. All simulations (100,000) for each parameter were done using Latin Hypercube sampling in @Risk4.5 (Palisade Corporation).

The values for expected consignments' number and size were assumed at their average values for four years. The probability of pest survival after import, γ, in general, is difficult to estimate (Roberts *et al.*, 1998). It depends on the specific pest species and is related with the distribution pattern of a given commodity after import. With large uncertainty γ is set equal to 0.005 In other words, it is assumed that pest establishment on average results from 1 out of 200 infested plants. The values for the expected damage d_j per each ornamental species are also uncertain and require careful estimation. Without possessing exact estimates of this parameter, the chosen values were nevertheless assumed to capture the varying extent of possible economic losses related to each of the ornamental species and also to represent the importance of a given species for Dutch ornamental horticulture.

Table 2 Data and initial parameter values for the model*

Parameter	Species					
	Rose	Chrysanthemum	Dianthus	Dracaena	Impatiens	Yucca
Exporter specific data						
Kenya						
Proportion of infestation, (P^{ij}_{inf} [a])	1.05E-07	4.93E-05	3.66E-04			
Expected number of consignments [b]	125	600	700			
Average consignment size [b]	65,000	725,000	60,000			
Israel						
Proportion of infestation, (P^{ij}_{inf} [a])		1.05E-04	2.85E-04		1.22E-7	
Expected number of consignments [b]		150	1,815		210	
Average consignment size [b]		7,810	28,956		30,068	
Costa Rica						
Proportion of infestation (P^{ij}_{inf} [a])		1.41E-06		6.25E-05		9.33E-07
Expected number of consignments [b]		155		1,560		150
Average consignment size [b]		1015491		5,735		19,506
Non exporter specific data						
Probability of establishment (γ [c])	0.005	0.005	0.005	0.005	0.005	0.005
Yearly damage due to pest (d_j), euros[c]	10,000,000	12,000,000	3,000,000	5,000,000	3,000,000	1,500,000

* 9 pathways (3 ornamental species coming from 3 countries) are represented
a) own calculation
b) obtained from import inspection data
c) assumption

For example, rose and chrysanthemum are the two most important export cut flowers sold via Dutch flower auctions (VBN, 2003). Dracaena is an important export indoor plant. At the same time chrysanthemum and dianthus are known to host significantly more quarantine pests than, for example, impatiens and yucca (see http://www.defra.gov.uk/planth/checklst/glass-op.htm).

To set the quarantine budget *B*, the following approach was used. In the absence of the budget constraint, all 5465 import consignments would be inspected at a 95% confidence level. The costs per one inspection would be 83.28 euros (from Table 1), giving 455,125 (83.28*5465) euros of total costs. Taking the purpose of the model into account, the imposed constraint should be sufficiently low compared to the situation of no constraint. Therefore, the budget of 200,000 euros was chosen.

4.2 Specifics of solution algorithm

Recall that there are two alternative specifications of the model with the budget constraint imposed: the 'base' model and the 'proportional damage' model. Additionally, the unconstrained model outlined in section 3.3 (referred to as 'costs minimisation model') is solved too. For all models the ALOR was set in terms of the total risk from all pathways at 0.05, i.e. the maximum probability of pest establishment from all pathways should not exceed 5% per year. The reason for choosing this value was that it is a commonly used error level (one minus 95% confidence level) which can be flipped to represent the maximum probability of risk the Agency is prepared to take.

An important condition was introduced in both models in relation to the established ALOR. If the risk from the individual pathway was lower than ALOR divided by the number of pathways (i.e. 0.05/9=0.0056) then no inspection was required for consignments following this pathway. The rationale for such condition is simple: if risk posed by the pathway is lower than the maximum allowed risk contribution per pathway, then it is worthwhile to save budgetary resources and reallocate them for inspection of a pathway with higher risks. The solution algorithm for both models follows the above rationale. Hence, the available resources were allocated only for the pathways that represented risks larger than the maximum average contribution per pathway (i.e. 0.0056).

5. Results

Prior to presenting the main results, consider first the expected risks when no inspection is in place. This will allow seeing the effects of import inspection on reducing risks better. Tables I.1-I.3 in Appendix I present the necessary information. As can be seen from Table I.1, for five pathways (chrysanthemum from all countries, dianthus from Kenya and dracaena) pest establishment is almost certain or likely to occur; at the same time, for three pathways the probability of establishment is lower than the maximum allowed per pathway (i.e. 0.05/9=0.0056). So, no inspection budget is required for inspection of impatiens, yucca and rose. Other pathways, conversely, require import inspection. Tables I.2 and I.3 in the same Appendix show the expected damage per pathway and the contribution of the expected damage per pathway into the total damage. The total prior expected damage due to pest establishment summed over all pathways (as in equation 5) is equal to 29.85 mln euros per year. It can be seen that chrysanthemum contributes the largest share into the total expected damage from all ornamental species (irrespective of the exporting country). Furthermore, Kenya-chrysanthemum pathway is the most risky pathway among presented ones. Note the equal contribution of both dianthus pathways and dracaena to the total risk.

The results of the models themselves are presented in Appendix II. The results are shown from two perspectives. First, the budgets (or budget shares) allocated per each pathway (Tables II.1-II.3) are presented. Next, Tables II.4-II.6 show the inspection time that a specific number of consignments following a particular pathway should be inspected (of course, given that consignments of a certain pathway are inspected at all). First, the results from the 'costs minimisation' model are discussed.

Positive budgets presented in Table II.1 indicate that consignments of 6 out of 9 pathways will be inspected when the Agency has unlimited resources. As expected, yucca, rose and impatiens will not be inspected due to their low contribution to the total risk. The extent of budget allocation appears different for different pathways. Expectedly, the size of the calculated budgets is directly related with the expected number of consignments following a particular pathway (see Table 2). Therefore, dianthus from Israel received the largest share of budget costs, followed by dracaena and dianthus from Kenya. The main result form this model can be expressed as follows: given that there is no budget constraint, every consignment of a particular commodity will be inspected with inspection effort that is related to the historical proportion of infestation of this commodity and the expected number of consignments (see Table II.4).

More interesting are the results of the models with budget constraints. The results of the budget allocation for the base model in Table II.2 show that the largest shares of the total budget are allocated for chrysanthemum from Kenya and for dracaena. While the former result can be expected given the largest contribution of the corresponding pathway to the total risk, the second result may seem surprising. This outcome is even more striking given that calculated budgets for both dianthus pathways representing exactly the same risk as dracaena (see Table II.3) are equal to zero. To explain this result, it is necessary to recall the empirical formulation of the probability of pest establishment in the model (equation 6). The latter is the function of the size and the number of consignments expected along the pathway. For pathways with a large number of consignments, it is necessary to inspect a very large proportion of the entire import flow to achieve a significant reduction in the probability of pest establishment. Thus, when the budget is constrained, it is more effective to inspect more consignments following one pathway than to distribute resources for inspection of pathways with large number of consignments equally. This result is not logical because the reduction in risk is achieved only for one pathway, while for the rest pathways no inspection measures are applied. And this is despite the fact that the economic damage for these species is equal.

Above findings are reflected in the allocation of calculated budgets between different inspection times for different consignments shown in Table II.5. It is easy to see that when the budget for a given pathway is large (e.g. dracaena), the consignments of this pathway receive more intensive inspection treatment compared to pathways that received a low budget allocation according to the model. To conceive these last results better, recall that the model included the information on how the calculated budget could be spent (see Table 1) for conducting more thorough inspections (larger samples and more inspection time). These a priori set conditions are reflected in the results. For example, 100% of consignments of dracaena should be inspected with at least 15 minutes; at the same time 31% of consignments of chrysanthemum from Kenya should be inspected for 45 minutes and the remaining part- for 60 minutes. The results for other pathways can be interpreted similarly.

Such results- to inspect more consignments 'in depth', i.e. with more time, rather than to inspect as many consignments as possible- may be also attributed to the influence of the import tariff. The structure of the inspection tariff implies that it marginally costs less to inspect consignments with more time. Thus, more budgetary resources can be saved when inspections are conducted with more time and at the same time higher confidence that the consignment is not infested can be obtained per one inspection.

Before concluding the discussion of results for the 'base model', one last important result should be mentioned. It is the expected damage after the conduct of import inspection. It was equal to 8,58 mln euros. Thus, the overall reduction of risk due to inspection measures applied was approximately equal to 72%. In general, the results of the base model should be treated carefully. Firstly, the results indicating that some pathways will be thoroughly inspected while others with similar risks will not, contradict with the aim of minimising risk from all pathways. Secondly, even against the background of the obtained model choices it is not clear why the choice was made in favour of inspecting dracaena but not other pathways with similar risks.

In 'proportional damage' model, as opposite, the results in terms of the budget allocation correspond with the purpose of the minimising risk from all pathways better. From Table II.3 one may see that all pathways receive a non-negligible share of the total budget. Notice that both dianthus pathways and dracaena received almost equal budgets, consistently with the contribution of these pathways in the total damage (Table I.3). The results of the budget allocation in terms of inspection time are consistent with calculated budgets (see Table II.6). The results of inspection times' allocation per each pathway are relatively similar to the results of the 'base model'. The main distinction is that positive budgets are allocated for both dianthus pathways. Interestingly enough, the calculated budgets for both dianthus and dracaena (almost identical for all these pathways) are distributed differently among different pathways. For example, the percentage of non-inspected consignments of dianthus from Israel is the largest- 92% followed by 89% for dracaena and 63% for dianthus from Kenya. These findings are in line with the size of the available budget and the expected number of consignments for each pathway. Specifically, the expected number of consignments of dianthus from Israel is the largest among three pathways, so the budget constraint is the most binding for this pathway. Another noticeable finding is that many consignments are inspected in inspection categories with lengthier inspection times. This result indicates that the probability of pest establishment per one consignment is significantly reduced; however, it is unlikely that such long inspection are feasible in practice.

Finally, the expected damage in the 'proportional damage' model was equal to 8,99 mln euros, or ~30.14% of the initial expected damage. This result is slightly lower than in the base model because in the latter the resources were used to decrease the damage posed by a given pathway to a minimum by providing more lengthy inspections and at the same time completely ignoring some pathways. In the 'proportional damage' model, at least minimum-length inspections were provided for all pathways. However these inspections have smaller risk-reducing impacts compared to longer inspections prevailing in the 'base model'.

6. Discussion and future research

The purpose of this paper was to develop a theoretical framework for the optimal phytosanitary inspection of imported commodities taking the budget constraint of the inspection Agency into account. The second purpose of the paper was to construct a quantitative model for the optimal import inspection with application to ornamental plants.

Theoretical conditions for the budget allocation imply that the marginal benefits should be equal across budgets when the budget constraint is imposed. So, each euro added to the inspection budget (defined per commodity or pathway) should yield the same reduction in risk across all budgets. As can be seen from the analysis presented in section 3, ALOR established by a given importing country does not influence risk minimising solution simply because there is a budget constraint. So, even if the ALOR is exceeded (and provided that import cannot be banned) then, the optimal budget allocation will not necessarily yield the level of risk which is lower than ALOR. In fact, in most cases the actual risk can be expected to be higher than ALOR even when the import inspection is in place. The results of the quantitative models support this conclusion. Neither in the 'base' nor in the 'proportional damage' models ALOR was maintained after the model found the optimal solution.

ALOR may however influence the actual allocation of the inspection resources. If the a priori (i.e. in the absence of inspection) risk of a given pathway is assessed to be lower than the maximum average contribution allowed per pathway, then no inspection of the consignments following this pathway may be needed at all. The saved budgetary resources may be re-allocated for inspection of riskier pathways. This idea was implemented in the quantitative models of the optimal budget allocation.

Turning to the results of the quantitative models, it can be said that the model solutions are largely influenced by the a priori imposed rules concerning the way the budget is allocated. Therefore, the 'base' model produced results consistent with the imposed budget allocation pattern (in terms of inspection time) but not entirely consistent with reality. Mainly, the failure to allocate resources for some pathways that clearly pose a significant risk is a serious drawback of the 'base' model.

'Proportional damage' model overcomes this problem to some extent: all pathways receive budget allocation. However, more consistent results in the model are achieved at the price of the higher expected pest damage compared to the 'base' model. The next important factor influencing the results is the formulation of the objective function. The results may be changed significantly if the objective is to minimise the probability of pest establishment per consignment but not for the entire flow of commodities. In general, additional research to investigate the latter issue is warranted.

Overall, the presented model represents a novel contribution in the field of the economics of quarantine protection. More precise data estimates (for example, economic impact per ornamental species or the probability of pest establishment after import) are required for the application of this model in the actual quarantine decision making. Testing the models with changing values of key parameters (i.e., the sensitivity analyses) as well as the running the models with varying formulations of the objective function (e.g. the probability of pest establishment per one consignment or for the entire flow of consignments) are areas of future research.

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APPENDIX I Expected risks without import inspection

Table I.1 Probability of pest establishment without import inspection*

	Species					
	Chrysanthemum	Rose	Dianthus	Yucca	Dracaena	Impatiens
Kenya	0.9506	0.0042	0.9701			
Israel	0.3431		0.9999			0.0038
Costa Rica	0.4462			0.0040	0.9959	

Table I.2 Expected damage without import inspection*, euros

	Species					
	Chrysanthemum	Rose	Dianthus	Yucca	Dracaena	Impatiens
Kenya	11,407,034	42,422	2,910,199			
Israel	54,117,766		2,999,664			5,756
Costa Rica	5,354,737			19,978	2,987,801	

*Calculated multiplying values from Table I.1 with the value of economic impact per species (from Table 2 in the main text)

Table I.3 Contribution of the individual pathway risk into the total risk, %**

	Species					
	Chrysanthemum	Rose	Dianthus	Yucca	Dracaena	Impatiens
Kenya	38.22	0.14	9.75			
Israel	13.78		10.05			0.02
Costa Rica	17.94			0.07	10.01	

**Calculated dividing values from Table I.2 by the total expected damage from all pathways

APPENDIX II Results. Budget allocation

Table II.1 Budget allocation per pathway, euros (costs minimisation model, ALOR=0.05)

	Species					
	Chrysanthemum	Rose	Dianthus	Yucca	Dracaena	Impatiens
Kenya	88,974		111,121			
Israel	22,244		269,1463			
Costa Rica	22,985				231,332	

Table II.2 Budget allocation per pathway, in percent to total budget, TB = 200,000 €, (base model)

	Species					
	Chrysanthemum	Rose	Dianthus	Yucca	Dracaena	Impatiens
Kenya	36					
Israel	8					
Costa Rica	8				48	

Table II.3 Budget allocation per pathway, in percent to total budget, TB = 200,000 €, (proportional model)

	Species					
	Chrysanthemum	Rose	Dianthus	Yucca	Dracaena	Impatiens
Kenya	38		14			
Israel	9		14			
Costa Rica	10				14	

APPENDIX II Results. The number of consignments inspected in each inspection time category, per country

Table II.4 Allocation of inspection time per pathway*, % (costs minimisation model)

Time per one inspection	Species					
	Chrysanthemum	Rose	Dianthus	Yucca	Dracaena	Impatiens
Kenya						
0min		100%				
75min	100%		52%			
90min			48%			
Israel						
0min						100%
75min	100%		100%			
Costa Rica						
0min				100%		
75min	100%				100%	

* Here and in the following tables the numbers show the percentage of the consignments for the particular pathway, inspected in a given inspection time category. For example, 100% of consignments of chrysanthemum from Costa Rica will be inspected for 75 minutes. nth % value against '0min' entry means that consignments of this pathway will not be inspected.

Table II.5 Allocation of inspection time per pathway*, % (base model)

Time per one inspection	Species					
	Chrysanthemum	Rose	Dianthus	Yucca	Dracaena	Impatiens
Kenya						
0min		100%	100%			
45min	31%					
60min	69%					
Israel						
0min			100%			100%
45min	100%					
Costa Rica						
0min				100%		
15min					100%	
45min	100%					

Table II.6 Allocation of inspection time per pathway*, % (proportional damage model)

Time per one inspection	Species					
	Chrysanthemum	Rose	Dianthus	Yucca	Dracaena	Impatiens
Kenya						
0min		100%	63%			
45min			37%			
60min	92%					
75min	8%					
Israel						
0min			92%			100%
60min	100%					
105min			8%			
Costa Rica						
0min				100%	89%	
60min	100%					
90min					11%	