Economic Impact Assessment of Invasive Plant Pests in the European Union

Tarek Soliman

Thesis committee

Thesis supervisor
Prof.dr.ir. A.G.J.M. Oude Lansink
Professor of Business Economics
Wageningen University

Thesis co-supervisor
Dr.ir. W. van der Werf
Associate professor, Crop and Weed Ecology Group
Wageningen University

Dr.ir. M.C.M. Mourits
Assistant professor, Business Economics Group
Wageningen University

Other members
Dr. ir. J. Bremmer, Agricultural Economics Research Institute (LEI), The Hague
Dr. ir. J. Schans, Netherlands Food and Consumer Product Safety Authority (NVWA), Utrecht
Prof. dr. J. Mumford, Imperial College London, United Kingdom
Prof. dr. E.H. Bulte, Wageningen University

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Economic Impact Assessment of Invasive Plant Pests in the European Union

Tarek Soliman

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Abstract

International treaties require that phytosanitary measures against introduction and spread of invasive plant pests are justified by a science-based pest risk analysis, including an assessment of potential economic consequences. A quantitative economic impact assessment of invasive species in the European Union requires spatial integration of information on the potential for establishment, spread and impacts of the pest at the EU scale, which is a novel and challenging area in pest risk assessment. A spatial bio-economic framework is needed to enhance the objectivity and transparency of the European phytosanitary regulation decisions.

In this thesis, a bio-economic framework is developed to conduct quantitative economic impact analyses of pests. Case studies were performed to explore the feasibility of making quantitative impact studies at the European scale. Three case studies were made: Potato Spindle Tuber Viroid, Pine Wood Nematode and *Candidatus* Liberibacter Solanacearum. The effect of spatial resolution and economic assessment method on the results is analysed. The bio-economic framework enables extending of the common practise of impact assessment from a non-metric estimation of pest risk to true impacts in terms of losses in euros.

The main findings are, first, that partial budgeting and partial equilibrium modelling are the methods of choice when assessing the economic impacts of pest invasion. Second, a fine resolution analysis is more relevant than the coarse resolution analysis to risk managers as it shows a refined geographical distribution of the expected impacts. Third, the potential economic impacts of Potato Spindle Tuber Viroid into the European Union are demonstrably of importance when considering market effects or export losses and questionable if only accounting for the direct losses. Fourth, Pine Wood Nematode has large potential economic consequences for the conifer forestry industry in the EU. Fifth, an invasion of *Candidatus* Liberibacter Solanacearum is likely of ‘major’ economic impact to the European Union. Therefore, the organism qualifies for the EU quarantine list.

The economic impact assessment framework developed in this thesis shows that it is possible to quantify the direct and indirect impacts at several levels of detail, in terms of output resolution and scope of economic impacts, given the availability of required data. Utilization of this framework may enhance the policy and decision making by governments and international bodies on managing plant health risks, by making quantitative economic impact assessments.

Preface

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Tarek Soliman
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Contents

Chapter 1

General Introduction

1.1 Background

The worldwide increase of trade in plant material, the introduction of new crops and the continued expansion of trade blocks (e.g. the EU) have resulted in increased threats of introducing new plant pests (Enserink, 1999). The cost of non-native pests and diseases and their control has been estimated at $120 billion per year in the USA (Pimentel et al., 2005), and the estimated damage from invasive species worldwide is estimated at more than $1.4 trillion per year - five percent of the global economy (Pimentel et al., 2001). The damage caused by non-native plant pests varies from impacts at producer level by reducing product quality or quantity, to impacts at society level by creating food insecurity and economic disruption, or large-scale environmental damage.

In the nineteenth century, *Phytophthora infestans*, the causal agent of potato late blight, has demonstrated the enormous socio-economic impact that plant pests can have, by causing the Irish potato famine. Currently, the annual economic impact from late blight is estimated at €1 billion per year in Europe (Haverkort et al., 2008) and $5 billion per year worldwide (Haldar et al, 2006; Haverkort et al. 2009). An example of an invasive pest species responsible for economic and environmental impacts is the fungus *Ophiostoma ulmi,* causal agent of Dutch elm disease (Brasier, 1991). It was first recognized as a new disease in the Netherlands in 1919 and subsequently spread throughout most of Europe, western Asia and North America. During the twenty century, up to 40% of the European elm population was killed by *O. ulmi* (Brasier, 2001). Another pest example with economic and environmental importance is the pine wood nematode, *Bursaphelenchus xylophilus*, which threatens the European forestry industry since its introduction in Portugal in 1999.

Recently, in European agriculture, several pests were of main concern for potato production such as *Clavibacter michiganensis subsp. sepedonicus*, a bacterial pathogen causing potato ring rot, and *Ralstonia solanacearum*, a bacterium causing potato brown rot (CABI/EPPO, 1997). Yield losses due to invertebrates in potatoes were estimated at €1,688 million per annum in the European Union (Inman, 2007). For instance, the Colorado potato beetle, which was introduced in Europe from the USA, is considered one of the most destructive pests in potatoes. New threats in other crops include *Tuta absoluta*, a serious threat to tomato production in Mediterranean region (Desneux et al., 2010); and the western corn rootworm (*Diabrotica virgifera virgifera*), one of the most important insect pests, whose control costs and crop losses have been estimated at $1,000 million per annum in the USA

(Metcalf, 1986). *Diabrotica virgifera virgifera* is spreading rapidly in the EU where its cost has been estimated at €147 million per annum (Wesseler and Fall, 2010).

According to the International Plant Protection Convention (IPPC) and the World Trade Organization Agreement on the Application of Sanitary and Phytosanitary measures (WTO-SPS Agreement) (WTO, 2009), any measure aimed at preventing the introduction and spread of new pests must be justified by a science-based pest risk analysis (PRA). This technical justification is required to avoid any misuse of the measures for protectionist purposes.

PRA is a process that evaluates technical, scientific and economic evidence to determine whether an organism shall be categorized as quarantine pest and, if so, how it should be managed. It consists of three stages (1) initiation of the PRA through identification of a pest or pathway, or review of the existing phytosanitary policy, (2) pest risk assessment, and (3) pest risk management (FAO, 2011).

Historically, pest risk analyses are performed in individual countries for their own territory. These are called national PRAs. PRAs at supra-national scales, such as the EU, are needed to justify supra-national phytosanitary legislation and associated phytosanitary recommendations. As a result, supra-national bodies such as the European and Mediterranean Plant Protection Organization (EPPO) and the European Food Safety Authority (EFSA) started to conduct PRA at regional (e.g. European and Mediterranean) or EU scale since 2006. Conducting a PRA at supra-national scale could reduce costs and workload associated with conducting PRAs for individual countries (Petter et al., 2010). EPPO is the Regional Plant Protection Organization for Europe and Mediterranean region that was established under the International Plant Protection Convention (IPPC). EPPO promotes inter-regional cooperation in plant health without any legal force although their advisory powers can be strong (Mourits et al., 2011). EFSA is an agency of the European Union that provides independent scientific advice and communication on existing and emerging risks associated with plants and food chain. PRAs carried out by these international organizations facilitate decisions regarding plant health in the EU (Council Directive 2000/29/EC). To achieve a more effective and efficient PRA at the EU level, the techniques already applied for assessing economic impacts of plant pests need to be evaluated and enhanced (Baker et al., 2009).

1.2 Problem statement

Usually, economic impact assessments within a PRA are made using a decision tree framework with qualitative questions and no explicit quantification of costs (Sansford, 2002; Brunel et al., 2009). Such a qualitative approach is usually structured according to the International Standard for Phytosanitary Measures (ISPM) 11 developed by the International Plant Protection Convention (IPPC) (EPPO, 2009). The qualitative scheme consists of a sequence of questions that capture the expert opinion. These questions address the size of the expected impact with and without control measures, the efficacy of the existing control measures, expected increase in production costs if the pest is present, the expected change in consumer demand and the expected losses in the export market. For each question, the expert provides his answer by selecting a score (within five levels). The qualitative approach has low costs and makes efficient use of expert knowledge, but suffers from lack of transparency and repeatability (Sansford, 2002). A qualitative approach may be fit for purpose if data are seriously lacking or time is limited. However, if quantitative data on distribution of hosts, climate, and spread potential are available, a detailed quantitative impact assessment may be preferable. A quantitative approach could provide policy makers with better information for decision making (Carrasco, 2009) and provide a stronger position in trade disputes. However, in many cases where the essential data are available, these quantitative analyses are not performed (Leung et al., 2002).

ISPMs do not provide detailed guidance on how to conduct a quantitative risk assessment in PRA (Baker, 1996). This assessment is particularly difficult when a large area, such as Europe, with a wide variety of climatic zones and crop agro-ecosystems is being studied. In the last decade, efforts have been made to introduce quantitative methods in the pest risk assessment phase e.g. fundamental niche maps that integrate climate and host crops (Guisan and Zimmermann, 2000; Kriticos and Randall, 2001; Elith et al., 2006) and models of pest spread (Carrasco et al., 2010; Robinet et al., 2011). Limited efforts have been conducted to evaluate and improve economic impacts modelling at the supra-national scale.

Advances in economic impact assessment require integration of disciplines such as invasion biology, regulatory plant health, and economics, and are therefore difficult to achieve. From a practical perspective, economic impact assessment requires substantial biological, environmental and economic input data as well as multidisciplinary skills to achieve integration, which provides a challenge for the teams conducting PRAs. The required biological data provide information on where the pest can establish (its fundamental niche), how it spreads from an initial point of entry, and builds up a population capable of causing damage. Economic data provide information on distribution and value of host crops, and market data such as quantities of host crops supplied by producers and demanded by consumers, quantities of host crop traded with the rest of the world and prices in relation to supply and demand.

By necessity, these biological and economic data, such as spread, suitability of the environment for establishment and assets at risk, are spatially explicit. Input data are rarely available at a common resolution. Therefore, rescaling (up - and down scaling) to one common resolution is usually required. The choice of resolution for data integration depends on the resolutions of the original source data, on the formulation of the objectives, and on the time available for making the analysis, taking into account that analyses at finer resolution cost more time.

A wide array of economic techniques is available to assess impacts. Techniques can be applied at several spatial resolutions (e.g. farm, national and continental level) and address different impacts (e.g. producer, market/sector and the whole economy). Evaluation of the performance of different techniques is needed to determine the most suitable method, given the purpose of the analysis and the available data and resources. It is difficult to derive the best method without considering practical examples. Case studies are needed in which the outcomes of different techniques and approaches are contrasted, so these can act as “case in point” and “reference cases” when choosing between techniques.

1.3 Research objectives

The overall aim of the research is to develop a bio-economic framework at the EU level to assess the economic impacts of pest invasion, integrating relevant knowledge on fundamental niche, spread, and direct and indirect economic effects. The framework combines niche and spread models with economic impact models bridging differences in spatial resolution. The framework is applied to pests that differ in terms of the scope of economic impacts, available information, and assessment objective, to attest its feasibility. Four sub-objectives were identified:

- Review the economic techniques that can be used in economic impact assessments as a part of a PRA.

- Develop a bio-economic framework that determines the direct and indirect economic impacts and estimates either the dynamics of economic impacts over time from the start of the invasion till the steady state situation, or the yearly impact at the steady state situation.
- Compare economic impact assessments based on coarse and fine projections of economic impacts.
- Explore the strengths and weaknesses of qualitative and quantitative assessment approaches to estimate the economic impacts and to determine the data and model requirements of quantitative economic impact assessments.

1.4 Case studies

Three case studies were conducted: Potato Spindle Tuber Viroid (PSTVd), Pine Wood Nematode (PWN) and *Candidatus* Liberibacter Solanacearum (CLS).

PSTVd is a pest that is already present in the EU and listed as regulated pest. Phytosanitary measures against PSTVd are already in place. However, a quantitative impact assessment has never been conducted and a quantitative economic justification for the present measures is therefore lacking. Although the pest has been present in the EU since 1976 (Scottish Plant Breeding Station, 1976), data and knowledge on pest biology are rather poor, raising the question how to conduct a quantitative pest impact analysis under uncertainty.

PWN has been introduced recently into Portugal in 1999 (Mota et al., 1999) and threatens to invade other parts of Europe. Although emergency measures have been applied to prevent the further spread of PWN, recent inspections indicated that enforcement of the control measures has been insufficient. A detailed economic assessment is made here to evaluate the economic justification of the expected future intensification of control measures and to provide decision support to spatially explicit targeting of management programs to high risk areas (i.e. those areas where the expected economic impacts are the highest).

CLS is a bacterium that has been recently discovered in 2008 (Liefting, 2008), but has not yet been introduced into the EU. There is a need to determine whether the bacterium poses an important potential economic impact to the EU.

1.5 Overview of the thesis

Chapter 2 evaluates the main techniques that could be selected for conducting quantitative economic impact assessment: partial budgeting, partial equilibrium modelling, input output analysis, and computable general equilibrium analysis. This evaluation process will support the selection of the most appropriate technique to estimate the economic consequences of pest invasion.

Chapter 3 develops a bio-economic framework that assesses the economic cost of PSTVd in the EU. Direct impacts are estimated as well as the total change in welfare. These estimated impacts are compared with the costs of the current phytosanitary measures in order to verify whether the measures are economically justified. Uncertainty due to scarcity of data on PSTVd spread and impact on yield is addressed.

Chapter 4 develops a bio-economic framework to estimate the dynamics of economic impacts over time due to the expected spread of PWN in the EU. The bio-economic model integrates a pest spread model with economic models. The case study clarifies the impact of spatial resolution and economic assessment method on the results. Also, the requirements in terms of effort and data are discussed in order to support the risk analyst in deciding the selection of method.

Chapter 5 assesses the potential economic impacts of CLS in the EU. The bio-economic model is based on a potential pest spread module elicited from experts and a quantitative economic module. The economic analysis could be followed in similar cases where it is difficult to make a reliable point estimate of the economic impact, but where it can nevertheless be shown that the uncertain economic losses are with a high degree of certainty greater than the threshold that identifies pests with major economic impacts.

Chapter 6 clarifies the data and models required to conduct a quantitative economic impact assessment to make a decision on pest quarantine status or to justify management measures. It compares the strengths and weaknesses of a qualitative versus quantitative approach when conducting economic impact assessment.

Chapter 7 is devoted to a general discussion on the methodological contributions and plant health policy implications derived from this research. The chapter finishes with the main conclusions of the thesis.

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Chapter 2

Economic Impact Assessment in Pest Risk Analysis

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Abstract

According to international treaties, phytosanitary measures against introduction and spread of invasive plant pests must be justified by a science-based pest risk analysis (PRA). Part of the PRA consists of an assessment of potential economic consequences. This paper evaluates the main available techniques for quantitative economic impact assessment: partial budgeting, partial equilibrium analysis, input output analysis, and computable general equilibrium analysis. These techniques differ in width of scope with respect to market mechanisms (relationships between supply, demand, and prices), and linkages between agriculture and other sectors of the economy. As a consequence, techniques differ in their ability to assess direct and indirect (e.g. economy-wide) effects of pest introduction. We provide an overview of traits of the available methods to support the selection of the most appropriate technique for conducting a PRA. Techniques with a wider scope require more elaborate data, and greater effort to conduct the analysis. Uncertainties are compounded as methods with greater scope are used. We propose that partial budgeting should be conducted in any risk assessment, while more sophisticated techniques should be employed if the expected gains in insight outweigh the costs and compounded uncertainties.

Keywords:

Pest risk analysis - economic methods – impact analysis – pest invasion – risk assessment

2.1 Introduction

The worldwide increase of trade in plant material, the introduction of new crops and the continued expansion of trade blocks (e.g. the EU) result in increased threats of introduction of new plant pests. According to the International Plant Protection Convention (IPPC) and the World Trade Organisation Agreement on the Application of Sanitary and Phytosanitary Measures (WTO SPS Agreement) (WTO, 2009), any measure against the introduction and spread of new pests must be justified by a science-based pest risk analysis (PRA). As a result, PRAs are an essential component of plant health policy, allowing trade to flow as freely as possible, while minimizing to a reasonable and justifiable extent the risk of introduction of plant pests.

FAO (2007a) defines a PRA as "*the process of evaluating biological or other scientific and economic evidence to determine whether an organism is a pest, whether it should be regulated, and the strength of any phytosanitary measures to be taken against it*". As part of a PRA, an "*evaluation of the probability of the introduction and spread of a pest and the magnitude of the associated potential economic consequences*" is conducted. Estimation of the potential economic consequences of pest invasions is thus a fundamental component of every PRA. If the risk of introduction and spread is judged to be unacceptable, phytosanitary measures can be imposed to reduce the risk to an acceptable level (FAO, 2004).

Two International Standards on Phytosanitary Measures (ISPMs), ISPM No. 2 (FAO, 2007b), "Guidelines for Pest Risk Analysis" and ISPM No. 11 (FAO, 2004) "Pest Risk Analysis for quarantine pests" set out the procedures for conducting PRAs for quarantine pests (IPPC, 2009). Standard No. 2 focuses on the initiation stage of a PRA while the emphasis in standard No.11 is on the pest risk assessment and risk management components of a PRA. In ISPM No.11, a distinction is made between qualitative and quantitative approaches for economic analysis. Qualitative approaches use expert judgment measured in non-metric terms (e.g. Likert scale), while quantitative approaches focus on information expressed in metric terms (FAO, 2007a).

In practice, the economic assessment within most PRAs, including those undertaken in Europe follow the PRA scheme and are based mostly on a qualitative approach, i.e. expert judgment (Sansford 2002; Brunel et al., 2009). Expert judgment has enormous advantages in terms of low cost and efficient use of qualitative expert knowledge, but it may suffer from important drawbacks as lack of transparency and repeatability (Sansford, 2002). Qualitative approaches may be (ab)used for political or protectionist goals. To guard against this, many plant protection agencies in the world, including the European Plant Protection Organization (EPPO) have developed explicit decision schemes for making PRAs. The scheme provides detailed instructions for the successive stages of PRA, providing a framework for organizing biological and other scientific and economic information, and assessing risk. This leads to the identification of management options to reduce risk to an acceptable level (Anonymous, 1997; Brunel et al., 2009). Such a structured procedure makes a qualitative approach explicit and transparent, but the underpinning of a decision during application of the scheme may still be subjective, even if it is explicit. The need for quantitative and more objective approaches is therefore keenly felt (Baker et al., 2009).

ISPM No.11 mentions in particular three techniques for quantitative economic assessment: partial budgeting, partial equilibrium analysis and computable general equilibrium analysis. Partial budgeting is a method that addresses the additional costs and lost revenues that are incurred at the producer level when a pest invades. This method takes into account the area attacked by the pest, the loss per unit area, and the price of the product, but it does not include relationships between production volume and prices, or interlinkages between markets. Partial equilibrium modelling does take into account the price effects of changes in production volume in addition to those factors already taken into account by partial budgeting. Partial equilibrium modelling techniques also address linkages to other agricultural markets, e.g. due to substitution of one product by another. Computable general equilibrium modelling techniques are the most comprehensive and complex tools to look at effects of pest invasion on the whole economy. The techniques thus differ markedly in scope, i.e. the extent to which the impacts for the economy at wide are addressed. As a result they differ in data requirements, the level of expertise needed to conduct the analysis, and the time investment required to complete an analysis. Partial budgeting is the easiest and fastest to conduct, and computable general equilibrium modelling the most difficult and time consuming. No guidance is given in ISPM No.11 as to the pros and cons of different techniques for conducting economic impact assessment.

The limited use of quantitative economic techniques, and advanced economic techniques in particular, may be due to limited familiarity with these techniques in the professional field of regulatory plant protection. More generally, it is not clear whether the greater scope of more advanced techniques justifies the extra effort required in terms of data collection and human resources (Vose, 2001; Sansford, 2002). Also, it is felt that advanced techniques may require data that are impossible to obtain or characterize with sufficient certainty. It is felt that the more comprehensive techniques may introduce more uncertainty in the results than is justified by the extra insights they may provide (Vose, 2001; Sansford, 2002). The key question is: what added value does an advanced quantitative method for assessing economic impacts bring to the PRA, and does this extra value justify the costs in terms of data and resources?

In this paper we review the main quantitative methods that may be used for estimating the economic impact of pest invasions. We evaluate characteristics of these methods in terms of goals, founding principles, scope, and data requirements, and provide criteria that may be used in selecting the most appropriate technique for conducting a PRA.

2.2 Quantitative economic techniques

2.2.1 Partial Budgeting (PB)

PB is a basic method designed to evaluate the economic consequences of minor adjustments in a farming business. The method is based on the principle that a small change in the organization of a farm business will reduce some costs and revenues, but at the same time add others. The net economic effect of a change will be the sum of the positive economic effects minus the sum of the negative effects (Table 2.1). Due to the marginal approach, PB is not designed to show the profit or the loss of a farm as a whole, but the net increase or decrease in farm income.

Table 2.1. Partial budgeting layout.

<table>
<tr><td colspan="2">Partial budget:
Comparison current plan (no pest) versus alternate plan (pest invasion)</td></tr>
<tr><td>Costs</td><td>Benefits</td></tr>
<tr><td><u>A) Additional costs:</u>
costs under the alternate plan that are not required under the current plan</td><td><u>C) Additional returns:</u>
returns under the alternate plan that are not received under the current plan</td></tr>
<tr><td><u>B) Reduced returns:</u>
returns under the current plan that will not be received under the alternate plan</td><td><u>D) Reduced costs:</u>
costs under the current plan that will be avoided under the alternate plan</td></tr>
<tr><td>Total costs: A+B</td><td>Total benefits: C+D</td></tr>
<tr><td colspan="2" align="center">Net change in profit:
C+D-A-B</td></tr>
</table>

With respect to plant production, various PB applications are known, primarily assessing the profitability of management options such as irrigation, pesticide use and fertilizer use (e.g. Arpaia et al., 1996; Donovan et al., 1999; Pemsl et al., 2004). Partial budgeting is also a suitable tool for assessing the economic impact of pests (Macleod et al., 2003; FAO, 2004).

The strength of PB in conducting a pest risk assessment is its simplicity and transparency. PB has a low complexity level with respect to resource needs as it requires a limited amount of data, skills, and time investment (Holland, 2007). Although the method is designed to evaluate the direct impact at the producer level, PB can also be used at the national or continental level by scaling up the budgetary impacts of the individual farms (Rich et al., 2005). Macleod et al. (2003) and Breukers et al. (2008) used PB to assess economic consequences of invasion of a quarantine pest or disease at the national level. However, PB is not suited to measure long-term effects or impacts in other sectors of the economy due to its reliance on fixed budgets with predetermined coefficients (i.e. price) to describe an isolated activity. Any change in production caused by a pest invasion could have a long-term effect on total market supply and prices, thereby affecting other producers and other sectors of the economy such as transport and the processing industry (Macleod et al., 2003). Aggregation of PB results from a representative farm to reflect costs at a higher scale will therefore only be representative if price effects and interlinkages with other sectors are weak. These shortcomings of PB can be counterbalanced by a complementary use of techniques that are described below.

Box 1: An illustrative example on Partial budgeting.

The case study of Potato Spindle Tuber Viroid (PSTVd)

This example uses PB to evaluate the direct economic consequences (viz. yield and/or quality losses and additional protection costs) of a PSTVd invasion in the EU. Initiation steps within the evaluation consist of 1) identification of the endangered along with 2) estimation of the potential for spread and 3) determination of the economic value of susceptible assets within the endangered area. Regarding the second step, we assume for simplicity, that PSTVd will invade the whole endangered area (worst case scenario).

When considering only the main host crop, i.e. potatoes, the total endangered area within the EU is approximately 500,000 ha, yielding 14 M tons potatoes/year at a value of € 1890 M based on an average price of 140 €/ton. Based on the assumption of an average yield loss of 30% by PSTVd, revenues are expected to reduce € 567 M/year (30% x € 1890 M). Additional crop protection cost can be quantified by multiplying the current protection cost (€118 M/year) with the expected increase. Experts expect that in case of a PSTVd invasion, farmers will double their protection efforts, resulting in € 118 M/year extra costs. The total negative impact of a PSTVd invasion is the sum of yield loss and additional protection cost, which equals € 685 M/year.

Results (in M€) of partial budgeting analysis for potato spindle tuber viroid (PSTVd)

Costs		**Benefits**	
Additional costs		Additional returns	0
Control costs	118		
Reduced returns		Reduced costs	0
Yield loss	567		
Total costs	685	**Total benefit**	0
Net change in profit	**-685**		

2.2.2 Partial Equilibrium Modelling (PE)

PE is a powerful tool to evaluate the welfare effects on participants in a market which is affected by a shock like a policy intervention or an introduction of a pest. The approach is based on defining functional relationships for supply and demand for the commodity of interest to determine the market equilibrium or, in other words, the combination of prices and quantities that maximizes social welfare (Mas-Colell, 1995). Maximum social welfare is realized when consumers and producers - in aggregated terms - maximize their utilities and profits as illustrated in Figure 1A.

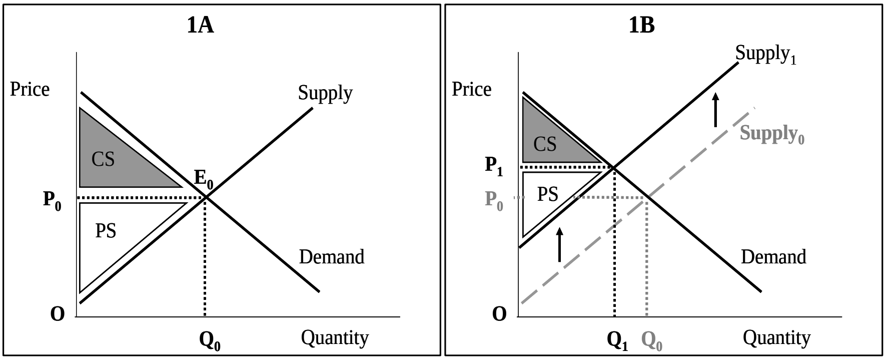

Figure 2.1 Impact of shock on market equilibrium.

This figure shows a downward-sloping demand curve, reflecting diminishing marginal utility as consumption increases, and an upward-sloping supply curve, reflecting increasing marginal costs of production. The market equilibrium (E_0), where quantity supplied equals quantity demanded, occurs at an equilibrium price of P_0 and quantity Q_0. The difference between P_0 and the demand curve represents how much consumers benefit by being able to purchase the product for a price that is less (P_0) than they would be willing to pay. This total benefit derived by the consumers, or consumer surplus, is represented by the triangle labeled CS. Since the supply curve represents the marginal variable cost of production, the area below the curve equals the total variable costs. The revenues from sales are equal to price (P_0) times quantity (Q_0), which is the area enclosed between the dashed lines. Hence the producer surplus, defined as the difference between total revenue and total variable costs is reflected by the triangle PS. Social welfare is defined as the sum of consumer surplus and producer surplus.

By PE analysis, the aggregated impact of a shock is determined by measuring the differences in equilibrium price and quantity, and change in welfare before and after the shock. A shock, like a pest invasion, may lead to a loss in yield and an increase in production costs, resulting in an upward shift in the supply curve (Figure 2.1). This shift in the supply curve alters the equilibrium point (Figure 1B), implying a decrease in quantity supplied (from Q_0 to Q_1) and an increase in market price (from P_0 to P_1). Producer losses, or the reduction in producer welfare, that result from the new equilibrium point can be calculated by comparing PS before and after invasion. In the same way, changes in consumer welfare can be calculated. The change in social welfare is determined by the aggregated impact of the changes in producer welfare and consumer welfare (Just et al., 1982).

For the purpose of illustration, the demand curve in Fig.1B is assumed to be unaffected by the shock. In reality, demand can also be affected; for instance, the presence of a pest might affect consumer preferences, thereby shifting the demand curve down, resulting a lower price and quantity at equilibrium.

Partial equilibrium modelling has been widely applied to the analysis of agricultural policy, international trade and environmental issues (e.g. Qaim and Traxler, 2005; Elobeld and Beghin, 2006; Cook, 2008; Kaye-Blake et al., 2008; Schmitz et al., 2008). Examples of recent applications on pest risk assessment are the analyses performed by Arthur (2006), Breukers et al (2008) and Surkov et al (2009). Arthur (2006) used PE to evaluate the impact on net social welfare of liberalizing the Australian apple market for imports from New Zealand, accounting for the risk of entry of *fire blight* disease in Australia. The benefits were presented in terms of consumer welfare gain, resulting from lower apple prices due to an increased supply from abroad, while the costs were derived from the reduction in producer welfare as a consequence of losses in production and expenditures to control the pest. Measuring the change in net social welfare, Arthur concluded that Australia would be better off by $90 million even if fire blight became established across all areas. Breukers et al. (2008) modelled the impacts of repeated brown rot outbreaks on supply and (national and export) demand of seed potatoes. They found that the indirect effects as a consequence of reduced export demand are far bigger than the direct effects (yield losses). Surkov et al. (2009) determined the optimal phytosanitary inspection policy in the Netherlands given the estimated costs of introduction of pests through trade pathways. In this study the PE approach was used to account for the potential price effects due to a pest introduction.

Box 2: An illustrative example on Partial equilibrium modelling

The case study of Potato Spindle Tuber Viroid (PSTVd) in the EU – continued.

The indirect economic consequences of a PSTVd invasion (viz. price and economic welfare effects in the potato market) are estimated using PE modelling.

Before PSTVd invasion, the potato market is in equilibrium, which means that Supply (S) = Demand (D). Supply of potatoes (i) is given by the function ($S_i = \beta_i P_i^{\theta}$), where P_i is producer price, β_i *a parameter,* θ_i *the supply elasticity, representing the percentage change in the quantity supplied after a 1% change in the price. Demand for potatoes is given by* $D_i = \chi_i P_i^{-\eta_i}$, *where* η_i *is the demand elasticity and* χ_i *a parameter.*

After the PSTVd invasion, the total potato area is divided in an affected and a non-affected area. In the affected area, the supply of potato growers is determined by the change in the price of potatoes (P_i), yield loss (h_i), *additional crop protection costs* (v_i) *and the size of the area affected* (z_i). *Thus the supply of affected producers is represented by* ($SA_i = (1-h_i)\beta_i (v_i P_i)^{\theta_i} z_i$). *In the non-affected area, producer supply is affected only by the change in the price of potato and is given by* ($SN_i = \beta_i P_i^{\theta_i}(1-z_i)$). *With* M_i *representing import volume, the difference between total supply* $S_i = SA_i + SN_i + M_i$ *and domestic demand* (D_i) *reflects export volume* (X_i) *Therefore, total demand (i.e.* $D_i + X_i$) *is equal to total supply (i.e.* S_i). *The net export is given by* ($X_i = \phi_i WP_i^{\omega i}$), *where* ω_i *equals export elasticity,* ϕ_i *a parameter and* WP_i *the world market price which is connected to the domestic price through a price margin (Surkov et al., 2009).*

Results of a partial equilibrium model are presented in terms of changes in quantity supplied and demanded, price and economic welfare for producers and consumers.

Based on input assumptions of a production level of 58.9 M ton/year, a consumption level of 57.5 M ton/year, exports of 2.7 M ton/year, imports of 1.3 M ton/year and demand and supply elasticities of -0.48 and 3.2 respectively, the PE results demonstrate that – as a consequence of a PSTVd invasion - production and consumption decrease by 0.41% and 0.4% respectively, exports decrease by 0.44%, domestic and world prices increase by 0.73% and 0.84% respectively, producer welfare increases by 0.02% and consumer surplus decreases by 0.43%. Supply by affected producers decreases, which explains the increase in the price of potatoes. The price increase leads to an increase in total producer welfare (of producers in the affected and non-affected area). In this example, the direct negative impacts (i.e. yield loss and additional control cost) are transferred from producers to consumers. In this case the PE analysis adds a valuable insight by showing how the negative impact of the PSTVd invasion is distributed between producers and consumers and by showing what the underlying causes for the indirect impacts are.

The use of PE within a pest risk assessment is appropriate when the pest impacts are expected to change prices or social welfare significantly. PE analyses can be conducted with respect to one sector (single-sector model) or multiple sectors (multi-market model). Multi-market models link related markets and are, therefore, able to capture spillover effects between main markets as, for example, the impact of a pest affecting wheat supply on supply and demand of potential substitute crops like corn. The calculation of producer and consumer surplus in multiple markets involves sequentially computing the effects in each of the affected markets.

Within each PE model main assumptions needs to be made to define the structure of the affected market(s) (e.g. perfect competition), the level of homogeneity for products from exogenous markets and the influence of domestic producers on the world market. Data requirements can be substantial (Mas-Colell, 1995; Rich et al., 2005; Backer et al., 2009) as data are needed to reflect the affected markets, including data on prices, quantities, and price elasticities of both supply and demand.

Despite its suitability for the evaluation of effects on markets of agricultural commodities, PE is limited in its ability to account for economy-wide effects. PRA by PE is, therefore, only appropriate when the indirect impact of the pest is not expected to significantly affect other non-agricultural markets or to generate measurable macroeconomic changes (e.g. changes in income and employment). For applications that require an economy-wide scope Input-Output analyses or Computable General Equilibrium modelling approaches may be needed.

2.2.3 Input – Output Analysis (I-O)

The technique of I-O analysis focuses on the interdependencies of sectors in an economy (regional or national), making it suitable to predict an economy-wide impact of changes within a particular sector (Leontief, 1986). Central to an I-O analysis is the specification of an I-O table to describe the monetary flows of inputs and outputs among the productive sectors of an economy (Miller and Blair, 1985). In an I-O table, economic sectors are aggregated into representative groups. Each sector-group is represented by a row and a column. The rows of the table specify the distribution of total output of a specific sector sold to other sectors (i.e., to intermediate demand) or to final demand (e.g. to final consumption, investments and exports). The columns refer to the production side of a given sector, by denoting the value of inputs of each sector required to produce output.

Table 2.2 represents a hypothetical I-O table with 3 productive sectors, viz. agriculture, industry and transport. In this example, the agricultural sector sells a value of 80 of output within agriculture, 300 of output to industry and 30 of output to transport, whereas a value of 60 is intended for the final demand. As denoted by the column accounts, the industrial sector purchases for its production a value of 300 in intermediate products from the agricultural sector, 500 of input within industry and 200 of input from transport, leading to a value added of 120. The value added cell includes payments to employees, holders of capital, and governments (e.g. wages and salaries, interest, dividends, and taxes) and represents the value that a sector adds to the inputs it uses to produce output. The value added row measures each sector’s contribution to wealth accumulation.

Table 2.2 Hypothetical I-O table indicating monetary flows of an economy in a specific time period.

		Purchasing sectors			Final Demand	Total Output
		Agriculture	Industry	Transport		
	Agriculture	80	300	30	60	470
Selling sectors	Industry	120	500	150	350	1120
	Transport	40	200	10	10	260
Value-added		25	120	15	100	260
Total Input		265	1120	205	520	2110

Any change in final demand for the products of a sector generates direct as well as indirect effects on the economy as a whole. Changes create large primary "ripples" by causing a direct change in the purchasing patterns of the affected sector. The suppliers of the affected sector must alter their purchasing patterns to meet the demands placed upon them by the sector originally affected by the change in final demand, thereby creating a smaller secondary "ripple". In turn, those who meet the needs of the suppliers must change their purchasing patterns to meet the demands placed upon them by the suppliers of the original sector, and so on. The relationship between the initial change and the total effects generated by the change is known as the multiplier effect of the sector, or the impact of the sector on the economy. To compute this multiplier effect, I-O tables are mathematically converted into matrices of multipliers that reflect the amount by which production, employment and income would alter as a result of one-unit change in final demand (Miller and Blair, 1985).

Based on I-O analysis, the impact of a pest invasion on an economy can be evaluated by adjusting the final demand in the affected agricultural sector according to the expected shock to demand (e.g. reduction in exports), multiplied by the multiplier matrix. Examples of recent applications to pest risk assessment are the analyses performed by Elliston et al. (2005) and Julia et al. (2007). Elliston et al. (2005) used I-O analysis to investigate the regional economic impact of a potential incursion of *Karnal bunt* in wheat in Queensland. As *Karnal bunt* is considered a quarantine disease in Australia's most important wheat export markets, an incursion in Australia would lead to a significant loss of export markets. In the scenario of a widespread incursion the direct effect in the wheat and other grains industries was estimated as an $89 million decline in output over a fifteen year planning horizon and a loss of 400 full time jobs. The indirect effects of the incursion in all other industries were estimated as a decline of $38 million in output and a decline in employment of 200 full time jobs.

Another example of I-O analysis is the analysis of the total costs of the invasive weed *Yellow starthistle* in the rangelands of Idaho (Julia el al., 2007). In this analysis, direct and indirect economic effects of the weed were determined in relation to its interference with agricultural and non-agricultural benefits (e.g. wildlife recreation expenditure and water winning). Agricultural related economic impacts accounted for 79% of the total impact on the rangeland-economy, and non-agricultural impacts for the remaining 21%.

The strength of the I-O approach is its ability to capture spillover effects between economic sectors. The accuracy of this ‘capture’ depends on the level of sector aggregation in the I-O tables. If the level of aggregation is too high, indirect impacts of a shock will be overestimated. Lower levels of aggregation are, however, associated with substantial increases in data requirements.

In addition to its high data requirement, the potential use of I-O analysis is restricted by two fundamental assumptions. First, I-O models only account for changes in the economy due to shifts in demand; supply is assumed to be perfectly elastic. Since supply constraints are often present in agriculture, I-O models may miss important effects of a pest introduction. Second, due to the use of fixed coefficients, I-O models cannot account for changes in prices or for changes in the structure of a sector over time. This means that I-O models assume fixed prices, no substitution between inputs, and constant returns to scale. However, this static assumption can be justified if the I-O technique is used to analyze only short-term impacts.

To conclude, the I-O approach provides the opportunity to measure short-term, spillover impacts across broad sectors of the economy given plant health incidents that affect the demand side only. For applications that require the economy-wide scope of I-O models as well as the economic realism of PE models, a Computable General Equilibrium Modelling approach would be more appropriate.

2.2.4 Computable General Equilibrium Modelling (CGE)

The CGE approach combines the strengths of I-O analyses and PE models to answer a wide range of questions. It uses I-O tables to represent the entire economy with the inclusion of functional relationships between actors in this economy as in a PE model. The basic structure of a CGE model can be described in terms of “blocks” of equations that specify demand relationships, production technologies, relationships between domestic and imported goods, prices, household income and numerous equilibrium conditions. Such a framework enables CGE models to address questions concerning impacts across sectors and employment groups as well as price changes and longer-run impacts. This capacity, however, makes CGE models highly complex, imposing high costs in the development of such a model as well as in the interpretation of its results (Sadoulet and de Janvry, 1995; Dixon and Parmenter, 1996).

By nature CGE models are highly aggregated, making it difficult to analyze a change in a sub sector of the economy. Many CGE models are disaggregated into only two agricultural sub-sectors, such as tradable and non-tradable crops, or food crops and cash crops (Bourguignon and Pereira da Silva, 2003). Applications of CGE models are, therefore, only appropriate to address large-scale problems which are most likely to generate measurable macroeconomic impacts. Pest invasion problems rarely generate such major effects as changes in aggregate employment, income or inflation rate. As a consequence, there are few applications of CGE applications in pest risk assessments. Recent applications are those of Wittwer et al. (2005, 2006). In Wittwer et al. (2005) a CGE model was used in order to quantify the impact of a hypothetical outbreak of the *Tilletia indica* fungus (the causal agent of Karnal bunt) on the wheat crop in west Australia. In their analysis, the effects on output, income, employment, wages, capital stocks and exports were estimated. In a second paper, Wittwer et al. (2006) investigated by the use of CGE the economic consequences of introducing *Pierce’s* disease of grapevine in South Australia. Special attention was given to the adjustment in the labour market as a result of the disease outbreak.

2.3 Synthesis and implications

Plant import regulation is an indispensable tool for protecting agriculture and the environment against pest invasions, but overly strict import restrictions can unnecessarily limit trade and reduce welfare. Science-based pest risk assessment is needed to ensure that import regulations are commensurate with the risks they mitigate (WTO, 2009). Quantitative economic impact assessment is a pivotal element of science-based pest risk assessment, and this paper has addressed the four most important techniques that may be used for such assessments.

Techniques based on linear or dynamic programming were excluded from the overview as these optimization methods are more suitable for risk management evaluations than risk assessment analyses. With respect to plant health economics few applications are known of which the majority focuses on the determination of an optimal pest control management scheme (Hall and Hastings, 2007; Chalk-Haghighi et al., 2008).

The four evaluated economic risk assessment techniques differ markedly in their scope and contents (Figure 2.2). While PB is a basic and easily understood technique for assessing direct impacts, its scope is limited, and does not include indirect effects of pest damage as a result of effects on market prices, supply, and demand, nor does it address spill-over effects to other sectors of the economy. PE or CGE modelling techniques widen the scope to include those price effects, in the first case for the affected commodity only, and in the latter case for the whole economy. A technique intermediate between general equilibrium modelling and partial budgeting is I-O analysis. This technique allows calculation of spill-over effects of a reduction in production of an agricultural commodity to other sectors in the economy, but does not address changes in prices. The techniques are thus very different in scope, level of sophistication, data requirements, and time needed to complete an analysis (Holland, 2007; Mas-Colell et al. 1995; Miller and Blair, 1985; Dixon and Parmenter, 1996). Table 2.3 summarizes these differences.

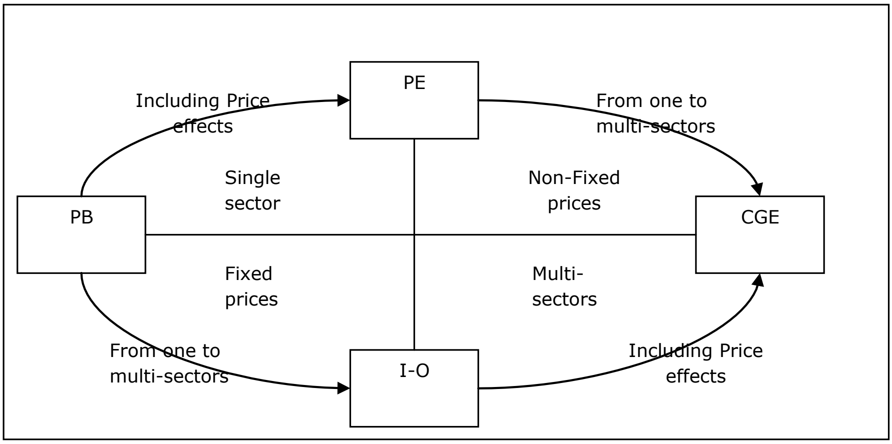

Figure 2.2 Relationships between the presented quantitative economic techniques.

Table 2.3 Resource requirements, scope and scale of the evaluated economic methods.

	Data	Time	Skills	Software	Scope	Scale
PB	- production volumes - % yield loss - production prices - % increase in control costs	one week to one month	basic accounting skills	Excel	direct impact; farm impacts on yield and crop protection	producer level
PE	- product prices - product quantities - Price elasticities of supply and demand - % yield loss - % increase in control costs - export and import data	few weeks to few months, depending on level of detail	basic partial equilibrium modelling and micro-econometric estimation techniques	Excel, Stata, E-views, SAS, GAMS or any software able to solve a system of non-linear equations	indirect impact; single-sector effects on price, trade and social welfare	regional, and continental level
I-O	- detailed input-output table - income and employment data - expected reduction in demand due to pest incursion	one month to few months	basic macro-economic theory and mathematical skills (e.g. matrix algebra)	GUASS, GAMS, MATLAB or other available software for matrix algebra	indirect impact; multiple-sector effects on output, income and employment	regional, and continental level
CGE	- social accounting matrix - elasticities - % yield loss - % increase in control cost	few months to a year	advanced economical and statistical background.	GUASS, GAMS and MATLAB	indirect impact; whole economy effects on income, employment, social welfare	regional, and continental level

Based on Holland, 2007.

The question is; what is the method of choice, given the purpose of the analysis and the available data and resources. We suggest that, despite its limitations, the default method of choice for basic economic analysis is PB. This technique provides insight in the immediate impacts of the pest, while it is easily understood and explained. The required data can often be obtained at a reasonable level of accuracy, and the human resources needed to apply the method are modest. Moreover, results of PB evaluations provide necessary input for the remainder techniques. If the objective goes beyond a first assessment of the costs of pest introduction, more sophisticated techniques warrant consideration. Partial equilibrium modelling is worthwhile if the changes in production volumes are very large, indicating the possibility of price effects. As a general rule, a pest invasion reduces supply of crops.

However, with the occurrence of price effects, part of these invasion costs is transferred from producers to consumers who pay a higher price. As a result, the negative effect of pest invasion on welfare is shared between producers and consumers. A more broad-based economic technique like I-O analysis or CGE modelling may be considered if large spillover effects to other sectors of the economy are expected, or even elimination of an entire industry, along with its suppliers. In exceptional cases CGE modelling has indeed been used (Wittwer et al., 2005). I-O and CGE techniques are fundamentally feasible to calculate pest impacts, but they have been very little used in impact assessments, and are probably over the optimum level of scope needed for a proper science-based impact assessment that is fit for purpose. The ability of I-O analysis and CGE analysis to capture indirect impacts to the entire economy is rarely needed in PRA since few pests have a wide economy impact. In most cases, a combination of partial budgeting and partial equilibrium modelling can provide a sufficient scope where both direct and indirect impacts occur (Rich et al., 2005).

An ironic aspect of the choice of method is that it is difficult to know ex ante whether a more advanced technique is needed without actually applying the method in the first place. The results of a partial budgeting exercise are not sufficient to judge whether a partial equilibrium modelling technique would yield different results. This can only be assessed when information on price elasticities of supply and demand has been gathered, i.e. when a first exploration in the domain of partial equilibrium is attempted. There is a need for case studies in which the outcomes of different techniques is contrasted, so these can act as “case in point” and “reference cases” when choosing between techniques.

It is also important to take into account the possibilities of adaptations. Adaptation is defined as ex-ante efforts aimed at reducing the severity of a pest invasion. Adaptation differs from mitigation, which comprises ex-ante efforts to reduce the probability of pest invasion. A direct negative impact on a producer could be countered by a substitution effect with a switch to other crops that are not vulnerable to the pest. If producers can adapt by growing less vulnerable crops, the total overall impact for all producers could be less severe than that indicated if only direct impacts are evaluated. Another factor that needs to be taken into account is management. Normally, if a pest invades, producers take measures to limit pest damage. It is unrealistic to calculate pest damages, assuming that producer practices will remain unchanged. Producers are profit maximizers and hence will adapt. Including issues of adaptation and management into PRA to avoid overestimation of pest impacts, requires a high level of expertise of the PR-analyst. In order to avoid subjectivity, the PRA analyst should explicitly report the extent to which adaptation and management have been accounted for.

Finally, uncertainty about model outcomes and model parameters is an important issue. What matters in the end is not whether the impact assessment was accurate in its quantitative outcome, but merely if the action justified by the assessment was correct. In other words, the mathematical problem is not so much one of estimation, but of selection (Binns et al., 2000). Thus analysis of the performance of impact assessments should not focus so much on the quantitative outcomes, but on the error rates (e.g. Nyrop et al., 1999). Two types of errors are relevant: type I errors, i.e. rejecting the null hypothesis (of no action needed) while it is true, and type II errors, i.e. accepting the null hypothesis while it is false. Type I errors occur if the impact assessment tool suggests the economic risks justify phytosanitary measures where in reality the risks are too low to warrant measures. Type II errors occur when the tool does not correctly detect risks where the actual size of the risks would warrant phytosanitary measures. Uncertainty in PRA may lead to an overestimation of the economic impacts, particularly if the precautionary principle (which is allowed under ISPM No.11) is applied, and will therefore increase the occurrence of Type I errors. Use of the precautionary principle will, on the other hand decrease the occurrence of Type II errors. The occurrence of Type I and Type II errors may be reduced by using more advanced economic impact assessment techniques such as PE, I-O and CGE, since these techniques capture a wider range of potential economic impacts. However, the extent of this reduction will be hard to quantify. Receiving Operating Characteristics (ROC) analysis could provide some insights in these error rates by providing tools to select the optimal set of techniques and to discard suboptimal ones by indicating all possible combinations of the relative frequencies of the various kinds of correct and incorrect decisions given a defined threshold (Brown and Davis, 2006). Such an analysis would require a retrospective evaluation of a sufficient large number of performed PRAs to obtain any information on the relative distributions of the correctness of the decisions made.

Uncertainty about model parameters affects the reliability of outcomes of economic impact assessment techniques in different ways. We think that the degree of belief in economic models should decrease with level of sophistication, because the greater sophistication entails making assumptions about processes that may work quite differently from how they are modelled. Thus, PB has a greater potential of giving credible results, while confidence is bolstered as anybody can check the assumptions and calculations using a basic spread sheet. PE and CGE techniques give already more uncertain results, because mathematical statements are made on the relationships between prices, and supply and demand of agricultural produce that may work out quite differently in practice than they are modelled mathematically. This is not to say that the model is wrong. The models are theoretically correct, but they are simplifications of economic reality, and it is very difficult to know the parameters that apply to the producer and consumer behaviour in the future. Therefore, such models should be interpreted as plausible trends, inferred from past behaviour, and should be used to complement the results of a PB rather than replace them. Results of PE modelling should be interpreted with caution as to the absolute magnitude of the effects. The same applies to I-O and CGE modelling techniques. The parameters for these models are usually based on historic data, augmented with theoretical arguments, and each of these methods may not provide those parameter values that correctly model future economic behaviour of producers and consumers.

Monte Carlo techniques or sensitivity analysis may help to assess uncertainty bounds for model outcomes, but it should be remembered that these bounds are derived within the chosen model framework and domain of data collection. Future behaviour needs not stay in the confines of those bounds (e.g. Gilligan and van den Bosch, 2008). Although impact assessments should as much as possible be supported and enriched by objective analyses, we believe that there is no substitute for expertise, experience, caution and wisdom in the domain of regulatory plant protection. The greatest strength can be found in the combination of qualitative and quantitative approaches.

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Chapter 3

Quantitative Economic Impact Assessment of an Invasive Plant Disease Under Uncertainty – a Case Study for PSTVd Invasion into the European Union

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Abstract

International treaties require that phytosanitary measures against introduction and spread of invasive plant pests are justified by a science-based pest risk analysis, including an assessment of potential economic consequences. This study evaluates the economic justification of the currently applied phytosanitary measures against Potato Spindle Tuber viroid (PSTVd). It assesses the impact of an unregulated EU infestation, while accounting for uncertainty due to scarcity of data. Expert opinions were elicited to describe the possible range of PSTVd spread. Stochastic simulations, based on the assessments of separate experts, indicated that the direct impacts exceed the costs of current phytosanitary measures (€5.6 M/year) with a probability of 44%, but with large differences between experts making it hard to justify the measures solely by the expected savings in direct impacts. The direct impact on potato producers was estimated with partial budgeting. This impact is 2.1 M€, based on an assumed prevalence of PSTVd of 0.73%, while the direct impact on tomato producers was estimated at 3.5 M€. The total economic impact, considering price changes and higher costs for consumers, was estimated at 4.4 M€ for potatoes and 5.7 M€ for tomatoes. Consumers bore 92% of the total costs of invasion in the case of potato and 77% in the case of tomato. If the presence of PSTVd would imply export restrictions, resulting in an annual loss of more than 1% of the total EU export value of potatoes and tomatoes, the cost of current phytosanitary measures would also be justified. The potential economic impacts of PSTVd into the European Union are therefore demonstrably of importance when considering market effects or export losses but questionable if only accounting for the direct losses. The large degree of uncertainty in the prevalence of disease contributes to the justifiability of measures based on the precautionary principle. The assessment approach can be useful for assessing the economic justification of phytosanitary measures.

Keywords

Economic impact assessment – uncertainty – pest risk analysis – risk management - PSTVd

3.1 Introduction

Potato spindle tuber viroid (PSTVd) is a small, circular RNA molecule, that infects a variety of species within the Solanaceae, including potato and tomato (Singh 1973; Singh & Slack 1984), pepino (Puchta et al., 1990), avocado (Querci et al., 1995) and compositae (Singh, 1973) as well plant species from other families (Singh, 1973; Matousek et al., 2007). PSTVd has been registered and regulated as an EU-quarantine organism (listed in Annex IAI of Council Directive 2000/29/EC) since 1993, because of its potential economic impact on European potato and tomato production. Different strains of PSTVd exist and symptoms range from mild to severe. Symptoms depend on environmental conditions and are most severe in warm and dry regions (Singh, 1983 and 1989). PSTVd can spread by natural means (i.e. seed and pollen transmission) (Singh et al., 1992) and by human assistance (i.e. mechanical and vegetative propagation transmission) (Diener, 1987; Verhoeven et al., 2010).

Although still present in potato crops in some parts of Eastern Europe, PSTVd is currently not cited as a major crop pest (EFSA, 2011a). However, recent findings of PSTVd in ornamental plants, i.e. *Brugmansia* spp. and *Solanum jasminoides*, (Di Serio, 2007; Verhoeven et al., 2008) have raised concern that these ornamentals may provide a new source of the viroid that could increase exposure of potatoes and tomatoes. Consequently, the EU has issued a provisional emergency measure (listed in Commission Decision 2007/410/EC4) to mitigate this potential risk. By this emergency measure, import and movement of the specified ornamentals plants within the Community have been regulated and need to comply with the requirements laid down in the Directive 2000/29/EC. Furthermore, Member States need to conduct official surveys, and where appropriate, test for the presence of PSTVd on these symptomless host plants.

According to international treaties, phytosanitary measures against introduction and spread of invasive plant pests must be justified by a science-based pest risk analysis, including an assessment of potential economic consequences. However, data to make reliable quantitative economic impact assessments are rarely available. Therefore economic impact assessments are usually qualitative, weakening the justification of management measures. The International Standard For Phytosanitary Measures (ISPM) No. 11 (FAO, 2004) states that (paragraph 2.3) "*it is necessary to examine economic factors in greater detail when the level of economic consequences is in question, or when the level of economic consequences is needed to evaluate the strength of measures used for risk management or in assessing the* *cost-benefit of exclusion or control*". The current program of phytosanitary measures against PSTVd (2000/29/EC and 2007/410/EC4) has only been justified by a qualitative impact assessment of their technical efficiency; no quantitative economic justification has been given (EFSA, 2011a). A quantitative economic justification is hard to make due to the lack of accurate, consistent data on potential pest prevalence and detailed spatially indexed production values of host crops in the EU member states and to insufficient documented knowledge of viroid biology. The considered change in the status of the provisional measure from temporal to permanent (EFSA, 2011a) could, however, require a more sound scientific justification to be accepted by stakeholders in Europe and the rest of the world.

This paper estimates the possible range of economic impacts of an unregulated PSTVd infestation in Europe while accounting for the uncertainty and the data scarcity on PSTVd spread and impact on yield, by stochastic simulations. We compare the simulated range of economic impacts with the current costs of phytosanitary measures, to assess whether the measures are economically justifiable.

3.2 Materials and Methods

The analytical model for economic impact assessment of an unregulated PSTVd outbreak in European potato and tomato consists of four components, 1) a spread component to define the level of potential pest spread, 2) a climate component to describe the climate suitability for damage expression, 3) a host component to determine the spatial distribution and value of hosts, and 4) an economic component to quantify the resulting impacts.

3.2.1 Potential pest spread

The potential spread (infestation level) is defined as the proportion of potato and tomato plants that is infected with PSTVd. Accurate and consistent quantitative data is lacking due to insufficient knowledge on pest biology and epidemiology. Therefore, we assessed the potential for infestation by expert elicitation, assuming a scenario in which one percent of the starting seed stock for the host plants within the EU is infected with PSTVd and current phytosanitary regulations are lifted. As a result of spread within a crop and between crop species, disease incidence changes over time until after some time a steady state situation is reached in which the rate of infestation with PSTVd stabilizes. We asked 30 experts by written questionnaire to assess the likely infestation rate with PSTVd in the steady state.

The majority of experts, however, indicated that they were unable to estimate expected incidence (proportion of infested plants) due to the high level of uncertainty involved and the difficulty of allowing for spatial variation in incidence. Only four experts were confident enough to provide an estimate. The first expert indicated that in the majority of the cases the infestation level would be minimal. This expert distinguished three levels of incidence, *viz.* 0.5%, 5% and 10%, and estimated that these would occur with likelihoods of 96%, 3% and 1%, respectively. The average incidence is 0.73%. The second expert estimated uncertainty in incidence in terms of a triangular distribution with a minimum incidence of 0.01%, a most likely incidence of 0.25%, and a maximum incidence of 0.5%. Expert 2 thought that mechanical transmission would cause only little spread, while greatest risk was to be expected from seed transmission. Although only officially certified (and therefore PSTVD free) seed potato can be marketed within the EU, some farmers, especially in eastern European countries, use farm-saved seed for their own production. Such practice could increase the incidence of PSTVd when no official action is taken. The third expert provided a semi-quantitative estimate mentioning an incidence level of 0% as the lowest value, a value “close to zero” as the most likely value and “close to 0.1%” as the upper level. The low values and narrow range indicate low expected incidence as well as low uncertainty. The fourth expert, on the other hand, provided a wide range, from 0.1% to 50%, indicating both a high expected incidence and large uncertainty.

The impact of the level of uncertainty on the estimation of economic impacts will be studied by a stochastic assessment based on the elicited distributions of the four experts as well as the average distribution. The average distribution was obtained by using the linear opinion pool method (Clemen and Winkler, 1999; Chambers, 2007).

3.2.2 Host and climate

Climatic and host data on potato and tomato are extracted from the SEAMLESS database (Van Ittersum et al., 2008; Janssen et al., 2009). Within this database, data are available at various levels of spatial resolution, which are (sorted from coarse to fine resolution) the levels of environmental zones (EZ), climate zones and agri-environmental zones (AEZ) (Figure 3.1).

The EU is subdivided into 12 EZs that represent a broad climatological/environmental subdivision of Europe. The climate zones are defined as unique combinations of NUTS (Nomenclature of Territorial Units for Statistics, source: EuroStat) regions and EZs. There are 560 climate zones. The climate data (e.g. temperature from 1982 to 2006) in the SEAMLESS database are obtained from the European Interpolated Climate Data (EICD) (JRC, 2008), which are available at the resolution level of the climate zones. The AEZs are the intersection of the NUTS regions, EZs and soil types. There are 3,513 AEZs in the EU (Figure 3.1). Host data in SEAMLESS are imported from the Farm Accountancy Data Network dataset (FADN) (EC, 2008), providing data on host physical production in tonnes and value of this production in Euros at the AEZ level for the EU-25 (Figure 3.2). The spatial distribution of the assets at risks is determined by combining the spatial information on climate suitability for PSTVd disease expression and host distribution. Spatial integration is conducted at two levels of resolution, i.e. coarse resolution (EZ) and fine resolution (AEZ), to study the impact of spatial resolution level on the economic assessment. ArcGIS Desktop 9.3 is used to integrate the spatial data layers and to present the resulting economic impacts spatially.

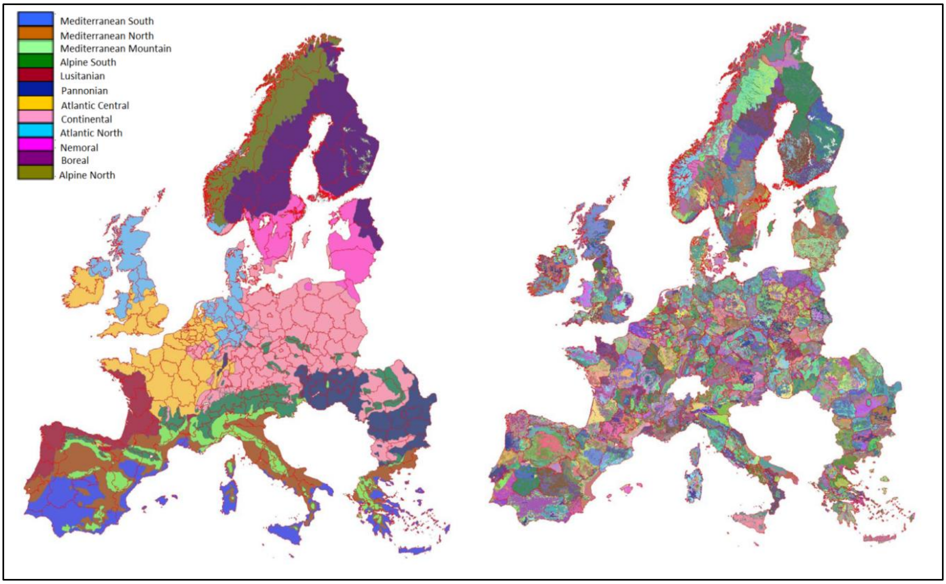

Figure 3.1 The Environmental Zones (EZ – left panel) representing a broad climatological / environmental subdivision of Europe and Agri-Environmental Zones (AEZ-right panel) representing a combination of the NUTS regions, Environmental Zones and soil types based in Carbon content in topsoil (Source: Hazeu et al., 2010).

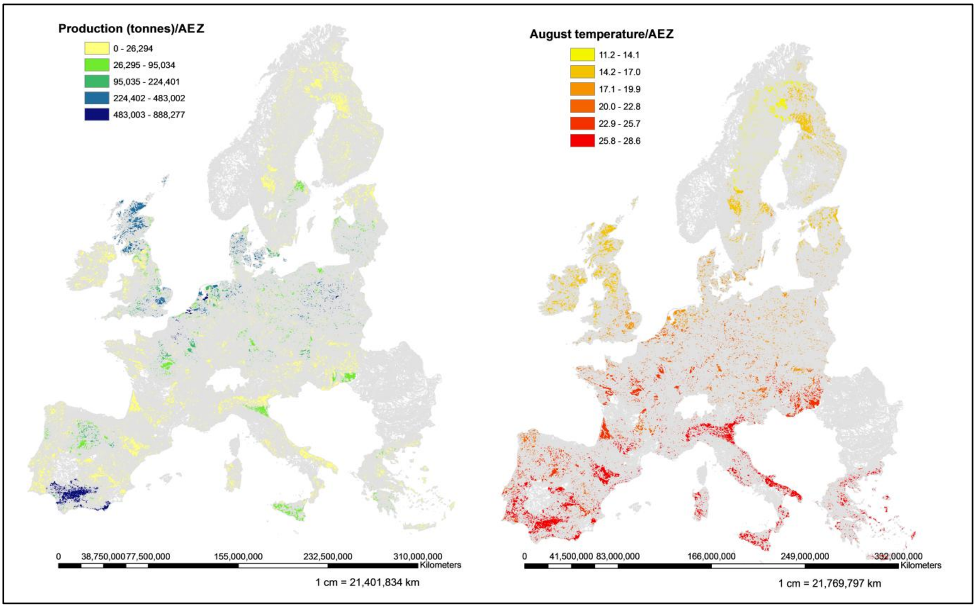

Figure 3.2 Potato production (left panel) and mean august temperature (right panel) of the endangered areas at AEZ level.

3.2.3 Economic impacts

The economic impact of a PSTVd infestation consists of direct and indirect impacts. Together they constitute the total economic impact. Direct impacts are directly related to the production process and include yield losses and additional production costs (e.g. costs of crop protection). They are calculated by partial budgeting (Soliman et al., 2010). Indirect impacts are generated downstream from the production process itself, and are related to changes in prices, producer and consumer responses to price changes, and effects on international trade. The total economic impact is calculated by partial equilibrium modelling, where changes in production volume and cost of production are integrated with changes in the market. The total economic impact is the change in total welfare, and has two components: the change in producer surplus and the change in consumer surplus. We use Partial budgeting (PB) to estimate the direct impact and assess the distribution of losses within EU. This analysis is made at a coarse level of resolution, EZ, and at a fine level, AEZ. Partial equilibrium (PE) modelling is subsequently used to estimate the change in social welfare at the EU level. The results of partial budgeting are input to the partial equilibrium analysis.

3.2.3.1 Direct impact

Yield loss due to PSTVd depends on temperature (Sanger and Ramm, 1975; Morris and Smith, 1977; Harris and Browning, 1980) and the strain of PSTVd (Singh and Slack 1984; Owens, 2007). Yield loss in potatoes and tomatoes is expected when summer temperature is 20^{o}C or higher (Salazar et al., 1985; Singh, 1983 and 1989).

There is evidence in the literature that supports a positive relationship between temperature and yield loss, but there is no literature that defines the shape of this relationship precisely, e.g. as linear or logistic. For example, Singh (1983) indicated that “although viroid diseases have been reported in both tropical and temperate regions of the world, they induce more severe symptoms at high temperatures”. Furthermore, Morris and Smith (1977) stated that “high air temperature not only exaggerates the symptoms on aerial parts, but it has been shown to double the amount of viroid synthesized in potato tissues at 30°C as compared to 25°C”. A similar response to high temperature has been observed in tomato (Sanger and Ramm, 1975; Morris and Smith, 1977; Harris and Browning, 1980). Goss (1930) observed that “the tuber symptoms became more severe at high soil moisture content or temperature”. Based on this information, we parameterized a linear relation between temperature and yield loss due to PSTVd. Uncertainty within the temperature-yield loss relationship was accounted for in the stochastic analysis (see section 3.2.4 below).

Based on Singh et al. (1971) and Cui et al. (1992), we assume, for potato and tomato, a yield loss of 3% at 20^{o}C and an increase of 3% with every degree increase in average August temperature till a maximum yield loss of 27% at 28^{o}C, the warmest summer temperature in Europe. For potato we take the ambient mean August temperature to calculate yield loss. In the case of tomato, we use at least 20^{o}C as temperature because tomatoes are often grown as protected crops in glasshouses with an average temperature of 20^{o}C (Hurd and Graves, 1984), and take the ambient mean August temperature for the zones where it is above 20^{o}C. The 3% yield loss per degree above 19^{o}C represents a weighted average of loss rates reported for mild and severe strains of PSTVd (Singh & Slack 1984; Singh et al. 1992; Owens, 2007), assuming that yield loss of severe strains are three times as high as yield loss of mild strains (Singh et al., 1971) and that the mild strains prevail over severe strains in a ratio of 11:1 (Singh et al., 1970; Chrzanowska et al., 1984). Total damage per zone is obtained by multiplying the value of production by the assigned relative yield loss. In addition to crop losses, presence of PSTVd will result in higher costs of crop protection.

Unlike potato viruses that may be controlled through the use of resistant cultivars (Reeves et al., 1994) or chemicals (e.g. Potato yellowing virus) (Jeffries, 1998), PSTVd can only be controlled by stricter surveillance. Indeed, observation of deformed potato tubers at harvest is the most likely method of detecting PSTVd (PHA, 2010). As PSTVd surveillance will usually be done through general surveillance of other potato pests, the additional protection costs for PSTVd are estimated as a small increase (*viz.* 10%; Benninga, personal communication 2011), on top of the regular crop protection cost obtained from SEAMLESS database (Janssen et al., 2009).

Aggregation of the yield losses and additional protection costs over the spatial zones provides insight in the total annual direct impact for tomato and potato producers at the EU level.

3.2.3.2 Total economic impact

PE modelling is used to estimate the total economic impacts. PE extends the impact scope from producer to the whole society by including impacts on consumers. This is determined by measuring the differences in equilibrium price and quantity, and change in welfare before and after pest outbreak (Soliman et al., 2010).

The model distinguishes two regions: the European Union (EU) and the rest of the world (ROW). We assume that (1) crop products in the EU and in ROW are perfect substitutes and their respective prices differ only in the transportation costs and tariffs, and (2) the domestic market for the potentially affected commodity is perfectly competitive, implying product homogeneity.

Within the PE model, the demand and supply in the EU are defined by equations 1a-1g (Surkov et al., 2009). The first equation (1a) describes the demand (D_i) in the domestic market as a function of the domestic price (P_i).

$$D_i = \chi_i P_i^{-\eta_i} \tag{1a}$$

Where η_i is the price elasticity of demand and χ_i is scale parameter. The supply in the domestic market has two components (equation 1b): supply by affected farmers (SA_i) and supply by non-affected farmers (SN_i).

$$S_i = SA_i + SN_i \qquad (1b)$$

The supply by non-affected farmers (SN_i) depends on the price P_i, with supply elasticity θ_i and scale parameter β_i, and is also determined by the proportion of farmers that is not affected by the pest (1-z_i):

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

The supply by affected farmers (SA_i) depends furthermore on the proportional yield loss, h_i, caused by the disease, and by the reduced net price for the product that affected farmers experience as a result of increased costs of production v_i (e.g. for control or sanitation) (1d):

$$SA_i = (1 - h_i)\beta_i (v_i P_i)^{\theta_i} z_i \qquad (1d)$$

Prices in the domestic and world market are linearly related where μ_i represents, e.g. transport costs or tariffs (1e):

$$P_i = WP_i + \mu_i \qquad (1e)$$

The equilibrium condition for international trade is expressed by two equation, 1f and 1g. The first of these (1f) calculates exports or imports (X_i) as a difference between domestic supply and demand.

$$X_i = S_i - D_i \qquad (1f)$$

The second equation (1g) expresses the relationship between international trade and the world price (WP_i), where υ_i is a scale parameter, α_i is the proportion of the banned export and ω_i is export/import elasticity.

$$X_i = \upsilon_i \alpha_i (WP_i)^{\omega_i} \qquad (1g)$$

Data for the potato and tomato market is obtained from FAO statistics (FAO, 2009). The inputs for the partial equilibrium PSTVd analysis are presented in Table 3.1. The results of the partial equilibrium analysis provide insight in the total economic costs on a yearly basis on EU level.

Table 3.1 Input parameters for the partial equilibrium model.

Parameter	Potato	Tomato
European production (M tonnes)	59.1[a]	16.2[a]
European consumption (M tonnes)	58.4[b]	16.3[b]
European producer price (€/tonne)	113[c]	301[c]
World price (€/tonne)	119[c]	332[c]
Supply elasticity	3.2[c]	0.5[d]
Demand elasticity	-0.5[e]	-0.62[f]
Excess demand (Export) elasticity	-3.4 [b]	---
Excess supply (Import) elasticity	---	4 [b]

[a] FAO (2009)
[b] own calculation
[c] Janssen et al (2009)
[d] Chern and Just (1978)
[e] De Gorter et al. (1992); Bunte et al.(2009)
[f] Yen et al. (2004); Balestrieri (1983)

3.2.4 Assessments

The following analyses were conducted;

- *Deterministic evaluation of direct economic impacts by level of spatial resolution*.

Direct economic impacts were determined deterministically (PB) at two levels of spatial resolution, i.e. coarse resolution (EZ) and fine resolution (AEZ). The deterministic setting of the expected level of infestation was based on the average incidence (0.73%) of Expert 1 (section 2.1). As experts were unable to differentiate between regions, this level of infestation was taken to be homogeneous over the whole EU. The deterministic rate of expected yield loss was defined by a linear function increasing with temperature (section 3.2.3.1). In the coarse resolution analysis, temperature data was up-scaled from the climatic zone to the EZ level by averaging, while production data on the host crops (i.e. potato and tomato) were up-scaled from the AEZ level to the EZ level by summing production values for all EZs within an AEZ. For the fine resolution analysis, temperature data at the AEZ level were obtained from the source zone at the climatic level by direct cell assignment, while the host data was kept at its original resolution (i.e. AEZ level).

- *Deterministic evaluation of total economic impacts on EU level*.

Total economic impacts were estimated by the application of the PE model (section 3.2.3.2), using the deterministic settings as presented by Table 3.1 and the same settings for expected infestation level and yield loss as described above.

- *Stochastic evaluation of direct economic impacts*.

The impact of uncertainty with respect to infestation level and yield loss relationship on the resulting direct economic impacts was evaluated by the use of stochastic simulation (Monte Carlo simulation by 1,000 replications) of the PB model at EZ level. To account for the uncertainty in the level of infestation, direct economic impacts were stochastically determined by each of the four elicited distributions of incidence, as well as their average (section 3.2.1). The expert distributions within these 5 scenarios were defined by, successively, a trinomial distribution with values 0.5%, 5% and 10% and corresponding probabilities of 96%, 3% and 1% (expert 1), a triangular distribution with a minimum incidence of 0.1%, a most likely incidence of 0.25% and a maximum incidence of 0.5% (expert 2), a triangular distribution with a minimum incidence of 0, a most likely incidence of 0.01% and a maximum incidence of 0.1% (expert 3), and a uniform distribution between 0.1% and 50% (expert 4).

The uncertainty in yield loss was simulated by drawing the yield loss percentage from a triangular distribution with a lower bound of 3%, an upper limit of 27%, and the most likely value depending on temperature as described in the deterministic analysis (3.2.3.1), i.e. a 3% change in yield loss percentage per degree increase in mean August temperature above 19°C. Yield loss percentage was drawn from the triangular distribution independently for each EZ. No yield loss is assumed if temperature is below 19°C.

3.3 Results

3.3.1 Deterministic analyses

The following paragraphs describe the economic impact based on a deterministic evaluation of the expected steady state of an unregulated PSTVd infestation in the EU.

3.3.1.1 Direct impact

The direct economic impact estimated at a fine resolution level equalled 2.2 M€ for potatoes and at 4.7 M€ for tomatoes (Table 3.2), representing an expected loss in EU production value of only 0.03% and 0.07%, respectively. Differences in impacts among the EZs were minor; the relative impact on total production value was highest for the Mediterranean South and North zones (Table 3.3).

The coarse and fine resolution analysis resulted in similar estimates of direct impact; total direct economic impact estimated by the fine resolution analysis was 1.2 M€ higher than estimated by the coarse resolution analysis (Table 3.2). The difference follows directly from the applied aggregation procedure. Averaging temperatures over large areas as in the coarse resolution analysis reduces the proportion of areas with higher temperatures and, consequently, the prevalence of higher yield losses.

Table 3.2 Annual direct impact (k€) determined by partial budgeting at a coarse level of spatial resolution (Environmental Zone) and a fine level of spatial resolution (Agri-Environmental Zone).

	Potato		Tomato	
	EZ	AEZ	EZ	AEZ
Yield loss	1,918	2,028	3,385	4,529
Protection cost	185	136	155	155
Total	2,103	2,164	3,540	4,684

Table 3.3 Direct economic impacts per Environmental Zone, in absolute terms (k€) as well as relative with respect to the total value of production within each region.

Environmental zones	Potato		Tomato	
	Absolute	%	Absolute	%
Continental	415	0.02	116	0.02
Pannonian	57	0.07	19	0.07
Boreal	0	0	7	0.02
Alpine South	10	0.02	4	0.03
Mediterranean North	281	0.12	679	0.11
Lusitanian	38	0.06	51	0.05
Mediterranean Mountains	64	0.09	91	0.09
Atlantic Central	686	0.03	405	0.02
Nemoral	0	0	4	0.02
Alpine North	0	0	3	0.02
Mediterranean South	548	0.14	2,094	0.14
Atlantic North	0	0	66	0.02
Total	2,10	0.03	3,54	0.07

3.3.1.2 Total economic impact

The total economic impacts estimated by PE were higher than the direct impacts estimated by PB because PE considers price and trade changes and their consequences on social welfare. Total welfare loss is estimated at 4.4 M€ and 5.7 M€ for potato and tomato, respectively, where the majority of the negative impact is borne by the consumers (Table 3.4). The reduction in the host crop production will trigger price increases, which will then decrease demand, decrease exports and increase imports. As a result of price increases, a large part of the economic impacts due to yield loss will be passed on to consumers. Affected producers experience a reduction in their supply as well as a decrease in exports but these losses are partly compensated by higher prices realized in the market. Non-affected producers experience increased welfare because their production is unaffected and produce is sold at higher price. Consumers experience a reduction in welfare as they pay higher prices for the same products. Consumers bore 92% the total costs of invasion in the case of potato and 77% in the case of tomato.

Table 3.4 Change in social welfare (k€) estimated by partial equilibrium modelling at the EU level.

	Potato	Tomato	Total
Producer	-340	-1,278	-1,618
Consumer	-4,070	-4,390	-8,460
Total	-4,410	-5,668	-10,078

3.3.2 Stochastic analyses

Assessment of direct impacts varied widely when incidence estimates of different experts were used (Table 3.5; Figure 3.3). The 5th and 95th percentiles of expected direct economic impacts were estimated at 5 and 9.5 M€ for expert 1, 1.4 and 6 M€ for expert 2, 0.3 and 1.3 M€ for expert 3 and 28 and 633 M€ for expert 4. The direct impact based on the infestation level as indicated by expert 4 thus showed considerable uncertainty. Naturally, in such diverse and large PRA area like the EU, comparisons and assessments of pest spread are hard because such an analysis demands from the expert a more accurate knowledge and a larger capability of taking all the options into account. As the experts' individual estimates did not agree, the equally weighted combination scenario (5th scenario) resulted also in a wide uncertainty interval (between 1 and 488 M€ for the 5th and 95th percentiles).

Table 3.5 Direct impacts resulting from the stochastic analyses.

Experts	Mean (M€)	Std dev (M€)	5% (M€)	50% (M€)	95% (M€)	Replicates with impacts > costs of control (%)*
One	9.4	14.8	5.0	6.7	9.5	82.3
Two	3.5	1.4	1.4	3.3	6.0	9.3
Three	0.7	0.3	0.3	0.7	1.3	0.0
Four	316.3	192.2	28.0	310.7	633.0	99.3
Averaged	80.6	163.4	1.0	5.3	488.0	43.7

* Proportions of the replications resulting in higher direct impacts than the costs of current phytosanitary measures against PSTVd, which are estimated at 5.6 M€ a year.

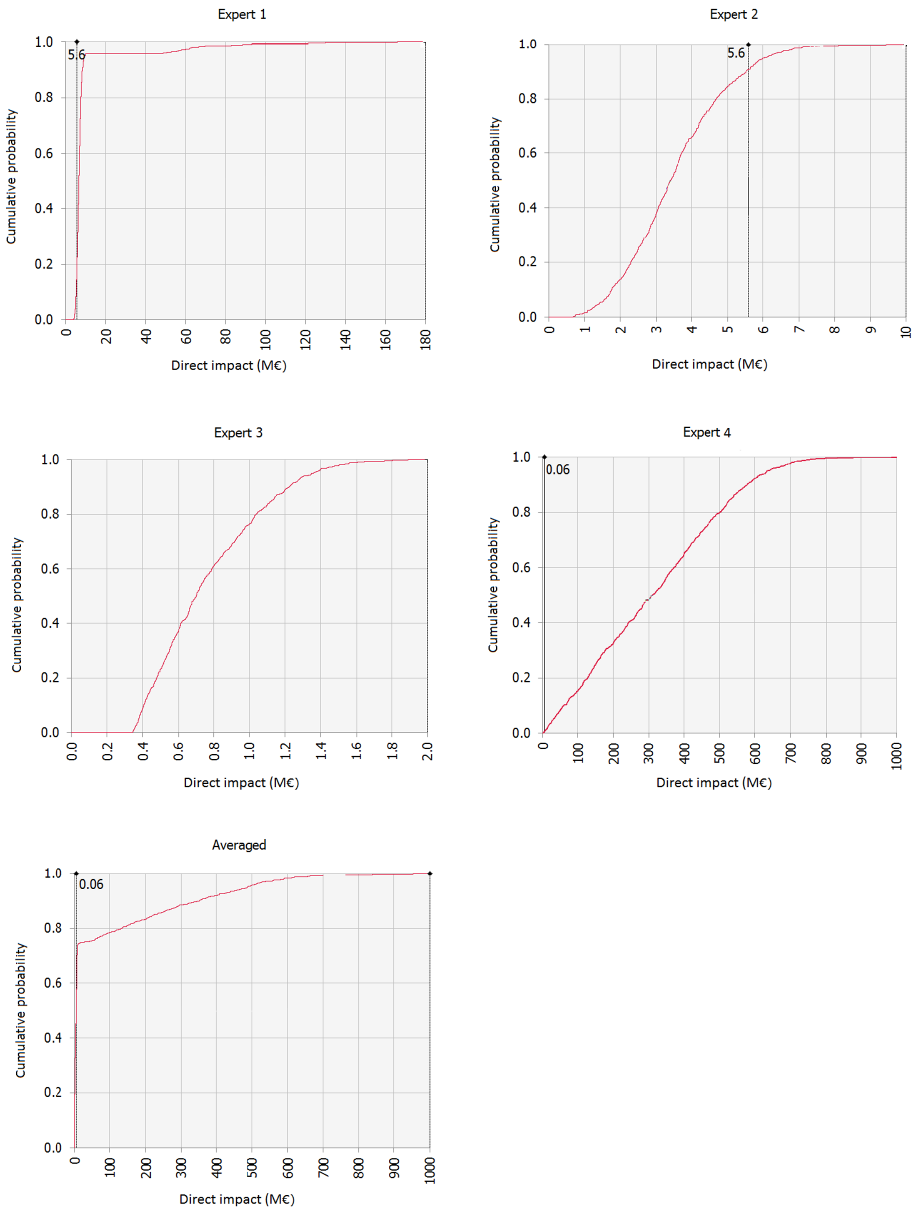

Figure 3.3 Cumulative distribution of direct economic impacts of PSTVd under an unregulated outbreak, based on elicitation of four experts, and according to the average probability distribution of incidence (see text). The cost of current measures (5.6 M€) is indicated by the vertical arrow.

3.4 Discussion

The impact assessment of PSTVd, made here, shows large differences in estimated economic impact based on estimation by different experts of the likely incidence of the disease if current phytosanitary measures were lifted. According to these different estimates, the current costs of measures (5.6 M€ per year; Table 3.6) represent the 18, 91, 100, and 1 percentile of the distribution of impacts. In other words: according to the estimates of experts 1 and 4, the measures are justified because costs of outbreak are likely to exceed costs of measures, but according to the estimates of experts 2 and 3, economic justification of measures is weak at best as losses are likely to be less than the costs of measures. If the incidence estimates of the four experts are combined, the costs of measures correspond to the 56 percentile of economic impacts if measures were lifted. Thus, the assessment of direct costs of a PSTVd outbreak, with current knowledge and uncertainty does not result in a convincing justification of measures.

However, partial budgeting gives a limited perspective on economic consequences. Price effects and effects on trade and import should also be considered. The market analysis using PE modelling resulted in higher economic impacts than those estimated at the producer level using PB. This is because PE has a wider scope in assessing economic impacts, by accounting for price changes and its consequences on producer and consumer welfare (Soliman et al., 2010).

The potential for export losses is an important consideration for regulation as PSTVd is a quarantine pest for many trading countries outside the EU. Exports of potatoes must be free from PSTVd. The value of EU potato exports is 410 M€ (Anonymous, 2007) and the value of tomato exports is 106 M€ (GTAS, 2007). The costs of regulation for PSTVd represent approximately 1% of this export value. Measures would therefore already be justified if the presence of PSTVd would result in export value losses of 1% or more. The potential economic impacts of PSTVd into the European Union are therefore demonstrably of importance if considering export losses or market effects and questionable if not considering these impacts. Based on the precautionary principle, we conclude that the current measures against PSTVd are economically justified.

Table 3.6 Cost of the current phytosanitary measures in 2010 in the whole EU

Crop	Number of inspections	Inspection cost (1000€)	Number of samples tested	Testing cost (1000€)
Vegetables and unknown/mixed	50,320[a]	4,766[b]	7,456[a]	650[b]
Ornamentals	1,716[a]	162[b]	752[a]	50[b]
Potato	--	45[c]	--	--
Total cost		4,973		700

[a] FVO, 2011

[b] inspection price=94.7€, testing price=87€ (for vegetables) and 67€ (for ornamentals) (source: NAK Tuinbouw laboratories and EuroStat for average wages in the EU)

[c] Benninga et al., 2010

The results showed that assessing the economic impacts based only on deterministic partial budgeting could lead to a misleading conclusion. While stochastic analysis in a PB framework helps clarify the probability that uncertain economic losses are higher than the cost of the measures, this analysis result is still too narrow in scope to evaluate the need for regulation.

As indicated by the experts' responses, the potential pest prevalence level of a situation without regulation is uncertain. Several contradicting factors lead to this uncertainty. A limited level of infestation seems plausible because the seed certification system and associated inspections, mainly aimed at ensuring varietal purity and absence of virus infections, might already be sufficient to curtail the spread of PSTVd. In addition, despite recent findings of PSTVd in ornamentals, there is no evidence for transmission of PSTVd from ornamentals to potato, and PSTVd genotypes from potato are phylogenetically different from those in ornamentals and tomato (Verhoeven et al., 2010). On the other hand, several factors support the possibility of a high PSTVd prevalence. First, the risk of potential transmission from ornamentals to tomato. Tomatoes and ornamentals are increasingly grown in greenhouses and are sometimes grown in the same compartment. This would increase the potential for transfer of PSTVd from ornamentals to tomato. Second, in Eastern Europe, farmers use farm-saved seed for their own production and this tradition could increase the incidence of PSTVd.

The analysis was conducted at two levels of spatial resolution: EZ and AEZ. The analysis could also be conducted at the climate zone level which would have provided the same results as the analysis on AEZ level because yield loss rate is dependent on temperature, data for which are available at the climate zone level. We chose the AEZ level for representation and pragmatic purposes. The analyses on EZ and AEZ level yielded similar results in terms of total impact across Europe. However, the finer analysis at the AEZ level did not provide additional insight in the spatial distribution of the impacts because there was no information on spread. Therefore, the gains in insight did not outweigh the additional effort and time spent to conduct the analysis at the finer AEZ level.

ISPM No. 11 states that the implementation of phytosanitary measures should be economically justifiable. However, to date, the impact assessment of PSTVd at the EU level has been ad hoc and largely limited to documenting losses where pest outbreaks have occurred (EFSA, 2011b, 2010a), and without the application of a quantitative assessment to evaluate the economic justification of measures. As a matter of principle, the European Food Safety Authority (EFSA) does not assess economic impacts in monetary terms (EFSA, 2010b). Limiting the PRA to only qualitative assessment could lead to a weaker position in trade disputes with other countries. Furthermore, limiting the quantitative assessment only to the cases where all relevant data are available will restrain the potential contribution that can be provided by the quantitative approach to the economic justification of the measures. To be relevant to real world situations, the challenge should be faced of making an analysis when the quantitative evidence is scarce. This paper demonstrates that a quantitative analysis, based on expert assessments, can provide management relevant insights in the economic justification of the phytosanitary measures, despite uncertainties.

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Chapter 4

Framework for Modelling Economic Impacts of Invasive Species, Applied to Pine Wood Nematode in Europe

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Abstract

Economic impact assessment of invasive species requires integration of information on pest entry, establishment and spread, valuation of assets at risk and market consequences at large spatial scales. Here we develop such a framework and demonstrate its application to the pinewood nematode, Bursaphelenchus xylophilus, which threatens the European forestry industry. The effect of spatial resolution on the assessment result is analysed. Direct economic impacts resulting from wood loss are computed using partial budgeting at regional scale, while total (direct and indirect) impacts on the round wood market are computed using partial equilibrium modelling at EU scale. Substantial impacts in terms of infested stock are expected in Portugal, Spain, Southern France, and North West Italy but not elsewhere in EU in the near future. The cumulative value of lost forestry stock over a period of 22 years (2008 – 2030), assuming no regulatory control measures, is estimated at €22 billion. The greatest yearly loss of stock is expected to occur in the period 2014-2019, with a peak of three billion euros in 2016, but stabilizing afterwards at 300–800 million euros/year. The reduction in social welfare follows the loss of stock with considerable delay because the yearly harvest from the forest is only 1.8%. The reduction in social welfare for the downstream round wood market is estimated at €218 million in 2030, whereby consumers incur a welfare loss of €357 million, while producers experience a €139 million increase, due to higher wood prices. The societal impact is expected to extend to well beyond the time horizon of the analysis, and long after the invasion has stopped. PWN has large economic consequences for the conifer forestry industry in the EU. A change in spatial resolution from fine to coarse affected the calculated directed losses by 24%, but did not critically affect conclusions.

Keywords

Pest risk analysis – pine wood nematode – economic impact assessment – EU – spatial resolution

4.1 Introduction

A quantitative economic impact assessment of invasive species requires spatial integration of information on the potential for establishment, spread and impacts of the pest, which is a novel and challenging area in pest risk assessment (Baker et al., 2005). Difficulties of integrating spread and economic impacts arise from unavailability of data on pest population densities, lack of knowledge on the relationship between those densities and expected yield reduction or quality loss, and difficulties in up-scaling the impacts from field to market level. Several studies have been devoted to the development of biological spread models (Heesterbeek and Zadoks, 1986; Carrasco et al., 2010; Robinet et al., 2011) or economic evaluation models to estimate economic impacts (e.g. field and market scale) given predefined pest infestation rates (Wesseler and Fall, 2010; Heikkila and Peltola, 2004; Wittwer et al., 2005). Only few quantitative studies have integrated spread with impacts (Haight et al., 2011; Yemshanov et al., 2011; Hodda and Cook, 2009), and none of them accounted for the economic impacts at market level.

Wood production in forestry is vulnerable to invasive species, and enormous economic consequences have been reported. In the US, annual losses of forest products caused by invasive species exceed $4.2 billion (Pimentel et al., 2000) while in China these are estimated at $2.2 billion (Higgins et al., 2000) and in Canada at $9.6 billion (Colautti et al., 2006). Invasive forest pests could lead to similar massive economic impacts on the European continent.

Pine wood nematode (*Bursaphelenchus xylophilus*) (Steiner and Buhrer, 1934; Nickle et al., 1981) is recognized worldwide as a major forest pest (Evans et al., 1996). Originating in the US, pine wood nematode (PWN) has spread to East Asia (OEPP/EPPO, 1986), Portugal (Mota et al., 1999), and North West Spain (Anonymous (2010). The nematode can reproduce quickly at high temperatures in summer. Huge populations of the nematode develop in infested trees, impeding water transport and causing the symptoms of pine wilt disease (PWD). Ultimately, PWD results in the death of the infested trees. PWN is vectored from diseased to healthy trees by bark beetles in the genus *Monochamus*. Pines (*Pinus* spp.) are favoured hosts but other genera of conifers (*Abies, Picea, Larix, Cedrus* and *Pseudotsuga*) are also attacked (Evans et al., 1996).

Since May 2008, Portugal has been classified as a demarcated area for PWN and subjected to emergency measures set out in Decision 2006/133/EC to prevent the further spread of PWN in the European Union (EU) (Anonymous, 2008). Despite an intensive containment program (i.e. PROLUNG) (Rodrigues, 2008), recent inspections carried out by the Food and Veterinary Office (FVO) of the European Commission indicated that the applied emergency measures have been insufficient (FVO, 2008). Moreover, Sweden, Finland and Spain notified PWN findings in pallets imported from Portugal (FVO, 2008). Intensification of the control measures may thus be required to eradicate the pest in Portugal and prevent further spread to the rest of the EU. However, the intensification of control measures must be economically justifiable. It is therefore important to make an objective quantitative assessment of the expected economic consequences on European forest production and downstream markets that may result from a possible future spread of PWN from Portugal.

The objective of this paper is twofold. The first objective is problem oriented: to assess the expected economic consequences after 22 years of an uncontrolled PWN infestation in the EU by integrating information on climate, spread of PWN and value of forestry assets in Europe. The results give insight in the distribution of losses among geographical regions and show the impact on social welfare at pan-European level. The second objective is methodological. As little information is available on the effect of spatial resolution on economic impact assessments, this study compares the results of different spatial and economic techniques to arrive at an evidence-based quantification of economic impacts. The comparison clarifies how spatial resolution and economic assessment method affect the results and the associated requirements in terms of effort and data.

4.2 Materials and Methods

4.2.1 Conceptual framework

The economic impact model consists of four modules, one for calculating the spatio-temporal spread of the nematode, a second for climatic modelling to determine the areas where the climate is suitable for disease expression in infested trees, a third for modelling the spatial distribution and value of potential hosts or habitats and a fourth for calculation of economic impacts (Figure 4.1). Data layers resulting from the spread, climate and host modules are integrated in a geographic information system (GIS) to quantify and map economic losses. To enable integration, the different data layers need to be at the same level of spatial resolution.

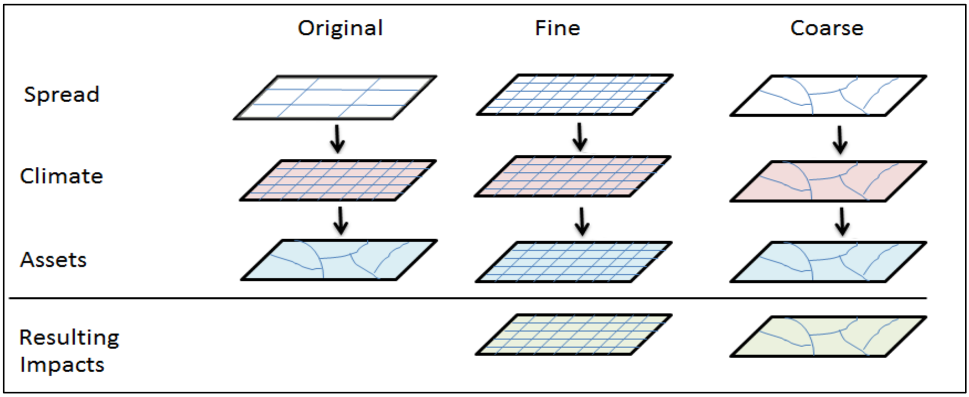

Figure 4.1 Conceptual framework for the risk assessment of PWN. The framework consists of four modules, one for calculating the spatio-temporal spread of the nematode, a second for climatic modelling to determine the areas suitable for disease expression, a third for modelling the spatial distribution and value of potential hosts or habitats and a fourth for calculation the resulting economic impacts.

The evaluated impacts involve direct (i.e. host related) impacts such as yield reduction or quality loss, and additional production costs, as well as total, i.e. direct and indirect (non-host related) impacts such as changes in prices, demand, supply, and trade. Direct impacts are spatially indexed, and mapped, whereas the total impacts are calculated using a market model for the whole EU. Total impacts are calculated with a partial equilibrium model for the whole EU, since there is one internal market for wood in the EU.

4.2.2 Empirical application

The scope of the empirical application in this paper is to estimate the economic impact resulting from PWN affected trees in all coniferous host species present in the EU and the subsequent impact on the industrial round wood market resulting from the wood loss.

GIS (ArcGIS Desktop 9.3) was used for spatial integration. Integration of the data layers was performed on a coarse resolution level (NUTS; Nomenclature of Territorial Units for Statistics) (EC, 2003) and on a fine resolution level (1 km^2), resulting in two independent analysis results that are compared to study the effect of spatial resolution on the assessment result.

4.2.2.1 Data layers

The first key data layer describes the potential spread of PWN in Europe from the year 2008 till the year 2030. Information on spread was derived from simulations with a process-based model of PWN spread from the initial infested sites in Portugal to the rest of Europe (Robinet et al., 2009 and 2011). Short distance spread of the nematode by long-horned beetles is modelled by diffusion, while long distance spread, which is assumed to be anthropogenic, is modelled by a stochastic, kernel-based model, based upon trade pathways. The frequency of transport that is responsible for the long distance spread of PWN is based on human population densities. The output of the model is presented as the presence/absence of PWN in individual grid-cells at the European level, where each grid-cell is 0.8° latitude x 0.8° longitude. The area of these grid cells varies with latitude, averaging 51 km^2 over the simulated domain. Two hundred replicate simulations were run to obtain a probability distribution of invaded area (quantified as number of invaded cells) in the year 2030. The median invaded area covered 12,734 cells out of the total of 393,120 cells in Europe, while the 5 and 95 percentile invaded areas covered 11,445 and 14,448 cells, respectively (Figure 4.2). The median result was used in further calculations. In the uncertainty analysis the 5th and 95th percentile were used to explore the sensitivity of economic impact to variation in spread.

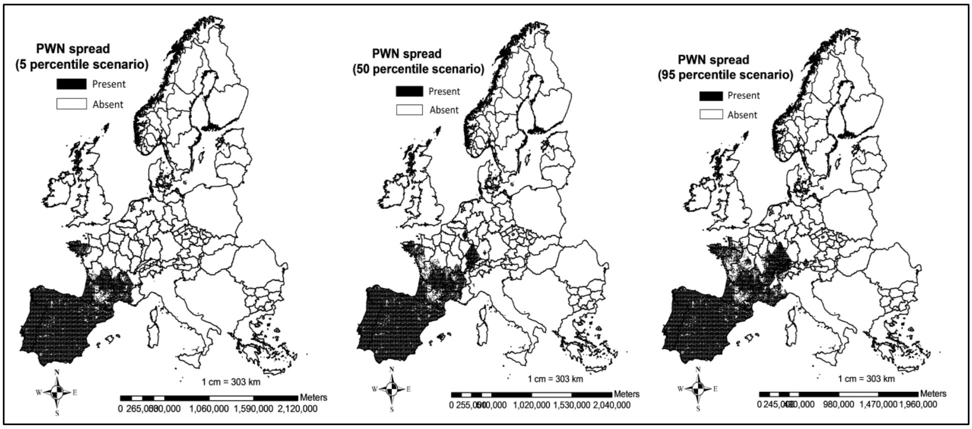

Figure 4.2 Simulated spread of PWN among Europe. Presented spread is based on the results of the 5th, 50th, and 95th percentile replication of total extent of spread according to the spread model.

The second data layer describes climate suitability. The key variable is temperature as the development of pine wilt diseases (PWD) is sensitive to summer temperatures (Anonymous, 2007). Average summer temperature data (i.e. mean of July and August) over the years 1950-2000 were obtained from the WORLDCLIM database at 1 km^2 resolution (Hijmans et al., 2005). Data from PWN outbreaks in North America and Japan indicate that trees die due to PWD if temperatures are higher than 20°C for at least 8 weeks (Sathyapala, 2004; Rutherford and Webster, 1987; Rutherford et al., 1990). If PWN is present, but temperature is lower than the threshold for symptom expression, no PWD will be expressed.

The third data layer is the distribution of the assets (hosts) at risk within the EU. Host data were extracted from the European Forest Information Scenario Model - EFISCEN (Nabuurs et al., 2007; EFSOS II, 2011), containing conifer forestry information for 25 countries of the EU plus Switzerland and Norway (Figure 4.3). Data representing the situation in Malta and Cyprus were not available and were therefore not included in the study. Data on Spain, Portugal and Italy were only available at country level, while data for the rest of Europe were represented at the more refined NUTS-1 or NUTS-2 region level. Only those conifer species that are susceptible to PWN infestation (Evans et al., 1996) were considered as assets at risk. The vulnerability of these assets and, therefore, the value at risk vary with the species related level of PWN susceptibility (Evans et al., 1996) and age (Bain and Hosking, 1988; Wingfield et al., 1984). We classified the trees according to three levels of susceptibility (viz. susceptible, intermediate or resistant) and two classes of age (<= 20 years or > 20 years), resulting in six vulnerability classes.

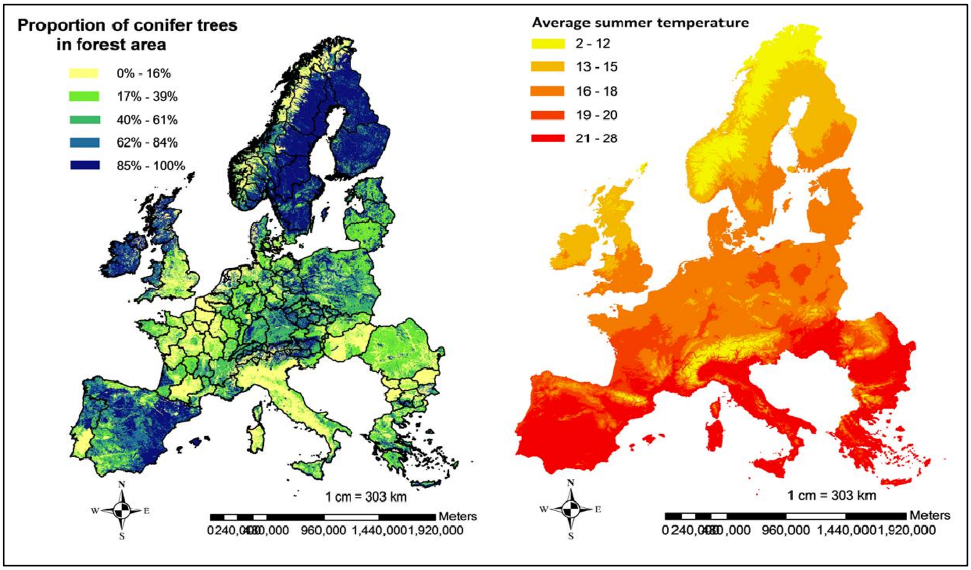

Figure 4.3 Proportion of conifer trees in forest at 1 km^2 resolution (left) and average summer temperature in Degrees Centigrade (right).

- *Spatial integration of data layers*

The data of different layers were integrated at two levels of resolution, coarse and fine, to explore sensitivity of calculated impacts to resolution adapted in the modelling. In the coarse resolution analysis, the units are NUTS-1 and NUTS-2 regions, depending on the level of detail at which the data are available from the original data source on host distribution. The coarse resolution analysis accounts for 117 NUTS regions. For the fine resolution analysis, the units are 1 x 1 km squares grid cells of which there are 3,856,062 in the modelled spatial domain. Information in the three data layers (spread, temperature and assets) were up- or downscaled as required to attain the desired level of resolution.

For the coarse resolution analysis, the three basic data layers were upscaled to the NUTS region level. The average summer temperature was calculated for NUTS regions by averaging across the grid-cells in each NUTS region. The presence/absence indicator of PWN was scaled up by calculating the proportion of infested 0.8 x 0.8 degree grid cells within each NUTS region. Assets at risk categorized by vulnerability class were already presented at the NUTS region level.

In the fine resolution analysis, data were integrated at a 1 km^2 resolution. Temperature data were originally available at 1 km^2 level but other variables needed to be downscaled. The value of the spread indicator in each 1 km^2 grid (presence/absence) was obtained from the source cell of the spread model (0.8° x 0.8°), assuming that presence in the source cell implied presence in each 1 km^2 grid cell within it. Assets at risk were known by NUTS region. Damage at NUTS level was obtained by multiplying the value at risk in the region by the proportion of 1 km^2 cells that met two criteria, 1) infested with PWN and 2) temperature higher than the threshold value for expressing PWD (see direct impacts). This total impact in a NUTS region was then distributed over the 1 km^2 cells that met the two criteria for impact, assuming a homogenous distribution of the production value within the NUTS region.

4.2.2.2 Economic impacts

A partial budget (PB) analysis was applied to calculate the loss of the standing stock available for round wood production in the EU resulting from 22 years of uncontrolled PWN spread, and to map the spatial distribution of direct losses over the EU. The economic impacts were estimated up till year 2030 in line with the time horizon of the spread model. We consider only the value of lost wood and ignore the costs of mitigation which can – in principle – be included in PB analysis (Soliman et al., 2010).

Partial equilibrium analysis was conducted to estimate the annual change in social welfare for the whole of the EU as a consequence of an affected wood supply destined for round wood production. Partial equilibrium analysis accounts for the phenomenon that changes in round wood production will trigger price changes that affect supply, demand, imports and exports. Due to a reduction in production volume by producers, prices are likely to increase, demand will decrease, exports will decrease and imports will increase. As a result of increased prices, some of the economic impact may be passed on to consumers. While results of partial budget analysis are local and therefore spatially indexed, the results of partial equilibrium analysis are aggregated values over the whole EU.

- *Direct Impacts*

The loss in standing stock available for round wood production was determined by the expected mortality rates as a consequence of the occurrence of PWD. In the valuation of the loss, it is assumed that trees expressing PWD are completely worthless, whereas healthy or symptomless trees retain their value.

Trees of 20 years or younger, and classified as ‘susceptible’, ‘intermediate’ or ‘resistant’ species were assigned default mortality rates of, respectively, 100% (Anonymous, 2007), 80% (Bain and Hosking, 1988; Furuno, 1993) and 50% (Chai and Jiang, 2003). Trees older than 20 years in these same susceptibility classes were assigned slightly lower mortality rates of, respectively, 90% (Sutherland et al., 1991; Mamiya, 1983), 70% (Anonymous, 2007; Anonymous, 2008) and 40% (Chai and Jiang, 2003).

The direct impact assessment assumes that PWN spreads after an invasion in 2008, assuming (1) the absence of any regulatory control measure, (2) no change in the structure of the standing stock. The direct impact is expressed in terms of the total loss in production volume. For the year 2030, i.e. after 22 years of spread this is equal to :

$$\text{Direct Impact} = p\sum_{i} r_i d_i \left(\sum_{jk} m_{ijk} s_{ijk} \right) \tag{1}$$

where

r_i = proportion infestation with PWN after 22 years in polygon i

d_i = indicator (0 or 1) for temperature above (1) or below (0) temperature threshold for expression of pine wilt disease (PWD)

m_i = mortality rates for trees of age class j and susceptibility class k in polygon i

s_i = standing stock available for wood production per age class j and susceptibility class k in polygon i.

p = market price of round wood

The summation over age and susceptibility classes of trees is made for each polygon to calculate the overall value of assets at risk in a polygon. The proportion of infestation is calculated from the spread model for each polygon, while the indicator value for PWD expression is calculated from the temperature model for each polygon. In the fine resolution analysis, each polygon is a 1 x 1 km square, while in the coarse resolution analysis, each polygon is a NUTS region.

- *Total impact*

Partial equilibrium (PE) modelling was used to assess the total (direct and indirect) impacts of PWN. The focus of this total impact assessment is on the conifer industrial round wood market which represents 79% of the total round wood market, the other 21% being for fuel wood and charcoal (UNECE/FAO, 2009). The average yearly tree removals for the purpose of conifer industrial round wood production represent 1.8% of the forestry standing stock (UNECE/FAO, 2009).

In the PE model, it is assumed that (1) conifer round wood in the EU and in the rest of the world (ROW) are perfect substitutes and their respective prices differ only due to transportation costs and tariffs and, (2) the EU market for conifer round wood is perfectly competitive, implying product homogeneity. Equations of the PE model are given in Chapter 3 (section 3.2.3.2).

The PE model calculated the expected annual total impact of PWN for the period 2008 till 2030, using data on prices and volumes in the round wood market from FAO statistics (FAOstat, 2009) and the expected proportion of infestation in time. The market price is the deflated EU market price of round wood of 2009, viz. 50.49 €/m^3. Infestation levels at the EU level were obtained from the spread model. The shift in the market supply of round wood due to tree mortality was obtained from PB (Figure 4.4). Based on the assumption that replacement of affected stock takes more than the evaluated 22 years before it will be effective for round wood production, it is assumed that the reduction in round wood supply in a year is equal to 1.8% of the accumulated annual loss in standing stock up to that year. Inputs for the PE analysis are given in Table 4.1.

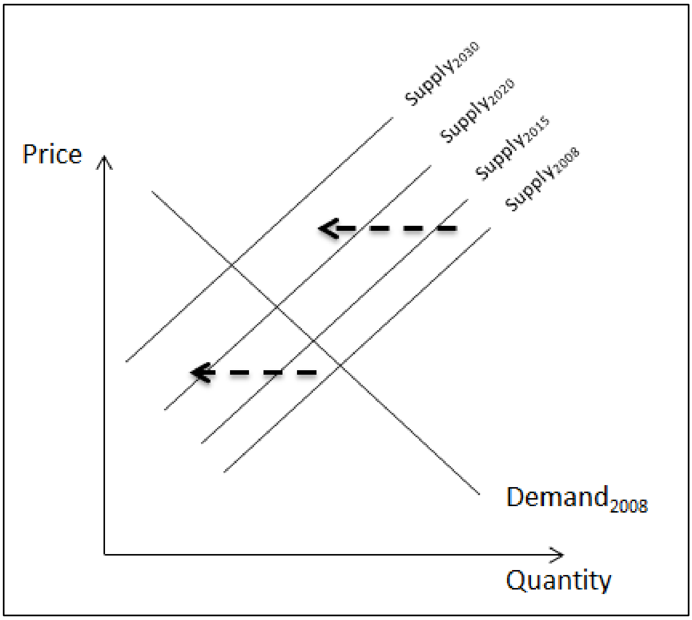

Figure 4.4 The annual shift in the supply curve based on the accumulated loss in standing stock (2008-2030). The dashed arrow represents the direction of the vertical shift in the supply curve of the market model.

Table 4.1 Parameters on European industrial round wood production as used in the partial equilibrium model.

Parameter		Parameter	
Production (1000 m^3) [a]	242,528	Consumption (1000 m^3) [a]	249,101
Supply elasticity [b]	0.8	Demand elasticity [c]	-0.11
Producer price (€/m^3) [a]	50.49	World price (€/m^3) [a]	54.5
Excess supply (Import) elasticity	6.07		

[a] FAOstat (2009)
[b] Zhu and Buongiorno (1998)
[c] Kangas and Baudin (2003)

4.2.2.3 Uncertainty analyses

- *Single parameter analyses*

A coarse resolution uncertainty analysis was performed to study how the calculated direct economic impact is affected by (1) modelled variation in the spread of PWN, (2) variation in the literature with respect to the temperature threshold for PWD expression, (3) uncertainty as to the mortality rates for the tree hosts and (4) fluctuations in the market prices of industrial round wood. Sensitivity to variation in spread was assessed by comparing impacts at the median spread with impacts at the 5th and 95th percentile of spread. Sensitivity to the temperature threshold for PWD expression was assessed by comparing impacts for three different thresholds values, viz.: 18°C, 19°C and 20°C (Anonymous, 2008; Braasch and Enzian, 2004). Sensitivity to mortality rates was assessed by constructing parameter sets representing low and high mortality as follows. For trees of 20 years or younger, minimum mortality rates for susceptible, intermediate and resistant trees were 60% (Anonymous, 2007), 60% (Anonymous, 2007) and 40% (Chai and Jiang, 2003) respectively, and maximum rates 100% (Anonymous, 2007), 100% (Anonymous, 2007) and 50% (Chai and Jiang, 2003). For trees older than 20 years, minimum mortality rates for susceptible, intermediate and resistant trees were 50% (Anonymous, 2008), 50% (Anonymous, 2008) and 40% (Chai and Jiang, 2003) respectively, and maximum rates 90% (Anonymous, 2008), 90% (Sutherland et al., 1991; Anonymous, 2008) and 50% (Chai and Jiang, 2003). Impacts of market prices were evaluated by accounting for the lowest (50.49 €/m^3) and highest (64.14 €/m^3) deflated EU prices of industrial wood recorded in the period 2003-2009 (UNECE/FAO, 2009).

- *Multi Parameter Analysis*

Worst and best cases were constructed by combining the parameter settings used in the coarse resolution uncertainty analysis. The worst case assumes PWN spread based on the 95th percentile spread value, an average summer temperature threshold of 18°C (i.e. low threshold), maximum mortality rate values and the highest market price for wood, while the best case assumes a PWN spread based on the 5th percentile spread value, a temperature threshold of 20°C (i.e. high threshold), minimum mortality rate values and the lowest market price for wood.

- *Data layers analysis*

In order to assess the sensitivity of the results to availability of information on (1) temperature threshold and (2) introduction and spread of the nematode, direct economic impacts were recalculated assuming, firstly, that there is no temperature threshold required for PWD expression and secondly, that the point of entry of PWN invasion is not known. The first assumption is reflected empirically in the model by ignoring the temperature data layer and calculating impacts for all areas where PWN was present. The second assumption is reflected empirically by removing the spread data layer and calculating impacts for all areas in Europe which had an average summer temperature above 20^{o}C.

4.3 Results

- ***Assets at risk***

Susceptible conifer trees available for wood production represent 13,665 million m^3 out of 24,594 million m^3 of forestry trees (Figure 4.3). Cells with presence of PWN and temperature above 20^{o}C are cells that show PWD. Depending on the resolution of the temperature data layer (NUTS and 1 km^2), the PWD is expressed in 4 out of 117 NUTS regions in the coarse resolution and in 696,764 out of 3,856,062 (1 km^2) cells in the fine resolution (Figure 4.5). These 696,764 cells were in 12 NUTS regions (Table 4.2).

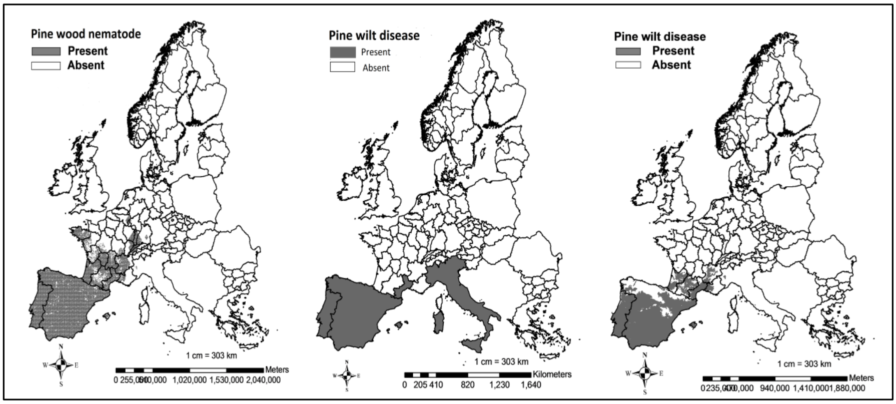

Figure 4.5 PWN and PWD potential spread in the year 2030. PWN potential spread at 0.8° latitude x 0.8° longitude resolution (left), PWD potential spread at 1 km^2 resolution, based upon summer temperature (middle), and PWD impact at NUTS level (right). Impact is cumulative over 2008-2030.

Table 4.2 Infestation level and cumulative direct impact over 22 years of uncontrolled PWN spread in Europe.

Region	**Coarse resolution**		**Fine resolution**		
	Proportion infested area	**Direct impact**	**Proportion infested area**	**Direct impact**	**Direct impact**
	(%)	**(M€/region)**	**(%)**	**(M€/region)**	**(€/km^2)**
Italy	0.15	30	0.15	30	43,136
Portugal	97.49	6,106	82.44	5,164	46,895
Spain	95.15	20,645	67.52	14,649	28,530
France					
Languedoc-Roussillon	84.65	1,084	50.32	644	28,831
Bourgogne	0	0	0.06	1	16,079
Poitou-Charentes	0	0	0.09	1	21,381
Aquitaine	0	0	19.86	1,219	90,611
Midi-Pyrenees	0	0	22.18	289	17,749
Limousin	0	0	1.71	15	30,124
Rhone-Alpes	0	0	14.71	215	19,626
Auvergne	0	0	0.19	3	31,792
Provence-Alpes Cote d'Azur	0	0	15.63	145	18,217
Total (EU)	**13.7**	**27,865**	**10.6**	**22,375**	

- ***Direct impact***

The partial budget analysis showed high expected timber losses in Portugal, Spain, Italy and France by 2030 (Table 4.2 and Figure 4.6). The cumulative wood loss in 2030 is estimated at €27 billion in the coarse resolution analysis at NUTS region level and at €22 billion in the fine resolution analysis at 1 x 1 km^2 level, representing, respectively, 4% and 3.2% of the total value of PWN sensitive coniferous trees in the EU. Due to the width of the potential distribution of PWN and the availability of susceptible and intermediate host species in high densities, losses in standing volumes in Portugal and Spain are extremely high, respectively, 89% and 84% of total stock. In Italy, PWN is predicted to be present in only a few areas in the northwest part, thus reducing impact. Based on the coarse resolution analysis, only the southern part of France (Languedoc-Roussillon) is predicted to be affected by the nematode. The fine resolution analysis extends the impacted area in France to other southern regions (i.e. Bourgogne, Poitou-Charentes, Aquitaine, Midi-Pyrenees, Limousin, Rhone-Alpes, Provence-

Alpes Cote d'Azur and the Auvergne). Of these regions, Aquitaine is predicted to have the highest impacts because of the presence of dense coniferous forests. Aquitaine is not predicted to be impacted in the coarse resolution analysis as the average summer temperature at the NUTS level was below the PWD temperature threshold of 20°C; however parts of Aquitaine have average summer temperature above 20°C, therefore the fine resolution analysis shows impacts in these parts of Aquitaine.

Overall, the total direct impact estimated by the coarse resolution was 24% higher than estimated by the fine resolution. This is due to spatial aggregation resulting in a higher area where PWD can express. For example, Spain (as a NUTS region) has an average temperature above 20°C and the entire area of Spain was selected as endangered area in the coarse resolution analysis while in the fine resolution analysis only 67% of the 1 km^2 grid-cells of Spain was selected as endangered area.

Annual marginal analysis of the direct impact showed a sharp increase between the years 2014-2019, reaching its maximum in 2016 with a damage value of €3,068 million and a minimum in 2022 with a damage value of €329 million. At 2030 (i.e. the last year considered), the damage value was estimated at €816 million (Figure 4.7).

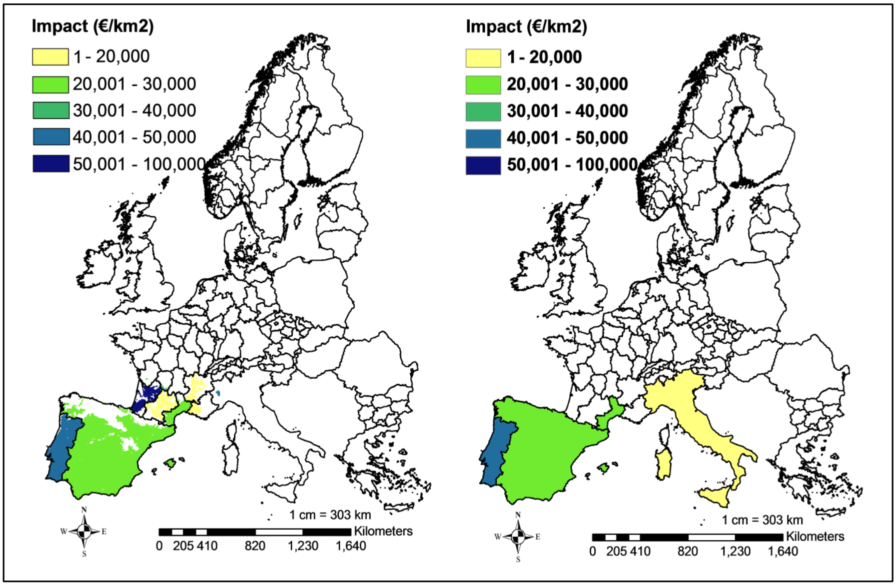

Figure 4.6 Cumulative direct economic impacts after 22 years of uncontrolled PWN spread in Europe. In the first panel, a fine resolution (1 km^2) was used to conduct the analysis and to present the results. In the second panel, the analysis was conducted and the results presented at coarse resolution.

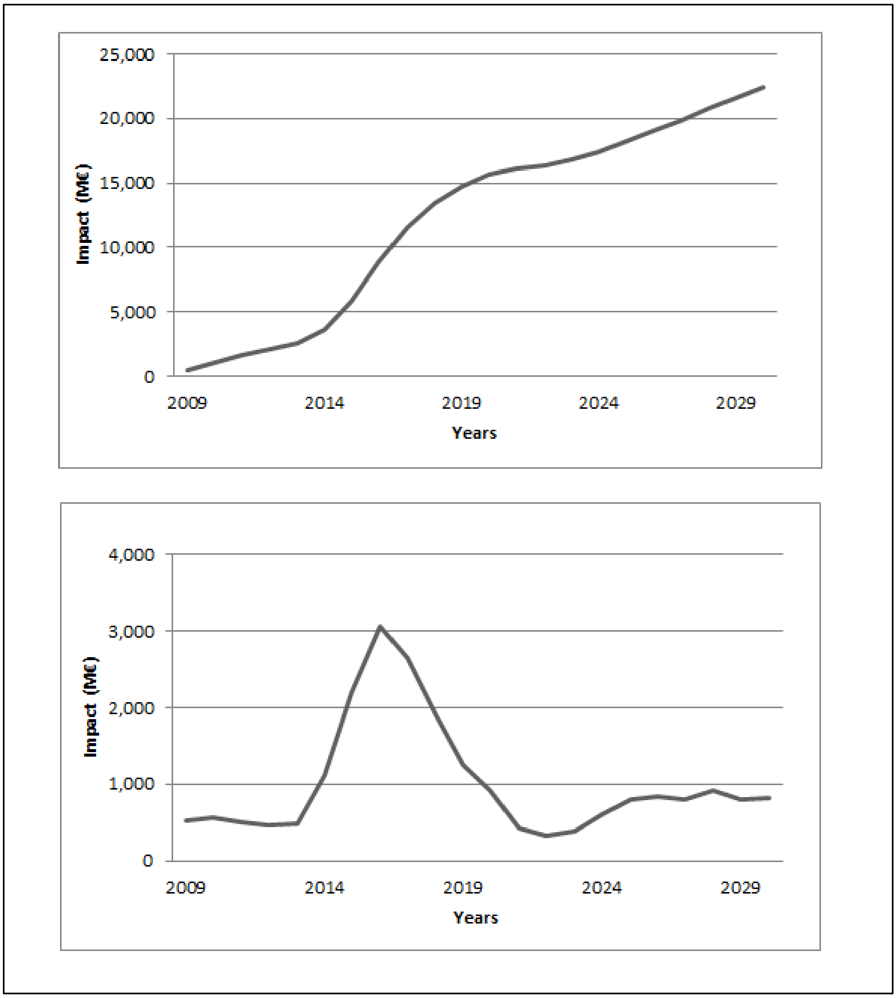

Figure 4.7 Direct impacts (2008-2030) during 22 years of uncontrolled spread of pinewood nematode in Europe. The first panel shows the cumulative direct impact, calculated as the total value of diseased trees over the entire infested area, i.e. the cumulative loss in harvestable stock. The second panel shows the marginal direct impact, i.e. the loss of harvestable stock due to the invasion process in each year.

- ***Total impact***

The results of the PE analysis showed that the reduction in domestic supply of industrial round wood (for both affected and non-affected producers) caused by unregulated PWN invasion, will lead to an increase in the domestic market price, and a decrease in domestic demand. Annual net total welfare (impact on affected, non-affected producers and consumers) after 22 years of spread (i.e. a shift in the supply side of the market due to accumulated direct loss of 22 years) will be reduced by € 218 million. The shortage in domestic supply (the gap between supply and demand) is covered by an increase in the imports and/or decrease in exports (i.e. change in net trade) (Table 4.3) and the increase in domestic price and changes in trade trigger an increase in the world price for round wood. The increase in prices causes an increase in supply leading to a new equilibrium in the industrial round wood market. Consumers would suffer a reduction in surplus of € 357 million due to higher prices. Non-affected producers are expected to experience a positive net impact as they benefit from the higher market price in the new equilibrium situation without suffering. Affected producers will experience a loss as the price increase will not wholly compensate for the reduction in production volume. On the whole, total producer surplus increases with €139 million. Coarse resolution analysis gives a 69% greater effect on annual total welfare than fine resolution analysis (Table 4.3).

Analysis of the total (direct and indirect) impact per year based on an accumulated shift in the supply side of the market, showed a net welfare reduction of 5 M€ in 2009, 142 M€ in 2019 and 218 M€ in 2030 (Figure 4.8).

Table 4.3 Annual total impacts due to pest invasion estimated by partial equilibrium modelling, based on direct impact assessment at coarse or fine resolution.

	Coarse resolution		**Fine resolution**	
	Absolute	**Relative (%)**	**Absolute**	**Relative (%)**
Supply (M m^3)	-3.24	-1.3	-1.89	-0.8
Demand (M m^3)	-1.27	-0.5	-0.77	-0.3
Price (€)	2.40	4.5	1.44	2.8
Net trade (M m^3)	-2	-23.0	-1	-14.6
Consumer surplus (M €)	-597	-4.1	-357	-2.5
Producer surplus (M €)	228	3.2	139	2.0
Total welfare (M€)	-369	-1.7	-218	-1.0

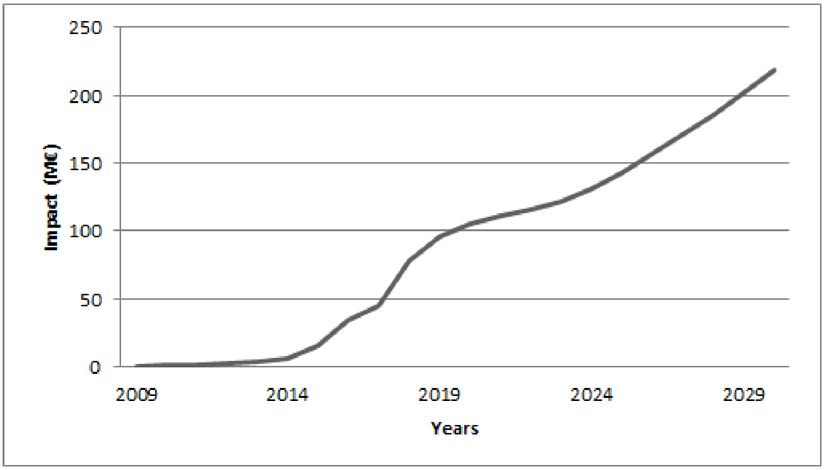

Figure 4.8 Annual total impact (i.e. net welfare) from 2008-2030 due to uncontrolled spread of pinewood nematode in Europe. Total impacts are calculated from shifting the supply curve of the market. The shift is calculated as the reduction in yearly flows resulting from the cumulative reduction in harvestable stock.

- **Uncertainty analysis**

- *Single Parameter Analysis*

The calculated direct economic impact was insensitive to uncertainties in the potential spread of PWN but sensitive to the assumed temperature threshold for PWD expression, the tree mortality rates and market prices (Table 4.4).

The estimated economic impacts based on the 5th, 50th and 95th percentile spread settings were similar at approximately € 27 billion. Due to the modelling condition of having the point of entry in Portugal and the presence of high host densities in Portugal and Spain, variation in spread within southern Europe turned out to be minimal. Spread variation among the northern European regions was larger (Figure 4.2). However, due to the temperature threshold for PWD expression of 20°C, spread variation only resulted in a small change in PWD occurrence and therefore in the economic impact. Impacts were sensitive to the settings of the temperature thresholds as the highly impacted regions (Portugal, Spain and Aquitaine (France)) occur between the 20°C climatic zone (i.e. Portugal and Spain), and the 19°C climatic zone (i.e. Aquitaine). The difference in impacts between the 18°C and 19°C climatic zones was minimal due to the presence of few susceptible trees in areas that are (1) in the invaded area till 2030, and (2) have summer temperatures between 18 and 19°C. Therefore the increase in temperature threshold from 18 to 19°C resulted only in a small number of additional trees at risk (Table 4.4).

Impacts were also sensitive to mortality rates as any change in this parameter immediately affects the results. Any change in the market prices changed the direct impacts proportionally.

Table 4.4 Parameter settings and results of the coarse resolution uncertainty analysis.

Parameters	Settings			Direct impact (M €)		
Spread (percentile)	5th	50th	95th	27,842	27,865	28,342
Temperature (°C)	18	19	20	35,020	34,353	27,865
Mortality rate (%)	minimum (40-60)	most likely (50-100)	maximum (50-100)	16,264	27,865	28,636
Market price (€)	minimum (50.5)		maximum (67.7)	27,865		37,363

- *Multi Parameter Uncertainty Analysis*

The direct economic impact entailed a cumulative loss of € 35.9 billion in the worst case, and a cumulative loss of € 16.2 billion in the best case (Table 4.5). The level of uncertainty in each region is reflected by the ratio of the difference in impacts of the best and worst case and the total value of trees within the corresponding NUTS region (Table 4.5). The results of this ratio suggest a high level of uncertainty in Aquitaine.

Table 4.5 Estimated direct impacts in the best and worst case scenario, given per NUTS region, in absolute as well as relative terms, as compared to the total value of trees within each region.

NUTS-2 region	**Worst case**		**Best case**		**Difference**
	(M€)	**(%)**	**(M€)**	**(%)**	**(%)**
Centre	124	7	0	0	7
Bourgogne	136	8	0	0	8
Pays de Loire	246	17	0	0	17
Poitou-Charentes	325	28	0	0	28
Aquitaine	5,290	80	0	0	80
Midi-Pyrenees	995	42	0	0	42
Languedoc-Roussillon	1,208	54	827	37	17
Provence-Alpes Cote d'Azur	210	14	0	0	14
Italy	33	0	20	0	0
Portugal	6,205	91	3,548	52	39
Spain	21,191	87	11,870	48	38
Total	**35,962**	**46**	**16,264**	**21**	**25**

- *Data layers analysis*

Assuming that all infested trees will express PWD regardless of the location temperature, the estimated value of wood loss of susceptible trees is M€ 56.5 billion, while the value of wood loss of all susceptible trees available in EU areas with average summer temperature above 20^{o}C, regardless of the locations invaded by PWN, represents a value of €43.3 billion.

4.4 Discussion

The results of this economic assessment demonstrate that an uncontrolled PWN invasion will lead to large economic consequences for the conifer forestry industry in the EU. The cumulated wood loss after 22 years of unregulated spread, calculated in a fine resolution analysis, is estimated at €22 billion, representing 3.2% of the total value of PWN susceptible coniferous trees in the EU. The reduction in social welfare in 2030 is estimated at €218 million. A PWN invasion from the current point of entry in Portugal is expected to affect 10.6% of the studied EU area by 2030.

There is a large difference in the magnitude of the estimated direct and total (direct and indirect) impacts. This is because the direct impacts represent the reduction in value of standing forestry stock, while the total impacts refer to the changes yearly flow of wood to the round wood market. These flows represent 1.8% on average of the standing stock (UNECE/FAO, 2009). Therefore, losses in flow accumulate slowly and for a long period of time after the standing stock should be considered as lost because of PWD. We do not consider in this study the recovery of rest value by planting resistant trees, because these would not be harvested within the time frame considered in this study (22 years). When the spread of PWN stops, the annual direct loss will disappear while the total impact will continue to increase until mitigation efforts become effective (i.e. replanted (resistant) trees flow to the round wood market).

The fine resolution analysis provided more plausible results in terms of size and distribution of the impacts, while requiring limited extra effort. The coarse resolution analysis did not identify Southern France as an area at risk as a result of averaging temperature over a large region, and therefore, it misrepresents the distribution of the impacts. Direct impacts estimated at a coarse resolution level were 24% higher than those obtained at a fine resolution level. The presented differences follow directly from the applied aggregation procedure on the temperature data layer.

While the difference in direct impact as estimated by the coarse and fine resolution analyses did not alter the assessment of the riskiness of the pest, the difference in the geographical distribution of the impacts predicted by the two resolutions is quite critical and management relevant. The fine resolution analysis is more relevant to EU risk managers as it provides a more plausible assessment of the expected distribution of direct impacts within the EU.

Economic impacts were on the basis of (1) the predictions of the spread model for the presence/absence of the PWN and (2) a temperature threshold of 20^{o}C for PWD. The sensitivity of the results to these two data layers was assessed in the data layers uncertainty analysis. The spread model was calibrated on the invasion history in China and should be refined in the future to determine more precise the potential expansion in Europe (Robinet et al., 2009 and 2011). Including no information on the potential spread implies that PWD infests all areas where host trees are available and the climate is suitable for expressing symptoms. This situation could arise if point(s) of entry other than Portugal are found.

Absence of a temperature threshold means that PWD is assumed to infest all areas invaded by PWN, regardless of their summer temperature. With global warming (+1.8 to +4° C predicted between 1980-1999 and 2090-2099 (Meehl et al., 2007)), the temperature constraint will be less restrictive in the future. When removing spread and temperature conditions, the cumulative direct economic impacts are massive: € 56.5 billion when the point of entry is unknown and €43.3 billion when there is no temperature restriction. Compared to the default impact of €27.8 billion, the availability of information on spread and climate as such did not critically influence the assessment of the risk posed by PWN. Nevertheless, the use of information on spread and climate demonstrated the geographical distribution of the impacts within the EU which is of value to EU risk managers. For instance, it allows a risk manager to compare the effectiveness of alternative management plans in terms of its temporal and spatial dimensions (e.g. early and late containment programs).

The economic impacts were estimated till the year 2030 conform the time horizon of the spread model. The time horizon of 22 years was considered long enough to allow the pest to show its invasion potential and short enough to have a reasonable technical processing time and an acceptable uncertainty level in the results (Robinet et al., 2010).

Integrating spread and impacts is a challenging area in pest risk assessment (Baker et al., 2005). The challenge arises from the fact that to quantify economic impacts, we need to know the areas of significant economic loss. Significant losses occur when the pest population densities exceed the economic injury level (EIL). The EIL is the population density at which the cost to control the pest equals the amount of damage it is likely to cause (Pedigo and Higley, 1992; Pedigo et al., 1986; Stern et al., 1959). To integrate spread and impact, knowledge is required on: (1) the areas where pest population densities exceed the EIL and (2) the relationship between pest population densities and the likely level of yield or quality loss. A number of recent studies followed this approach (Carrasco et al., 2008; Margarey et al., 2010) as they used pest population densities generated by a spread model and link it with yield loss. In the absence of spread models which can be used to predict pest population densities spatially, climate data (or other agro-ecological information such as soil type or irrigation) can be used as a proxy (Robinet et al., 2009). As climate influences the growth rate of the pest population, climate data can be used to indicate pest density levels. However, climate cannot be used to reflect the change in the pest population density over time.

Extending the economic assessment to market models with open economies (e.g. partial equilibrium) rather than just stick at the field/producer level models (e.g. partial budgeting) is essential as the market power of large areas like the EU in the world trade and the importance of the resulting spill over effects cannot be ignored. However, the main obstacle is that partial equilibrium models and invasion ecology models present different spatial and dynamic scales (Janssen and Ostrom, 2006) in addition to the unknown producers supply responses which play a critical role when scaling up impacts from field to market level.

The approach proposed in this study extends the risk mapping process from the establishment and spread phase to the economic impacts phase. Accordingly, our approach can be followed in PRAs where there is a need to represent impacts not only in relative pest risk levels but also in terms of euros, in order to increase the transparency and objectivity of evaluated plant health measures.

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Chapter 5

Economic Justification for Quarantine Status – the Case Study of *Candidatus* Liberibacter Solanacearum in the European Union

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Abstract

International agreements on plant health and trade require that regulating a pest should be justified by economic impact assessment. Economic impact assessments are usually qualitative, weakening the objective and transparency of the regulation decision. Here, we assess the potential economic impacts of the invasion of the plant pathogenic bacterium Candidatus Liberibacter Solanacearum into the European Union in order to economically justify a decision on the pest quarantine status. Direct economic impacts resulting from yield loss in potato and tomato are computed using partial budgeting at regional scale, while total economic impacts on the potato and tomato markets are computed using partial equilibrium modelling at the EU scale. The annual direct impacts at the most likely infestation level on infested potato and tomato producers are estimated at 222 million euros for the whole EU. Uncertainty analysis showed a distribution of foreseeable annual impacts with a 5 percentile of 192 million euros, and a 95 percentile of 512 million euros. Increased market prices of potato and tomato that result from reduced supply increase profits for non-infested producers and compensate in part for the production losses of infested producers. Consumers pay for this mitigation of impacts on producers. The expected negative impact on societal welfare at the most likely infestation level is less than the estimated direct impacts, viz. 114 million euros per year. The potential economic impacts of Candidatus Liberibacter Solanacearum into the European Union are demonstrably of major importance. Therefore, a decision to categorize Candidatus Liberibacter Solanacearum as a quarantine pest is supported.

Keywords:

Economic impact assessment – quarantine status – pest risk analysis - Candidatus Liberibacter Solanacearum

5.1 Introduction

International agreements on plant health and trade require that regulating a pest should be justified by economic impact assessment. European plant health regulations is organized through the legislative act of the European Union (EU) Council Directive 2000/29/EC (Anonymous, 2000). The Directive lays down measures designed to protect Member States against the introduction and spread of organisms harmful to plants and plant products from other Member States or third countries (EU, 2012). These protective measures can only be taken against organisms listed in Annexes I and II in the directive. Annex I list the banned organisms while Annex II list plants and plant products that could be contaminated by the relevant harmful organisms listed in that part of the Annex (Anonymous, 2000). Currently, 110 harmful organisms in Annex I and 138 harmful organisms in Annex II are listed and regulated to prevent introduction and spread within EU.

Candidatus Liberibacter Solanacearum (CLS) is a newly discovered species described in 2008 within the genus '*Candidatus* Liberibacter' (Liefting, 2008). CLS is phloem-limited, Gram-negative, unculturable bacteria (Liefting et al., 2009b) that infects a variety of species within the Solanaceae including potato (*Solanum tuberosum*), tomato (*Solanum esculentum*), pepper (*Capsicum spp*.), tamarillo (*Solanum betaceum*), chilli (*C. frutescens*) and Cape gooseberry (*Physalis peruviana*) (Hansen et al., 2008; Liefting et al., 2008a; Liefting, 2008; Liefting et al., 2009a; Munyaneza et al., 2009b; Munyaneza et al., 2009a; Liefting et al. 2009b; Liefting et al., 2008b).

CLS causes severe damage, in terms of yield and quality losses in host crops in its current area of distribution (i.e. USA, New Zealand, Mexico and central America) (Munyaneza et al., 2007; Liefting et al., 2008a). CLS has been found associated with the zebra chip disease in potatoes (Munyaneza et al., 2007). The disease is of great importance and has been reported since 1994. CLS is also associated with other significant tomato, *Capsicum* and tamarillo diseases (e.g. permanent yellow of tomato; Guttierez et al., 2009). For instance, in Texas, the annual potato yield loss due to CLS was estimated at 33 million dollars (equivalent to 25 million euros) (CNAS, 2009). In New Zealand, the annual potato losses due to CLS was estimated at 50 million NZD (equivalent to 30 million euros) (Berry et al., 2010).

CLS is transmitted by the leaf psyllid, *Bactericera cockerelli* (Hemiptera, Triozidae), which feeds on Solanaceous plants, especially tomato and potato (Lin et al., 2009b;

Munyaneza, 2009b). CLS has not been shown to be transmitted by seeds or mechanical means (Henne et al. 2010a). To date, CLS has not been detected outside the area of distribution of *Bactericera cockerelli*, indicating that the psyllid vector is the exclusive vector of the bacterium (Morris et al., 2009).

The bacterium and its vector have not been detected yet in the EU. In 2010, a different haplotype (i.e. a combination of DNA sequences at adjacent locations on the chromosome that are transmitted together) of CLS was found on carrots in Finland, transmitted by the carrot psyllid *Trioza apicalis* (Hemiptera, Triozidae) (Munyaneza et al., 2010, Nelson et al., 2011). However, *Trioza apicalis* does not feed on solanaceous plants, limiting its impact for further spread of CLS within the European community.

Based on International Standards on Phytosanitary Measures (ISPM), a procedure has been set by the European Commission to notify findings of organisms not yet listed in the Annexes of Council Directive 2000/29/EC. In case of a new notification of a harmful organism, a risk assessment should be initiated to assess the risk of the new organism (Knapic, 2007). If the evaluated risk is considered of major importance, phytosanitary measures will be applied. The recent findings of CLS in America and New Zealand suggest that the European Community may need to take action to prevent the introduction of the complex, CLS and its vector *Bactericera cockerelli*, into the European community territory.

The objective of this paper is twofold. The first objective is problem oriented: to estimate the economic impacts of CLS assuming a hypothetical introduction and spread of CLS and its vector *B. cockerelli* to Europe in order to provide the economic basis for a decision on the pest quarantine status. The second objective is methodological. As little information is available on the effect of spatial resolution and economic assessment method on the result of economic impact assessments, this study compares the results of different spatial and economic techniques to arrive at an evidence-based quantification of economic impacts.

5.2 Materials and Methods

The bio-economic model for assessing the impacts of CLS and its vector *B. cockerelli* to the European potato and tomato integrates four types of information: (1) expected spatial distribution of the disease, (2) effect of climate on yield loss, (3) distribution and value of hosts, and (4) market mechanisms affecting economic impact through the supply-demand interactions and price changes.

5.2.1 Host and climate

Climatic and host data on potato and tomato are extracted from the SEAMLESS database (Van Ittersum et al., 2008; Janssen et al., 2009). Within this database, data are available at various levels of spatial resolution, which are (sorted from coarse to fine resolution) the levels of environmental zones (EZ), climate zones and agri-environmental zones (AEZ) (Figure 5.1). The EU is subdivided into 12 EZs that represent a broad climatological/environmental subdivision of Europe. The climate zones are defined as unique combinations of NUTS (Nomenclature of Territorial Units for Statistics, source: EuroStat) regions and EZs. There are 560 climate zones. The climate data (e.g. temperature from 1982 to 2006) in the SEAMLESS database are obtained from the European Interpolated Climate Data (EICD) (JRC, 2008), which are available at the resolution level of the climate zones. The AEZs are the intersection of the NUTS regions, EZs and soil types. There are 3,513 AEZs in the EU (Figure 5.1). Host data in SEAMLESS are imported from the Farm Accountancy Data Network dataset (FADN) (EC, 2008), providing data on host physical production in tonnes and value of this production in Euros at the AEZ level for the EU-25 (Figure 5.2). The spatial distribution of the assets at risks is determined by combining the spatial information on climate suitability for CLS disease expression and host distribution. Spatial integration is conducted at two levels of resolution, i.e. coarse resolution (EZ) and fine resolution (AEZ), to study the impact of spatial resolution level on the economic assessment. ArcGIS Desktop 9.3 is used to integrate the spatial data layers and to present the resulting economic impacts spatially.

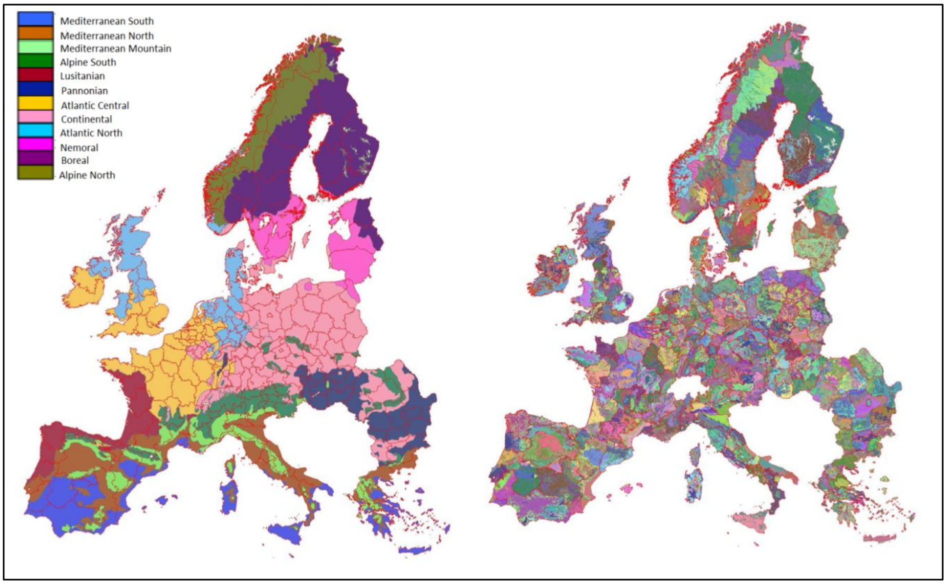

Figure 5.1 The Environmental Zones (EZ – left panel) representing a broad climatological / environmental subdivision of Europe and Agri-Environmental Zones (AEZ-right panel) representing a combination of the NUTS regions, Environmental Zones and soil types based in Carbon content in topsoil (Source: Hazeu et al., 2010).

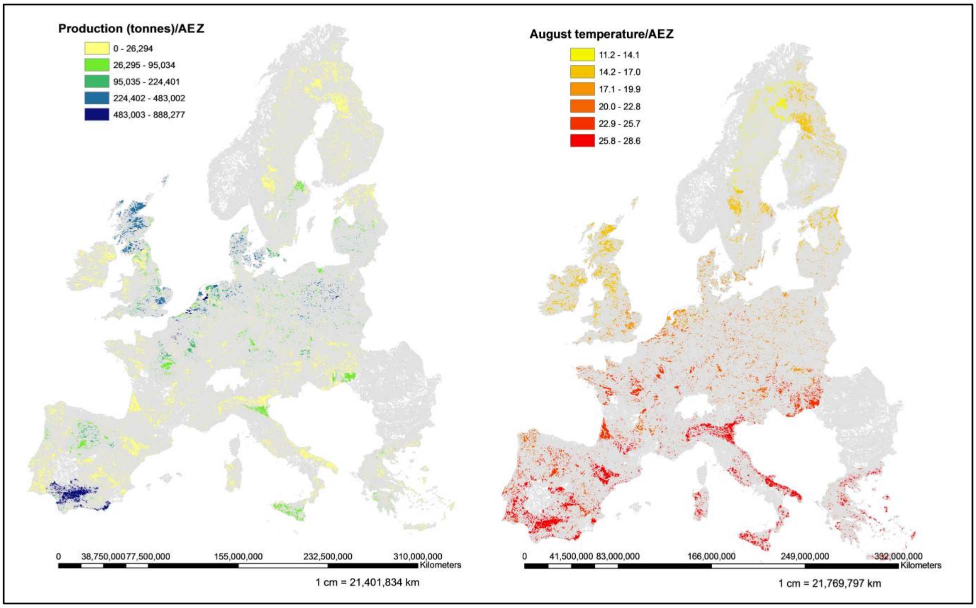

Figure 5.2 Potato production (left panel) and mean august temperature (right panel) of the endangered areas at AEZ level.

5.2.2 Potential pest spread

The potential spatial distribution of CLS was determined by eliciting the expected infestation level (proportion of infected potato and tomato plants) in each environmental zone in an expert elicitation workshop (Table 5.1). The workshop was a part of the European and Mediterranean Plant Protection Organization (EPPO) pest risk analysis (PRA). Eight experts, representing the EPPO expert working group, were selected by EPPO to conduct the PRA. During the workshop, there was opportunity for interaction among the experts so that they fully understand and agree upon the problem at hand.

Table 5.1 Expected infestation level of Candidatus Liberibacter Solanacearum elicited from experts

Scenario Environmental zone	Best case	Most likely	Worst case
Mediterranean South	1%	10%	40%
Mediterranean North	1%	10%	40%
Mediterranean Mountain	1%	10%	40%
Alpine South	0%	0.15%	0.70%
Lustanian	0%	0.15%	0.70%
Atlantic Central	0%	0.15%	0.70%
Atlantic North	0%	0.15%	0.70%
Panonian	0.15%	3.75%	15%
Nemoral	0.15%	3.75%	15%
Contenintal	0.15%	3.75%	15%
Boreal	0.15%	3.75%	15%
Alpine North	0.15%	3.75%	15%

The potential infestation level will depend on the ability of the bacterium and its vector to establish in the European continent. During the PRA the experts concluded that the bacterium can survive over a wide range of temperatures as shown from its current distribution. For the vector, given its current distribution in the Americas and New Zealand, it is thought that *B. cockerelli* would be able to establish and overwinter outdoors in Southern, Weastern and Central Europe. It is unlikely that *B. cockerelli* would establish in the cold northern regions of Europe (e.g. Scandinavian regions). However transient populations could occur there after migration from southern Europe as indicated by the immigrant populations in Canada originating from southern USA (Ferguson et al., 2003). Therefore, the Mediterranean basin is expected to be the most suitable because of the climate and the cropping pattern (i.e.

availability of hosts all year round). In the northern and eastern part of Europe, only transient populations may occur in the field.

To elicit the infestation level, the experts assumed a hypothetical situation in which the CLS and its vector are introduced into the EU through one of the possible pathways (i.c. association of CLS and its vector with imported commodities such as plants for planting and fruit of *solanaceous* plants). As a result of spread through the vector or by human activities (e.g. vegetative reproduction), the infestation level is expected to increase over time. The experts assumed a five years interval to reach a steady state situation where the infestation level of CLS remains constant. The experts collectively quantified the uncertainty of the future infestation level per EZ using a triangular distribution. Within this distribution, the most likely value represents the most likely infestation level while minimum and maximum values are those infestation level values that according to their expertise bracket the range of possible outcomes of the hypothetical invasion. This distribution is used in stochastic analysis (see below).

5.2.3 Economic impacts

The economic impact of CLS infestation consists of direct and indirect impacts. Together they constitute the total economic impact. Direct impacts are directly related to the production process and include yield losses and additional production costs (e.g. costs of crop protection). They are calculated by partial budgeting (Soliman et al., 2010). In the partial budgeting analysis, the spatial distribution of losses within EU is evaluated both at a coarse (EZ) and fine level of resolution (AEZ). The two modelling results are compared to assess the importance of spatial resolution in the analysis. Indirect impacts are generated downstream from the production process itself, and are related to changes in prices, producer and consumer responses to price changes, and effects on international trade. The total economic impact is calculated by partial equilibrium modelling (PE), where changes in production volume and cost of production are integrated with changes in the market. The total economic impact is the change in social welfare, and has two components: i) the change in producer surplus and ii) the change in consumer surplus (Soliman et al., 2010). In this study, the applied partial equilibrium analysis estimates the change in social welfare at the EU level.

5.2.3.1 Direct impact

CLS related yield loss depends on temperature (Munyaneza, 2010). Given Workneh et al. (2010) yield loss is expected when mean August temperature is higher than 15^{o}C. Yield loss by CLS increases with temperature. For example, Workneh et al. (2010) observed that "tuber symptoms develop at a much slower rate than at higher temperatures". Furthermore, based on laboratory experiments on potato, Munyaneza (2010) concluded that CLS is a heat sensitive bacterium. A similar response to high temperature has been observed in tomato (Liefting et al., 2009a). Based on this information, we parameterized a linear relation between temperature and yield loss due to CLS. Uncertainty within the temperature-yield loss relationship was accounted for in the stochastic analysis (see section 5.2.4 below).

Munyaneza (2010) stated that "the optimum temperature for CLS development in potato plants was estimated at approximately 28°C". The maximum yield loss is 93% (Munyaneza et al., 2008). This high yield loss percentage is realized at 28^{o}C which is the highest mean August occurring in Europe. Based on the linear relationship assumption, maximum yield loss and the threshold, an interpolation has been made to determine the potato yield loss per each degree centigrade resulting into 7.15% increase for each degree of mean August temperature above the threshold of 15^{o}C.

For tomato we use the same relationship between temperature and yield loss as in potato. We use the ambient mean August temperature if it is above 20^{o}C but we still use a temperature of at least 20^{o}C for the damage calculation if mean August temperature is less than 20^{o}C because tomatoes are often grown as protected crops in glasshouses with an average temperature of 20^{o}C (Hurd & Graves, 1984). The yield loss for tomato is 32.5% at a temperature of 20^{o}C and will increase by 6.5% per degree increase in average temperature above 20^{o}C, reaching 84.5% (Hansen et al., 2008) at 28^{o}C. Damage in the infested area in each zone is obtained by multiplying the value of production in infested areas with the temperature dependent yield loss percentage and the incidence of CLS.

For the moment, there is little experience with disease control, and it is likely that it will be essentially targeted against the psyllid vector or involves the use of resistant cultivars. Therefore, an infestation by CLS will most likely result in an increase in cost of production. However, due to lack of knowledge on expected additional control costs, we account only for yield losses in the PB analysis.

5.2.3.2 Total economic impact

The PE analysis extends the impact scope from producer to the whole society by including impacts on consumers. This is determined by measuring the differences in equilibrium price and quantity, and change in welfare before and after pest outbreak (Soliman et al., 2010). In this study the PE model of Surkov et al. (2009) is applied. Equations of the PE model are given in Chapter 3 (section 3.2.3.2). This model distinguishes two market regions: the European Union (EU) and the rest of the world (ROW). In the model it is assumed that (1) crop products in the EU and in ROW are perfect substitutes and their respective prices differ only in the transportation costs and tariffs, and (2) the domestic market for the potentially affected commodity is perfectly competitive, implying product homogeneity. The PE model estimates the total annual market impacts by assessing effects on both producers and consumers. Data for the potato and tomato market were obtained from FAO statistics (FAO, 2009). The PE inputs for the CLS analysis are presented in Table 5.2.

Table 5.2 Input parameters for the partial equilibrium model.

Parameter	Potato	Tomato
European production (M tonnes)	59.1[a]	16.2[a]
European consumption (M tonnes)	58.4[b]	16.3[b]
European producer price (€/tonne)	113[c]	301[c]
World price (€/tonne)	119[c]	332[c]
Supply elasticity	3.2[c]	0.5[d]
Demand elasticity	-0.5[e]	-0.62[f]
Excess demand (Export) elasticity	-3.4 [b]	---
Excess supply (Import) elasticity	---	4 [b]

[a] *FAO (2009)*
[b] *own calculation*
[c] *Janssen et al (2009)*
[d] *Chern and Just (1978)*
[e] *De Gorter et al. (1992); Bunte et al.(2009)*
[f] *Yen et al. (2004); Balestrieri (1983)*

5.2.4 Assessment approaches

To estimate the economic impacts due to the spread of CLS and its vector, the following analyses were performed;

- *Deterministic evaluation of direct economic impacts by level of spatial resolution.*

  PB was used to evaluate the direct impact at a coarse (EZ) and fine (AEZ) resolution. The deterministic setting of the expected level of infestation was based on the most likely infestation level estimated by the experts at the EZ scale. The deterministic rate of expected yield loss was defined by a linear function increasing with temperature (section 5.2.3.1). In the coarse resolution analysis, temperature data was up-scaled by averaging over the climatic zones in each EZ, while production data on host crops (potato and tomato) were up-scaled by summing over the AEZs in each EZ. For the fine resolution analysis, temperature data at the AEZ level was obtained from the source zone at the climatic level by direct assignment, while the host data was kept at the original AEZ level resolution. The level of infestation was considered to be homogeneous over the EZs.

- *Deterministic evaluation of the total economic impact at EU level.*

  Total economic impact was estimated by the application of the PE model (section 5.2.3.2), using the deterministic settings as presented in Table 5.2 and the settings for expected infestation level at EU level and yield loss as described above. The potential infestation at EU level is calculated as a weighted average over the estimated infestation at EZ level using the relative production volume per EZ as weight factor.

- *Stochastic evaluation of the direct impact.*

  The impact of the uncertainty with respect to infestation level and yield loss relationship on the resulting direct economic impacts was evaluated by the use of stochastic simulation (Monte Carlo simulation by 1,000 replications) of the PB model at EZ level. To account for uncertainty in the level of infestation, direct economic impacts were stochastically determined from the elicited triangular distribution of incidence (section 5.2.2). The uncertainty in yield loss was simulated by drawing the yield loss percentage from a triangular distribution with a lower bound of 7.15% and an upper bound of 93% (Munyaneza et al., 2008) for potato, and a lower bound of 6.5% and an upper bound of 84.5% (Munyaneza et al., 2008) for tomato at the EZ scale as shown in section 5.2.3.1. For both crops, the most likely value was calculated on the basis of the indicated linear relationship with temperature based on the mean August temperature at EZ level. Yield loss percentage was drawn from the triangular distribution independently for each EZ.

5.3 Results

Results of the deterministic analysis are given in paragraphs 5.3.1. while results of the stochastic analysis are given in paragraphs 5.3.2

5.3.1 Deterministic analysis

5.3.1.1 Direct impact

Analysis of the impacts at the producer level showed that the high risk environmental zones are the Mediterranean South, the Mediterranean North and the continental zone for potato as well as tomato (Table 5.3). The yield losses estimated at the coarse resolution were 75 M€ for potato, representing 1.12% of total potato production, and 147 M€ for tomato, representing 3% of total tomato production, Yield losses at the fine resolution were estimated at 80 M€ for potato, representing 1.19% of total production, and 177 M€ for tomato, representing 3.6% of total production. The differences between coarse and fine resolution follow from the aggregation procedure. Averaging temperatures over large areas as in the coarse resolution analysis reduced the proportion of areas with higher temperatures, resulting in slightly lower yield loss estimates.

Table 5.3 Annual yield losses estimated at the Environmental zone level

Climatic zones	**Potato**		**Tomato**	
	M€	**%**	M€	**%**
Continental	22.7	1.34	5.97	0.12
Pannonian	1.6	1.88	0.47	0.01
Boreal	0.0	0.00	0.40	0.01
Alpine South	0.02	0.05	0.01	0
Mediterranean North	15.7	6.44	34.77	0.71
Lusitanian	0.04	0.06	0.06	0
Mediterranean Mountains	4.0	5.72	5.12	0.1
Atlantic Central	1.4	0.05	0.83	0.02
Nemoral	0.7	0.54	0.24	0
Alpine North	0.00	0.00	0.00	0
Mediterranean South	28.4	7.15	98.97	2.02
Atlantic North	0.4	0.03	0.14	0
Total	75	1.12	146.98	3

5.3.1.2 Total economic impact

The total economic impact estimated by PE was lower than the direct impacts estimated by PB (Table 5.4) because yield losses are large enough to cause an increase in market prices that reduces direct impacts on producers more than it increases the negative impact on consumers. The surplus of infested potato producers is decreased by 38 M€ and of infested tomato producers by 71 M€. Non-infested producers of potato see their surplus increase by 42 M€ and producers of tomato by 94 M€, as a result of higher market price. Consequently, due to the higher market prices, consumers experience a decrease in welfare of 43 M€ with respect to potato and of 98 M€ for tomato, even after accounting for the lower consumption (a reduced demand). The total economic impact for producers and consumers together amounts to 114 M€, with the potato market accounting for 39 M€ loss and the tomato market for 75 M€.

Table 5.4 Change in social welfare estimating by partial equilibrium modelling at the EU level – Annual impact (M€)

	potato	**tomato**	**Total**
Consumer	-43	-98	-141
Producer-infested	-38	-71	-109
Total losses	**-81**	**-169**	**-250**
Producer-not infested	42	94	136
Total (Net)	**-39**	**-75**	**-114**

5.3.2 Stochastic analysis

The uncertainty analysis demonstrated a range of impacts (Figure 5.3). The mean, mode, and median of the annual direct impacts were estimated at 338 M€, 274 M€ and 329 M€ over the whole EU, respectively. The standard deviation is estimated at 97 M€ while the 5 percentile represents 192 M€/year and the 95 percentile 512 M€/year. This variability in the calculated impacts was due to the uncertainties in yield loss and infestation level that were accounted for. The resulting potential impacts had a skewness of 0.47 (small positive skew) and a kurtosis of 2.8 (excess kurtosis = 2.8 – 3 = -0.2), indicating a distribution of losses that is close to normal (skewness and excess kurtosis of 0).

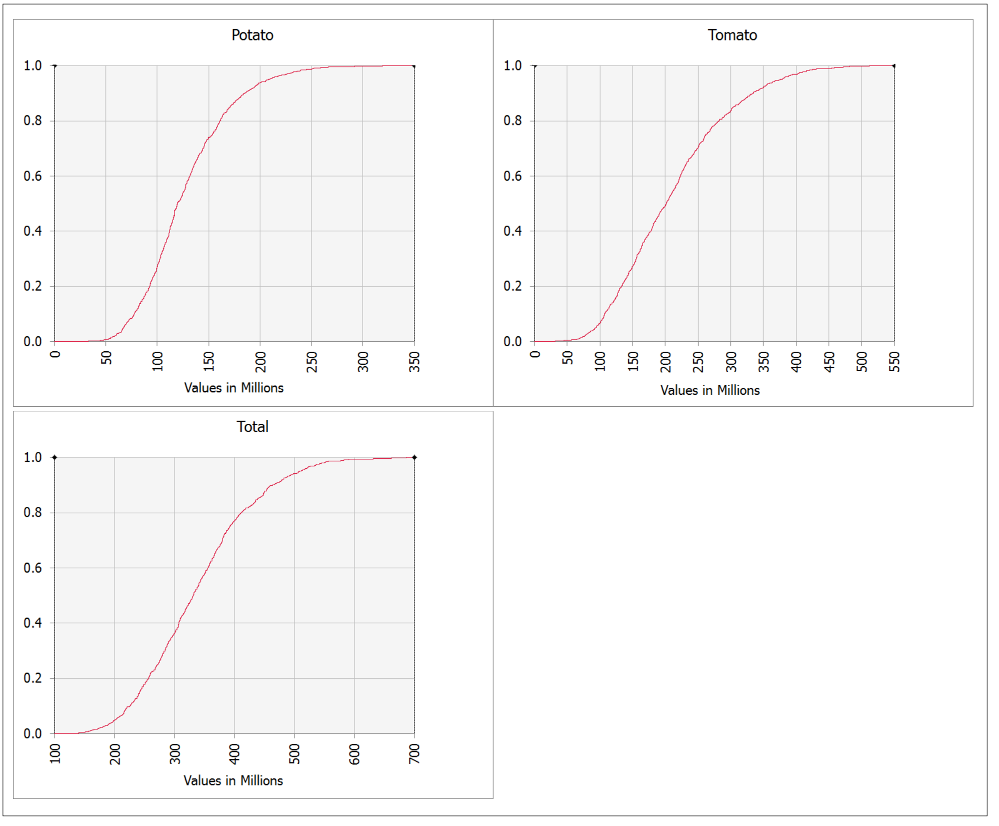

Figure 5.3 Uncertainty analysis of the direct economic impact, estimated with partial budgeting. For potato the mean impact is 127M€, the 5 percentile is 68M€, and the 95 percentile is 199.7M€ (upper left panel). For tomato, the mean impact is 211 M€, the 5 percentile is 94.1 M€, and the 95 percentile is 377.7M€ (upper right panel). The mean total impact is 338 M€, the 5 percentile is 192 M€ and the 95 percentile is 512 M€ (lower left panel).

5.4 Discussion

The applied economic impact assessment demonstrated a significant annual direct impact of a CLS invasion on potato and tomato production based on a mean value of 338 M€. Uncertainty analysis showed wide boundaries of 192 - 512 M€ (5-95 percentile) arising from uncertainty with respect to the potential infestation level and expected yield losses across Europe.

In the US, a pest is considered of ‘major’ economic impact and in need of regulation if the overall magnitude of annual economic change exceeds a federally-defined threshold of $100 million per year (Westbrooks, 1998; Pimentel et al., 2000; NISC, 2001). Considering this threshold, and taking into account that the value of agricultural production in Europe exceeds that of the US (360 billion euros as compared to 307 billion euros in 2007; Schnepf, 2010; Eurostat, 2012), the calculated direct economic impacts would justify CLS regulation.

The estimated indirect impact on consumers and infested producers evaluated by PE was higher than the direct impact estimated by PB, but if we consider also the impact on the non-infested producers, then the net impact is lower than that estimated by direct impact. Nevertheless, the resulting net negative impact is still high enough (114 M€/year) to consider CLS as a pest of major economic importance.

The economic direct impact assessment was conducted at two resolution levels, coarse and fine. While there was a difference between the two resolutions in the resulting impacts (5 and 30 M€ for potato and tomato respectively), it does not affect the final decision on the need for pest regulation. Therefore, conducting the analysis at a fine resolution or using advanced economic techniques (e.g. PE) just for making a decision on the pest quarantine status may not be justified (i.e. the additional insight in the impacts does not outweigh the efforts and time spend). In addition, in case of economic assessment of novel pests, uncertainty on the pest biology is quite high. It is uncertain whether using advanced geographical and economic techniques would reduce the biological and economic uncertainties. Therefore, a coarse level of analysis appears to be fit for purpose.

The common practice of economic impact assessment conducted to make a decision on the quarantine status of new pests is usually limited to literature review of the documented economic impacts of the pest in its current area of distribution (Macleod et al., 2002). Few exceptions exist in which quantitative economic analysis was conducted at the EU level to support the regulation decision. One such example is the analysis on Karnal Bunt (*Tilletia indica*) (Sansford, 1996; Sansford et al., 2006; Brennan et al., 2004). The common practice of qualitative assessments is sometimes sufficient to support the decision for the quarantine pest status on a fit for purpose basis. Nonetheless, for certain cases, where the potential economic impacts are ambiguous due to uncertainties, more detailed quantitative estimates may be required. The quantitative assessment will show the range of the expected impacts and the proportions of the replications resulting in higher impacts than the threshold that define the pest as of major economic impact. This quantitative analysis will lead to more transparent and objective justification of the quarantine status of the pest and accordingly a better position in any trade dispute. Moreover, a decision on a pest status is most likely followed by a decision on the most appropriate phytosanitary measure if the pest is classified to be of major importance. This stage usually requires a detailed quantitative analysis. As such, quantitative assessment strengthens the scientific grounds for making decisions on the regulation of pests.

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Chapter 6

Quantitative Economic Impact Assessment: When is it Worth the Effort?

Soliman T., Mourits M.C.M., Oude Lansink A.G.J.M., van der Werf W., 2012. Quantitative economic impact assessment: When is it worth the effort?, s*ubmitted to* Journal of Applied Ecology.

Abstract

According to the International Plant Protection Convention and the World Trade Organization Agreement on the Application of Sanitary and Phytosanitary measures, any measure against the introduction and spread of new pests must be justified by a science-based pest risk analysis. Economic impact assessment is usually made using a qualitative approach, based on classifying the size of impact into five categories, from "minimal" to "massive". Whilst the qualitative approach may be adequate in many instances, it may lack transparency and demonstrable objectivity. A quantitative approach for economic impact assessment may improve transparency and strengthen the justification for measures, if taken, but requires additional work, and it requires specific data and models. This paper, first, clarifies the data and models needed to conduct a quantitative economic impact assessment in support of a decision on pest quarantine status or to justify management measures. Second, it compares the strengths and weaknesses of the qualitative and quantitative approach. It is concluded that a quantitative approach is preferable if the expected economic impact is ambiguous when using a qualitative approach, and when there are sufficient resources to conduct the analysis.

Keywords

Quantitative impact assessment - Qualitative impact assessment – Pest invasion - Data requirements – Economic modelling.

6.1 Introduction

According to the International Plant Protection Convention and the World Trade Organization Agreement on the Application of Sanitary and Phytosanitary measures, plant health regulation is only to be used where technically justified and not to protect an industry from competition (FAO, 1995). Plant health regulations thus have to be applied in a transparent and non-discriminatory manner. A science-based pest risk analysis (PRA) provides the rationale for determining appropriate plant health regulation for a specified PRA area. Economic impact assessment plays a key role within the PRA process. A PRA could be initiated upon finding a new harmful organism either within or outwith the PRA area to determine whether the organism qualifies as a quarantine pest or whether measures for eradication or containment are required, respectively. If it is verified that the pest has a potential to pose unacceptable impacts, the most appropriate phytosanitary measure have to be defined based on the expected cost and technical effectiveness of the available measures.

The International Standard for Phytosanitary Measures (ISPM) 11 states that "*Pest risk assessment needs to be only as complex as is technically justified by the circumstances*" (FAO, 2004). This rule is critical because it gives the risk analyst the freedom to choose the complexity level of his assessment according to the level of uncertainty and the available resources.

Economic impact assessments are usually made using a qualitative approach (EPPO, 2011; EFSA, 2010). The qualitative approach is following a decision support scheme according to ISPM 11 developed by the International Plant Protection Convention (IPPC) (EPPO, 2011). The qualitative scheme consists of a logical sequence of questions that can capture the expert opinion. For each question the expert provides his answer by selecting a score (within five levels). The questions concern the size of the impact without control, the efficacy of control, the costs of control, and the costs of pest invasion, including the potential effects on international trade (EPPO, 2011; ACIA-CFIA, 2008; USDA, 2000; Biosecurity Australia, 2007). Although this qualitative approach, based on classification, is helpful to classify impacts, the status of the outcome is quantitatively not well defined. It has therefore some shortcomings in justifying measures, and entails weakness in case of trade disputes.

There is a growing awareness that quantitative economic impact assessment is essential to provide a better transparency and objectivity of the quarantine regulation (Sansford, 2002). Conducting quantitative economic impact assessment with the aim of supporting a decision on pest quarantine status or management measures requires subject specific information in terms of data and models. ISPM no. 11 requires general guidelines on the impacts that have to be taken into account (i.e. direct and indirect impacts) and analytical techniques for a quantitative economic impact assessment (i.e. partial budgeting, partial equilibrium modelling and computable general equilibrium modelling). However, risk analysts are usually not trained as economists, and they need guidance with respect to the required data and economic models for conducting economic impact assessment. This paper fills this gap in the literature. The objective of the paper is twofold: first, to compare the strengths and weaknesses of a qualitative and quantitative approach when conducting an economic impact assessment. Second, to clarify the data and models needed to conduct a quantitative economic impact assessment in support of a decision on pest quarantine status or management measures.

The remainder of the paper is structured as follows. First, this paper describes how the qualitative approach is applied to assess the economic impacts in PRA. This is followed by a presentation of the quantitative approach and its data requirements and economic models. The final section discusses the strengths and weaknesses of quantitative and qualitative approaches and presents the implications for practitioners.

6.2 Qualitative economic impact assessment

In Europe the EPPO PRA scheme is used to perform a qualitative assessment of the pest risk (EPPO, 2011). It provides a decision support scheme based on ISPM 11 developed by the International Plant Protection Convention. Similar schemes are used in other parts of the world. For instance, in the UK (DEFRA, 2005), Canada (ACIA-CFIA, 2008), the USA (USDA, 2000), Australia (Biosecurity Australia, 2007) and New Zealand (Biosecurity New Zealand, 2006).

The EPPO scheme consists of a logical sequence of questions addressing all elements of ISPM 11. The scheme is designed as a binary decision tree to eliminate quickly organisms that do not qualify as potential quarantine pests. The PRA section dealing with the economic impact assessment consists of 6 questions. The first two questions concern the size of the expected impact with and without control measures. The third question addresses the efficacy of the existing control measures (excluding the phytosanitary measures). The fourth question addresses the expected increase in production costs (including control costs), and the last two questions deal with the expected change in consumer demand and the expected losses in the export market. In the EPPO scheme, impacts are assessed on a five-point ordinal scale (minimal, minor, moderate, major or massive) based on the evidence and expert’s experience. These qualitative assessments are justified by detailed text. Due to the difficulty of creating generic rating guidance for the ordinal scale, clarifying notes are attached to the questions. These notes explain how the risk analyst can select the proper score with regard to the magnitude of the impact. The notes, for instance, provide examples which the risk analyst can use as a reference when making his assessment.

For example, in 2004, a PRA has been conducted on Tomato chlorosis virus (ToCV). In the economic impact assessment section, it was concluded that significant damage (i.e. high impact) in tomato fields and glasshouses is expected and that severity of symptoms and damage will vary according to the cultivar. Furthermore, the experts expected that ToCV would increase the price of tomatoes in case substantial losses occur causing potential changes in producer supply and subsequently consumer demand. Regarding potential trade, they concluded that the extent to which this would affect export markets from or within the EPPO region is unclear (i.e. highly uncertain) (EPPO, 2012a).

Since 2006, the starting year of conducting PRA at the EPPO scale, 11 PRAs were conducted for insects and mites, two for nematodes, one for a fungus, one for a bacterium, one for a virus and five for invasive plants. Eight PRAs are currently under development. A list of the finalized PRAs conducted by EPPO can be found on their website (EPPO, 2012b).

The qualitative schemes used in other parts of the world (mentioned above) are similar to the EPPO scheme. In general, all these schemes are targeting all types of plant pests except for the Australian and New Zealand schemes. The generic Biosecurity Australia and Biosecurity New Zealand schemes are generally not used for pest plants because these countries have built specific risk assessment schemes for weeds.

6.3 Quantitative economic impact assessment

To perform a quantitative economic impact assessment, a calculation framework is required to integrate information on assets at risk with information on the potential area of establishment, the spread, the potential damage, and the economic consequences to producers, consumers, and import and export. Soliman et al. (2012a) developed a generic bio-economic framework for assessing economic impacts that contains the following modules (Figure 6.1): (1) a climate module describing the climate suitability for the pest species, (2) a host module describing the spatial distribution of the hosts, (3) a spread module predicting the potential spread of invasive species, (4) a climate based host damage function and (5) an economic impact module defining the models to determine producer and market level impacts. To develop this framework, the risk analyst will need input data and economic models. The below sub-sections illustrate these requirements in detail.

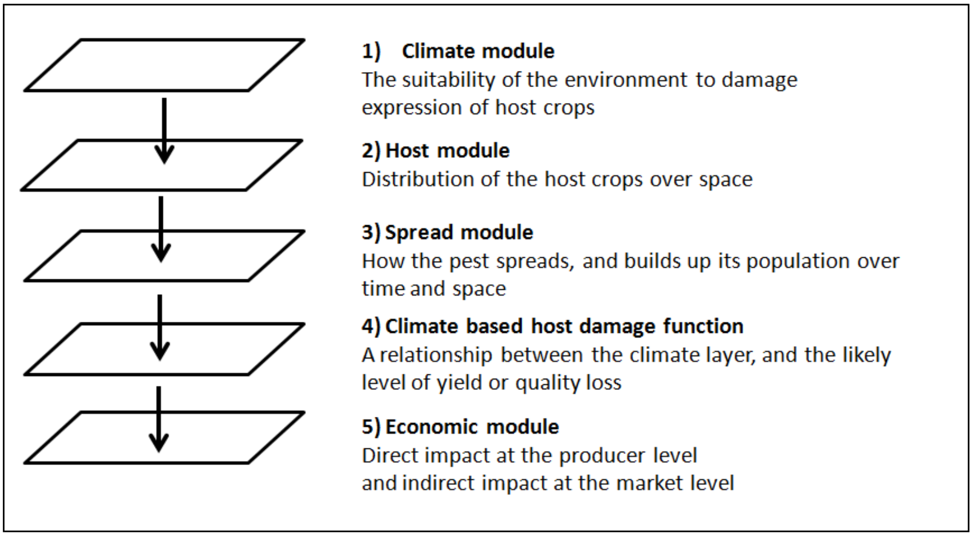

Figure 6.1 Bio-economic framework to assess the economic impacts using a quantitative approach.

6.3.1 Data availability

Data availability is of primary importance in determining the extent to which the quantitative economic impact assessment can be applied. According to the level of detail of the assessment, data requirements can vary. Critical data elements include climate data, host crops, potential pest distribution, pest spread and market data. Host and climate are usually spatially indexed data while market data are aggregated data on regional, national or continental level.

Availability and accessibility of these primary data differ (Table 6.1). Lack of data may arise because: 1) no data are collected on a particular topic, 2) data are only partially available due to confidentiality reasons, restricted access, language barriers or cost, 3) data exist but cannot be used due to low quality of the data, as data are too aggregated or out of date and 4) data exist but are limited to particular areas of the EU (Kenis et al., 2010). For example, host data are difficult to obtain while climate and market data are freely available. In addition, these data elements required for the analysis are rarely available at a common resolution. Therefore, rescaling (up and down scaling) and re-projecting the data to one common scale is usually required. If the data are integrated at a fine resolution, then a sophisticated assessment could be conducted and vice versa.

Table 6.1 Availability of input data needed for conducting a pest risk analysis

Type	Examples for data sources	References	Availability
Crop	1. Farm Accountancy Data Network dataset (FADN) 2. MacGill dataset, Canada 3. European Forestry Institute (EFI)	1. FADN, 2012 2. McGill, 2012 3. EFI, 2012	□
Climate	4. WorldClim 5. Intergovernmental Panel on Climate Change (IPCC) 6. National Climatic Data Center (NCDC) 7. Köppen-Geiger Climates	4. WorldClim, 2012 5. IPCC, 2012 6. NCDC, 2012 7. Kottek et al., 2006	+
Spread	8. Stochastic invasion models	8. Robinet et al., 2011	-
Market	9. Food and Agriculture Organization of the United Nations (FAOStat) 10. The Statistics Division of the European Union (EuroStat)	9. FAO, 2012 10. EUROstat, 2012	+

\+ High , □ Medium , - Low

- **Climate data**

Climate data are required for calculating the potential geographical distribution of the pest. Furthermore, climate affects the size of yield loss in host crops. Climate data are historical weather observations over space and time such as temperature, precipitation, humidity and evapotranspiration. Climate data are easily obtained as many datasets are in the public domain for academic and other non-commercial use. For instance, the intergovernmental panel on climate change (IPCC, 2012) and the worldClim-global climate (WorldClim, 2012) databases are open access. In addition, other computer-based packages (e.g. CLIMEX and NAPPFAST) include climate data and therefore can also be used (Sutherst et al., 2007; Magarey et al. 2007).

- **Host data**

The distribution of the host crops over space, and its overlap with the potential area of establishment of the pest in relation to climate, is an important determinant of potential impacts. Host data are required to determine the producer level impacts and must provide information on the area, physical production and value of the host crop in addition to information on the plant characteristics (e.g. crop variety, or tree age). Data of host crops, with high economic importance (e.g. potato and tomato for the case of the EU), are present but often not freely accessible. Examples of datasets with information on host crops are the European Forest Institute dataset that represent the distribution of broadleaf, coniferous trees at 1 km^2 resolution (EFI, 2012), McGill University crop dataset that contains spatial data on the harvested area and yields of 175 crops at 5 min resolution (McGill, 2012) and the Farm Accountancy Data Network (FADN, 2012). Data on hosts of minor economic importance are often more difficult to obtain or are not available at all (Kenis et al., 2009).

- **Potential pest distribution**

Spatially explicit data on host crops, pest spread and climate are combined to determine the endangered area, i.e. the area where the pest can establish at a given time and cause damage. A relationship between these data layers and the likely level of yield or quality loss should be identified. Pinkard et al. (2010) described a technique for regressing simple qualitative assessments of site suitability for a pathogen. They used historical observations of Mycosphaerella leaf disease damage to convert the relative score of climatic suitability generated by CLIMEX into a severity ranking, ranging from low to high, providing a direct link between risk and impact. Such an assessment can be used for the post-hoc classification of climate suitability for pest impact. Kriticos et al. (2012) regressed measurements of impact for *Thaumetopoea pityocampa* against modelled climate suitability at a number of European sites. The modelled climate suitability was combined with a simple spread model to estimate the present (discounted) value of a hypothetical invasion by this pest.

Pest establishment occurs in the area where the climate is suitable and hosts are present. Combining the host distribution and climate suitable for pest species modules will point to the locations in the PRA area that may harbour the invader. Climatic mapping could be done through programs that model fundamental niche maps (Venette et al., 2010). Examples are CLIMEX (Sutherst et al., 2007; Sutherst and Maywald, 1985) , MaxEnt (Phillips et al., 2006), Artificial Neural Networks (Gevrey and Worner, 2006), NAPPFAST (Magarey et el., 2007), BIOCLIM/ANUCLIM (Nix, 1986; Busby, 1991; Hutchinson et al., 1996) and Environmental Niche Factor Analysis (Hirzel et al., 2002). Based on such available information and programs that model fundamental niche maps, a worst case scenario can be estimated by assuming that the pest is present throughout the whole area of potential establishment. However, to provide more realistic estimates, risk assessors need to take into account the time it takes a pest to invade these areas by using the spread module. For instance, Macleod et al. (2002) assess the potential establishment of the Asian longhorn beetle (*Anoplophora glabripennis*) to hardwood trees in the European community.

Establishment and spread modules can indicate only the endangered areas with relative pest risk. Economic impacts are generated as a result of the spread of the invasive pest and, therefore, the climate based host damage function can relate the abundance of pest to the expected level of damage.

- **Pest spread**

Modelling pest spread in space and time is needed to provide realistic estimates of the materialization of potential economic impacts over time. A spread model provides information on how the pest spreads, and builds up its population over time and space. This information is used in the economic module to determine the yield loss in the impacted area. A spread model could be developed by the risk analyst or data on spread can be elicited from experts. For example, Soliman et al. (2012a) estimated the potential spread of potato spindle tuber viroid at the EU level using expert elicitation. The experts opinion in the quantitative context differ from the qualitative one as they identify distributions of the potential incidence level instead of providing a scale (e.g. low, medium, high) of the incidence level. Both spread modelling and expert elicitation, require substantial time and efforts.

The most commonly used spread models are temporal process models (e.g. population dynamics and temporal spread over cells integrated with impact models). For example, Rebaudo and Dangles (2011) developed an innovative approach through an agent-based model (ABM) combining social (diffusion theory) and biological (pest population dynamics) models to study the role of cooperation among small-scale farmers to share IPM information for controlling an invasive pest. A second group of approaches are spatial process models (e.g. radial range expansion, hybrid of logistic growth and radial rate expansion, and dispersal kernel models) (Robinet et al., 2012). For instance, Liebhold and Tobin (2006) model the spread of gypsy moth in North America using radial expansion to compare the behavior of these models with historical data. Robinet et al. (2011) developed a spread model for pine wood nematode on the European continent using a kernel-based approach. This model was used by Soliman et al. (2012c) to estimate the potential economic impacts of PWN. Moreover, Carrasco et al. (2010) modelled the invasion of the maize pest western corn rootworm in Europe using dispersal kernels and gravity models.

It is usually very difficult or impossible to reliably model the density of a pest population, leading to a spread model that generates only spatial data on presence-absence of the pest. However, population density may be an essential element for determining the level of yield loss. For instance, Carrasco et al. (2012) estimated the yield losses due to a western corn rootworm (WCR) invasion in the UK by calculating the density of WCR in the field and the level of control applied. Pest presence-absence data can only be used to delimit the endangered area. If pest density data cannot be obtained, as is often the case, another data layer is needed as a surrogate for the missing population density data (e.g. climate or any other ecological or cultural factors that are highly correlated with the population density such as irrigation, rotations, and type of soil).

- **Market data**

Market data are required to estimate the market level economic impacts (i.e. changes in social welfare). These data are the domestically produced quantities, the domestically consumed quantities, the traded quantities with the rest of the world, and the corresponding prices of these quantities (i.e. domestic and world prices). These data are freely available in public datasets such as FAOstat (FAOstat, 2012) or EUROstat (EUROstat, 2012). However, these data are often only available at a coarse resolution (i.e. aggregated at the national or regional level) and, comparable to the available host data, only for those hosts which are economically important. Data are also not available for all countries and not for all years. In addition, detailed market information that might be needed in PRA such as production, consumption and the trade of different crop varieties are not available.

6.3.2 Modelling Impacts

The economic impact of a pest infestation consists of direct and indirect impacts. Together they constitute the total economic impact. Direct impacts are directly related to the production process and include yield losses and additional production costs (e.g. costs of crop protection). They are calculated by partial budgeting (Soliman et al., 2010). Indirect impacts are generated downstream from the production process itself, and are related to changes in prices, producer and consumer responses to price changes, and effects on international trade. The total economic impact is calculated by partial equilibrium modelling, where changes in production volume and cost of production are integrated with changes in the market, particularly the feedbacks between prices and supply and demand for product. The total economic impact is the change in total welfare, and has two components: the change in producer surplus and the change in consumer surplus.

The time lines of the spread model and the economic model should be the same, unless it is clear from the first few years of the pest spread that the generated economic impact is high enough to categorize the organism as a quarantine pest. The time line of the spread model will depend on the pest type. The spread model should be long enough to show the potential of the pest to spread and at the same time should be short enough to have a reasonable technical processing time. Soliman et al. (2012c) choose a time period of 20 years for PWN spread in the EU. This time period was sufficient to show the potential spread and to capture a large part of expected economic impacts in order to support decision making.

- **Partial budgeting**

Direct economic impacts are assessed by partial budgeting (PB). The net economic effect of a change will be the sum of the positive economic effects minus the sum of the negative effects (Soliman et al., 2010). To apply this technique, the risk analyst needs to determine first the endangered area, i.e. the areas where hosts can show yield loss, in terms of quantity or quality, and the severity of the yield losses in the endangered area. Direct impacts are the producer level impacts that can be estimated at the farm, field, regional or continental scale. Choice of the most appropriate scale for PB will depend on the resolution of the input data and the expected uncertainty regarding the results. In addition to the yield loss estimation, the risk analyst need to estimate the additional protection costs that the growers will make to mitigate the losses, and whether this mitigation efforts will impact the level of yield loss estimated before. For instance, Macleod et al. (2003) used partial budgeting to estimate the impacts of Thrips palmi in England. In Australia, Sinden et al. (2004) estimated the economic impact of weeds using partial budgeting.

- **Partial equilibrium modelling**

Partial equilibrium modelling (PE) is a technique to estimate the total (direct and indirect) economic impacts. PE is based on defining functional relationships for supply and demand for the commodity of interest to determine the market equilibrium or, in other words, the combination of prices and quantities that maximizes social welfare (Mas-Colell et al., 1995) (Figure 6.2). This figure shows a downward-sloping demand curve, reflecting diminishing marginal utility as consumption increases, and an upward-sloping supply curve, reflecting increasing marginal costs of production. The market equilibrium, where quantity supplied equals quantity demanded, occurs at an equilibrium price of P1 and quantity Q1. The difference between P1 and the demand curve represents how much consumers benefit by being able to purchase the product for a price that is less than they would be willing to pay. This total benefit derived by the consumers, or consumer surplus, is represented by the triangle labelled CS. Since the supply curve represents the marginal variable cost of production, the area below the curve equals the total variable costs. The revenues from sales are equal to price times quantity. Hence the producer surplus, defined as the difference between total revenue and total variable costs is reflected by the triangle PS. Social welfare is defined as the sum of consumer surplus and producer surplus.

PE is used if there are changes in production volumes due to pest establishment, indicating the possibility of indirect impacts. For instance, Hoddle et al. (2003) used the partial equilibrium model to estimate the impact of *Scirtothrips perseae* Nakahara (Thysanoptera: Thripidae) in Californian avocado orchards.

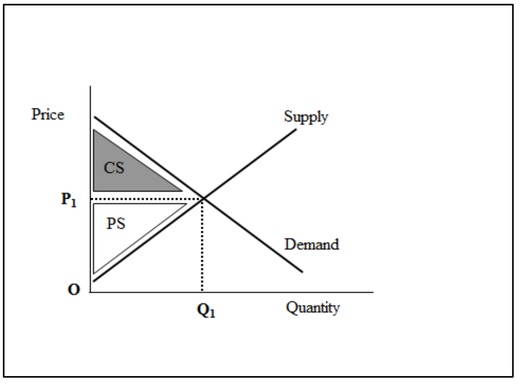

Figure 6.2 Partial equilibrium modelling.

The potential indirect impact could have a positive or negative effect on the quarantine status decision inferred from partial budgeting technique. For instance, Soliman et al. (2012) modelled the impact of *Candidatus* Liberibacter Solanacearum invasion into the EU. They showed that the total impacts (i.e. direct and indirect) estimated by the PE technique were lower than the direct impact estimated by the PB technique. A positive indirect impact could mitigate the negative initial impact estimated by partial budgeting leading to categorizing the pest as non-harmful instead of harmful organism. An example of a positive indirect impact is the situation where the PRA area is an important player in the world trade. A reduction in its world supply could increase the world price to a level that the PRA suppliers could transfer a majority of the initial negative impact to the rest of the world consumers. An example of a negative indirect impact is the situation where an export ban is imposed on the infested territory. This ban will reduce the producers revenues as they may have to sell their products in downgraded markets (e.g. selling seed potato as feed potato).

To apply the PE technique, the risk analyst needs to determine first the shift in the supply side of the market. This shift represents the reduction in the market supply due to pest invasion and is equivalent to the direct loss estimated by the partial budgeting technique. Second, market data are needed (as shown in section 3.1). To construct the PE model, the risk analyst needs to develop a functional relationship between quantity, prices and other related factors to represent the supply-demand market interactions and then use the market data to parameterize these equations. In addition, price elasticities for both supply and demand are needed to estimate the market level impacts. Elasticities are the percentage change in quantity demanded or supplied caused by a one percent change in price (Mas-Colell et al., 1995). Elasticities can be obtained from literature or estimated econometrically (Padilla-Bernal and Thilmany, 2000; Malaga et al., 2001). For example, Richards et al. (2009) conducted a trade-volume and welfare analysis of relaxing SPS regulations on the import of fresh U.S. potatoes into Mexico. The econometric model used in the analysis provides estimates of the elasticities of supply and demand parameters. Russo et al. (2008) estimated domestic own-price, cross-price and income elasticities of demand and estimated price elasticities of supply for various California commodities

The complexity of the partial equilibrium model can vary regarding its spatial scale, number of sectors considered, functional specification of the supply and demand equations, one or multi-level chains and the market structure. Concerning the spatial scale, Binfield et al. (2009), Tabeau and Van Leeuwen (2008) and Gracia et al. (2008) developed a PE model at the country scale (i.e. Ireland, Netherlands and Spain respectively), while Agrosynergie (2008), Garcia-Alvarez Coque et al. (2009), and Guyomard and Le Mouel (2003) developed a PE model at the continental level (i.e. EU). Concerning the numbers of sectors considered in the model, multi-market models offer more accurate ex-ante impact analysis than single-market models by including possible indirect effects such as substitution and complementarity between commodities. Breukers et al. (2008) used a single market partial equilibrium model to quantify export losses resulting from potato brown rot, while Gohin and Guyomard (2000), Sexton and Zhang (2001) and Moro et al. (2002) assumed a multi-market specification for their PE model. Concerning functional specifications , the use of model equations is limited as not all functional forms can be used within the PE model. Commonly used functional forms are the Cobb-Douglas and the Constant Elasticity of Substitution (CES), even though these functional forms impose constraints on the production technology and consumer preferences (Oude Lansink and Thijssen, 1998). In a market-oriented environment, any significant supply change, such as reduction in firm supply due to high pest incidence, will be transmitted to consumers, and a complete picture of an impact assessment, therefore, calls for modelling multiple levels of the chain. Another major sophistication of PE model is to account for market structure across the chain. Market structure affects the ability of stakeholders in the chain to exercise market power and is reflected in the slopes of the supply and demand curves. Failing to model the correct market structure may lead to a wrong estimation of the size of the potential economic impact and its distribution among producers and consumers. For example, the market power of food retailers (e.g. monopoly or oligopoly) can lead to an increased ability of the producers to transfer the impacts to the consumers. Several examples exist for modelling market structure in PE. Requiliart et al. (2008) assumed an oligopoly-oligopsony market structure in their comparative static PE model of the fresh tomato sector in France. Sckokai and Soregaroli (2008) assumed a monopoly and perfect competition for their dynamic PE model of the cereal sector in two fictive countries.

6.4 Synthesis and implications

PRAs including economic impact assessment are an essential component of plant health policy, aiming to allow plants and plant products to flow as freely as possible, while minimizing to a reasonable and justifiable extent the risk of introduction of plant pests. Although the commonly used qualitative economic impact assessment is adequate to apply in some situations, there is a growing awareness to use more quantitative economic impact assessment to ensure that decision makers are properly informed. The foregoing section clarified the essential data and models needed to conduct a quantitative economic impact assessment in order to support a decision on the pest quarantine status.

On conducting an economic impact assessment, the risk analyst has to make choices regarding the most appropriate technique to apply (Figure 6.3). The appropriate technique will provide an acceptable estimate of the economic impacts while minimising uncertainty with respect to conclusion. In addition, the technique should use the minimum possible resources in terms of data, skills and time. The first step in selecting the most appropriate technique is to make a decision on the need of a quantitative approach. Generally the qualitative approach is the default method to use. A quantitative approach is subsequently recommended when the qualitative approach does not give a clear indication of the importance of the potential economic impacts or when a metric estimation of the impacts is needed to justify or to support a management measure. Quantitative impact assessment can be conducted at various levels of complexity (i.e. less or more detailed analysis). Depending on the objective of the study and the available resources, the appropriate level of complexity can be chosen. An assessment in support of a decision on the quarantine status of an organism will require a less detailed analysis than an assessment that aims to assess the justification of management measures. A more detailed analysis could involve, for instance, finer resolution analysis, gathering of more detailed data, and using advanced economic techniques with wider scope.

Choosing the most appropriate output resolution of the economic model will depend on pest characteristics. In case of a pest invasion that covers almost the whole PRA territory or the case of an invasion where the pest is present in a very limited area, a fine resolution analysis will not have a large added value to the conclusion of the PRA. However, if the invasion potential is unclear, a detailed impact map will be very useful. For example, in the work done by Soliman et al. (2012c) a detailed impact map for PWN invasion provides time-bound estimates of the impact distribution. The map identified the areas within the EU with the greatest potential impact from PWN, at 1 km^2 resolution after 20 years of PWN invasion.

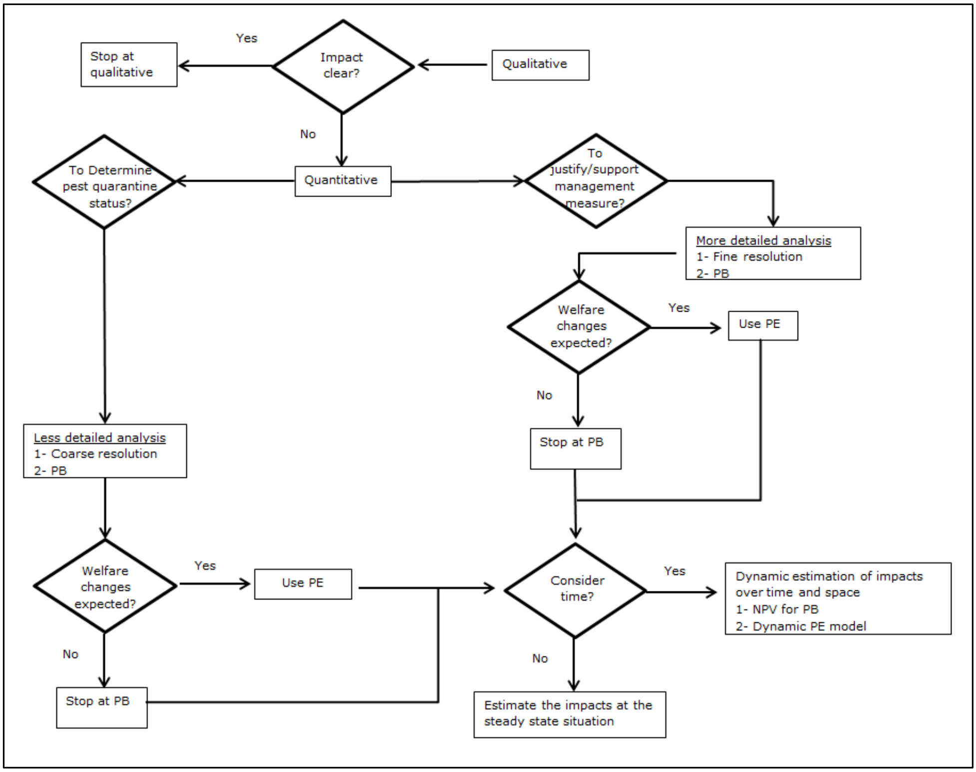

Figure 6.3 Guidance scheme for choosing the most appropriate technique for economic impact assessment

Partial budgeting is often considered as the default method of choice when estimating the economic impacts. Partial budgeting estimates the producer level impacts with low uncertainty and requires modest amount of resources. However, its scope is limited, and does not include indirect effects of pest damage that follow from changes in market prices, supply, and demand. Resource requirements for partial equilibrium modelling are higher than requirements for partial budgeting (Soliman et al., 2010). Partial equilibrium modelling could be used when a significant change in social welfare is expected, e.g. for economically important crops. This economic importance can be determined by: 1) the percentage of gross domestic product (GDP) the production of this host crop present and 2) whether the PRA area is an important player of the world trade. Soliman et al. (2012a) and (2012b) assessed the economic impacts of potato which is a host crop of economic importance for the EU and therefore it was essential to model the market indirect impacts using PE.

Another important element that needs to be defined within the economic impact assessment framework is the timeline of the assessment. The economic impacts could be estimated over time and space from the start of the invasion till a steady state situation or other arbitrary end point, or only at the steady state situation. Modelling the dynamics of the economic impacts (from the start of the invasion till the steady state situation) requires a detailed modelling of spread, and use of an economic methodology that considers the impact dynamics (e.g. net present value (NPV) for partial budgeting or dynamic partial equilibrium modelling).

The NPV will calculate the present value of the future impacts posed by the pest using a discount rate such as the interest rate. NPV provides a more accurate estimation of the future impacts than a simple summation of impacts over time.

A dynamic comparative PE modelling would constitute a step up in complexity, tracing the path of the equilibrium values of prices and quantities over time, which shows the short and long-term impacts of the pest invasion. In the short term, a significant reduction in supply could be anticipated (leading to large reduction in quantity and increase in price), while in the long term, producers are likely to adapt and take measures to increase supply.

Two elements can define the time line of the assessment. First, the pest characteristics (e.g. how fast it can spread) will play a role in defining the time line of the economic model. For instance, the rate of spread per year can provide an estimation of the expected period required by the pest to show its potential for invasion. Second, for perennial host plants, there is a possibility that the harvest impacts are accrued over the host life cycle after the time of first invasion and therefore the time frame of the assessment should account for this prolonged impact. However, the risk analyst needs to account for the increased uncertainty associated with a prolongation of the time horizon.

The development of the pest risk analysis science has been marked by a series of debates about the nature of plant health regulation and the methodologies that are appropriate for its study. In recent years, this debate has centred upon the relative merits of qualitative and quantitative methods to assess pest risk and impacts (EFSA, 2007). The overall lack of consensus among researchers is illustrated by the range of views expressed about the strengths and weaknesses of the qualitative and quantitative research methods (Table 6.2).

Table 6.2 Strengths and weaknesses of the quantitative and qualitative approaches

	Quantitative		**Qualitative**	
	Strengths	**Weaknesses**	**Strengths**	**Weaknesses**
Usage	More adequate to apply when the risk is ambiguous	High resource requirement (in terms of data, time and skills)	• More adequate to apply when the risk is clear beforehand • Low resource requirement (in terms of data, time and skills)	The possibility of being misused for political reasons
Transparency	Transparent and objective	Complexity of the underlying economic and spread models	Straightforward assessment procedure	Less transparent than quantitative approach
Impact estimation	Provides a (metric) evaluation of the impacts	It is not verified whether it can provide more accurate results (closer to the true value) than qualitative approach	Make the best use of the expertise, caution and wisdom of the PRA experts	Impacts could be overlooked (as it is hard to capture the indirect impact qualitatively, e.g. price changes,)

The question to be asked can be expressed as which approach (i.e. qualitative or quantitative) shall be used to have effective and efficient estimation of the expected economic impacts?. Those who advocate the choice between methodological approaches on such instrumental grounds tend to argue that qualitative methods are inadequate, on their own, to meet the research objective (i.e. assessing the pest impacts), particularly when the assessment involves large areas such as European Union which has heterogeneous ecological and agricultural zones (Baker et al., 2005).

A quantitative approach provides a more transparent and objective assessment than a qualitative approach (Soliman et al., 2010). This transparency can prevent the misuse of the pest risk assessment for protectionist purposes. Moreover, the more transparent evaluation of the impacts in a quantitative approach will lead to a stronger position in trade dispute with other countries. For example, the quantitative approach can estimate a metric value of potential impacts and the distribution of the impacts instead of a scale (e.g. low or high impact) provided by the qualitative approach. A quantitative approach is more adequate when the risk is ambiguous. This ambiguity can occur when potential pest spread, effect of climate on yield loss, distribution and value of hosts or market mechanisms that affect the economic impact is unclear. Market mechanisms usually mitigate impacts on producers and transfer them to consumers.

Although the quantitative approach provides additional insights, and a metric estimate of the impact, it is impossible to verify whether the results provided by the quantitative approach are more accurate (i.e. close to the true impact) than results provided by qualitative one (EFSA, 2007). In addition, these results are only applicable under the predefined model assumptions. For instance, Soliman et al. (2012a) concluded that a quantitative assessment of direct costs of a PSTVd outbreak, with current knowledge and uncertainty does not result in a convincing justification of the current phytosanitary measures. However, a qualitative assessment of direct impact suggested that direct impacts are substantial enough to justify the current measures (EFSA, 2011). Although the quantitative approach provides a metric and transparent assessment of the direct impact against the cost of the current phytosanitary measures, we are not sure whether this conclusion is more accurate than the qualitative conclusion, due to the very large differences between experts on the estimated levels of spread. The quantitative approach made this variability explicit, increasing transparency, but not necessarily strengthening the justification of measures. The quantitative assessment still supported the measures because it indicated a critical lack of knowledge on pest spread, justifying a precautionary approach.

In cases where there are limited resources in terms of time, data and skills, a qualitative approach can be more adequate to use than a quantitative approach. It is generally agreed that when the default qualitative analysis (Figure 6.3) gives a clear indication of the importance of the economic impacts, the quantitative approach is redundant, given the objective of the PRA. That was stated in the ISPM 11: “*Detailed analysis of the estimated economic consequences is not necessary if there is sufficient evidence or it is widely agreed that the introduction of a pest will have unacceptable economic consequences. It will, however, be necessary to examine economic factors in greater detail when the level of economic consequences is in question, or when the level of economic consequences is needed to evaluate the strength of measures used for risk management or in assessing the cost-benefit of exclusion or control*”. However, a main drawback of the qualitative approach is that some potential impacts could be overlooked by ignoring mitigation responses of producers. This mitigation response could reduce initial direct impact and therefore, this could lead to inclusion of organisms in the quarantine list that do not cause significant harm.

PRAs are heavily reliant on a range of evidences, many of them are qualitative and therefore may not be appropriate for quantification. These evidences should not be ignored or categorized as inaccurate or biased. On the other hand, whether pest impacts can be quantified should not prevent a careful consideration of its strength as evidence and therefore its usefulness in justifying a quarantine decision or a management measure. For instance, the Bayesian approach can make use of a priori knowledge elicited from expert in order to improve the estimate of the model parameters drawn from data. We believe that by adapting a valid conceptual framework that applies relevant qualitative and quantitative methods that support each other, we will be able to achieve a sound prediction of the pest economic impacts.

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Chapter 7

General Discussion

7.1 Introduction

A pest risk analysis is a process that evaluates technical, scientific and economic evidence to determine whether an organism needs to be categorized as quarantine pest and, if so, how it should be managed. The economic impact assessments within a pest risk analysis are currently based on a framework with qualitative questions and not on an explicit quantification of costs (Sansford, 2002; Brunel et al., 2009). Available quantitative methodologies to assess plant health risks, and in particular economic impacts, are currently insufficiently applied in the assessment of plant health risks for the EU, restricting the economic justification of plant health policies (Baker et al., 2009).

This research aimed to develop a bio-economic framework at the EU level to quantify the economic impacts of pest invasions, by the integration of relevant knowledge on fundamental niche, spread, and direct and indirect economic effects, while accounting for differences in spatial resolution. The framework is applied to pests that differ in terms of the scope of economic impacts, available information, and assessment objective, to attest its feasibility

Chapter 2 evaluates the main available techniques for quantitative economic impact assessment: partial budgeting, partial equilibrium analysis, input output analysis, and computable general equilibrium analysis. These techniques differ in width of scope with respect to market mechanisms (relationships between supply, demand, and prices), and linkages between agriculture and other sectors of the economy. As a consequence, techniques differ in their ability to assess direct and indirect (e.g. economy-wide) effects of pest introduction. Chapters 3, 4 and 5 apply a bio-economic framework to three case studies: Potato Spindle Tuber Viroid (PSTVd), Pine Wood Nematode (PWN) and *Candidatus* Liberibacter Solanacearum (CLS). Each chapter adapts the bio-economic framework in a way that addresses the objective of the study and fits the available input data. Chapter 3 assesses the economic impacts of PSTVd into the EU in order to determine whether there is sufficient economic evidence to justify the current phytosanitary measures against PSTVd. Chapter 4 assesses the economic impacts of PWN in order to assess the economic justification of the expected future intensification of control measures. Chapter 5 assesses the economic impacts of CLS in order to provide the economic justification for its quarantine status. Chapter 6 clarifies the essential data and models needed to conduct a quantitative economic impact assessment and compares the strengths and weaknesses of the qualitative and quantitative approach.

Here, the main findings of the research and their implications from a broader perspective are stated. This chapter first reviews the methodological contribution and insights, subsequently discusses the plant health policy implications derived from the results, and then discusses the research implications. The chapter ends with the main conclusions.

7.2 Methodological aspects

The application of economic impact assessment methods is part of the pest risk analysis that aims to derive a correct conclusion regarding the quarantine status of an organism. Moreover it provides satisfactory economic information to support the selection of appropriate management measures if the pest is categorized as quarantine pest. To achieve this objective, the bio-economic framework developed in this thesis applies techniques that can estimate the expected economic impacts and its range. A good understanding of the characteristics (i.e. strengths and weaknesses) of the different methods is required to select the most appropriate one for the PRA at hand. A trade-off has to be made between capabilities of the framework to capture the economic impacts and the resources consumed to apply the framework in the light of the objective of the PRA.

- **Economic technique**

After reviewing all available techniques for economic impact assessment (i.e. partial budgeting, partial equilibrium modelling, input-output analysis (I-O) and computable general equilibrium modelling (CGE)), it was concluded that partial budgeting and partial equilibrium modelling are the most suitable techniques (Chapter 2). Partial budgeting is the default method when conducting economic impact assessment. Its required data can often be obtained at a reasonable level of accuracy, and the human resources needed to apply the method are modest. Furthermore, results of partial budgeting evaluations provide necessary input for the more sophisticated techniques, like partial equilibrium modelling. The use of partial equilibrium modelling within a pest risk assessment is appropriate when the pest impacts are expected to change prices or social welfare significantly, while not affecting other non-agricultural markets nor generating measurable macroeconomic changes. Partial equilibrium modelling requires more advanced skills compared to partial budgeting. The technique is more complex and involves modelling producer and consumer reactions to price changes, which may result in more uncertain results, compared to partial budgeting. Partial equilibrium modelling provides policy makers insight in the distribution of the costs of a pest invasion across producers and consumers. It also shows whether the indirect market impacts will increase or decrease the initial direct impact of pest invasion. These additional insights are relevant to support policy responses, e.g. compensation policies. An economic technique like I–O analysis or CGE modelling needs to be considered if large spill-overs to other sectors of the economy are expected. These techniques require substantial data input and skills. The ability of I–O analysis and CGE analyses to capture indirect impacts to the entire economy is rarely needed in PRA since few pests have a wide economy impact (Soliman et al., 2010). In most cases, a combination of partial budgeting and partial equilibrium modelling can provide a sufficient scope where both direct and indirect impacts occur (Rich et al., 2005). Indirect impacts are important in determine the conclusion of the PRA as it can mitigate or increase the direct impact.

A quantitative approach provides a more transparent and objective assessment than a qualitative approach (Soliman et al., 2010). This transparency can prevent the misuse of the pest risk assessment for protectionist purposes. Moreover, the more precise evaluation of the impacts will lead to a stronger position in trade dispute with other countries. A quantitative approach is preferred if the expected economic impact is uncertain and when there are sufficient resources to conduct the analysis.

A critical element that the risk analyst needs to consider is the time line of the analysis. The economic impacts could be estimated over time and space from the start of the invasion till a steady state situation or other arbitrary end point (Chapter 4), or only at the steady state situation (Chapters 3 and 5). Modelling the dynamics of the economic impacts (e.g. from the start of the invasion till the steady state) requires spread modelling, and an economic methodology that considers the impact dynamics (e.g. net present value (NPV) for partial budgeting or dynamic partial equilibrium modelling).

Two elements define the time line of the assessment; the pest characteristics (e.g. how fast it can spread) and the type of the host (e.g. whether it is annual or perennial such as woody plants). For instance, the rate of spread per year can provide an estimation of the expected period required by the pest to show its potential for invasion. For the non-annual host plants case (Chapter 4), there is a possibility that the harvest impacts are accrued over the host life cycle after the time of first invasion and therefore the time frame of the assessment should account for this prolonged impact. The risk analyst, however, needs to account for the increased associated uncertainty upon prolonging the time horizon.

The time lines of the spread model and the economic model should be the same. Performed simulations of spread should cover a time period long enough to show the potential of the pest to spread and should at the same time be short enough to have reasonable technical processing time, and to keep uncertainties about future developments within reasonable bounds. For instance, economic market models are not recommended to have a long time line otherwise the resulting parameters (e.g. prices) will involve a high level of uncertainty.

- **Output resolution**

A framework for estimating economic impacts requires input on three data layers: climate, spread and hosts. These data layers could be integrated at a coarse or fine resolution. A fine resolution is more relevant to risk managers as it shows a refined geographical distribution of the expected impacts. Such insight will ensure plant health management measures that are targeted to the places where they are most effective (Baker et al., 2005).

However, it may be difficult to get this type of detailed data for the three input data layers, and it is costly in terms of time and money. In this thesis, one climatic variable (i.e. temperature) was considered to reflect the suitability of environment for causing damage to host crops. However, considering only temperature may be too simplistic as other variables such as dry and wet stress could play a role as well (Sutherst, 1985). A more sophisticated climatic mapping could be done through programs that model fundamental niche maps (Venette et al., 2010). For instance, CLIMEX (Sutherst et al., 2007; Sutherst and Maywald, 1985), MaxEnt (Phillips et al., 2006), Artificial Neural Networks (Gevrey and Worner, 2006), NAPPFAST (Magarey et el., 2007), BIOCLIM/ANUCLIM (Nix, 1986; Busby, 1991; Hutchinson et al., 1996) and Environmental Niche Factor Analysis (Hirzel et al., 2002).

7.3 Plant health policy implications

In Chapter 3, it is shown that assessment of direct economic consequences of PSTVd does not result in a convincing justification of measures. However, independent of the level of direct impacts, the cost of the measures would be economically justified if the presence of PSTVd would result in export losses representing more than 1% of the total value of the EU exports or market effects. The potential economic impacts of PSTVd into the European Union are therefore demonstrably of importance if considering export losses or market effects and questionable if not considering these impacts. Based on the precautionary principle, we concluded that the current measures against PSTVd are economically justified.

In Chapter 4, the economic assessment demonstrates that an uncontrolled PWN invasion will lead to large economic consequences for the conifer forestry industry in the EU. A PWN invasion from the current point of entry in Portugal is expected to affect 10.6% of the studied EU area by 2030 leading to cumulated wood loss of €22 billion, representing 3.2% of the total value of PWN susceptible coniferous trees in the EU.

In Chapter 5, economic impact assessment shows that CLS may have a significant impact on potato and tomato of 222 M€ per annum. Uncertainty analysis showed a wide boundaries of 192 - 512 M€ (5-95 percentile). The economic impact assessment suggests the pest is a ‘major’ risk and therefore needs to be regulated.

The current quarantine lists (i.e. EPPO A1/A2 list and Council Directive 2000/29/EC) include many organisms which are listed in the past based on a qualitative assessment only. In addition, the agro-ecological, cultural and economic aspects are changing over time, thereby changing the risk posed by a quarantine pest. Therefore, the listed quarantine pests should be revaluated, e.g. using the quantitative approach developed in this thesis to verify whether they still pose an unacceptable risk. Cleaning the quarantine list will help concentrating the available resources to pests that pose realistic risks and will increase the acceptance of measures by stakeholders.

Economic impact assessment at the EU scale can be used to show how the impacts are geographically distributed between countries and how they are distributed among, and within, producers and consumers. For instance, distribution of impacts within producers could be shown among large and small producers while distribution of impacts within consumers could be shown among high and low income consumers. This information could improve plant health management (e.g. compensation policies).

Although the objective of the bio-economic framework developed in this thesis was to assess the economic impact of invasive plant pests in the European Union, it is still possible to apply the framework to other continents (e.g. South America) or supra-national regions (e.g. Middle east region). This will result in more uniform quantitative impact assessment practices across the globe. However, the main issue that may arise is the data availability such as climate, spread and host distribution for these continents and regions.

7.4 Research implications

This thesis modelled the economic impacts of pest invasion. A partial budgeting technique was used to estimate the direct impacts. Subsequently, partial equilibrium modelling was used to estimate total impact including indirect impacts. Although partial equilibrium modelling is an adequate technique to model the market impacts, its results rely on the assumption of perfect competition for the host crop market. Therefore, if there is evidence that the market structure of the host crop is not perfectly competitive, the PE technique should properly account for the differences in market power across food supply chain (e.g. farmers, processors and retailers) by assuming the proper market structure (e,g, oligopoly).

Modelling the dynamics of economic impacts is one of the most complex areas in risk assessment. This complexity arises from necessity to account for the feedback mechanisms between pest spread, economic impacts and control efforts executed by producers (Finnoff et al., 2005). For instance, farmer’s behaviour towards disease spread and the political and institutional environment of the invaded territory could influence the degree of social acceptability and technical feasibility of disease control measures and programmes. In addition, further challenges are encountered when assessing the economic impacts because the vulnerability of the agroecosystem (i.e. host, climate, cultural practices) to the invasion is changing over time. However, including such dynamic factors into an economic impact assessment framework would result in an explosion of data needs as well as model complexity.

7.5 Main conclusions

The key findings of the thesis are, first, that partial budgeting and partial equilibrium modelling are the methods of choice when assessing the economic impacts of pest invasion (Chapter 2). Second, a fine resolution analysis is relevant to risk managers as it shows a refined geographical distribution of the expected impacts, while a coarse level analysis may be sufficient for determining whether an organism classifies as a quarantine organism (Chapter 4). Third, the potential economic impacts of potato spindle tuber viroid into the European Union are demonstrably of importance when considering market effects or export losses and questionable if only accounting for the direct losses (Chapter 3). Fourth, pine wood nematode has large economic consequences for the conifer forestry industry in the EU, and therefore justifies the potential intensification of the current control measures (Chapter 4). Fifth, *Candidatus* Liberibacter Solanacearum is considered of a 'major' economic impact to the European Union, and is recommended to be added to the quarantine list (Chapter 5). A quantitative approach is preferred if the expected economic impact is uncertain when based on qualitative approach, and when there are sufficient resources to conduct the analysis (Chapter 6). The economic impact assessment framework developed in this thesis shows that it is possible to quantify the direct and indirect impacts at various levels of detail, in terms of output resolution and scope of economic impacts, given the common available data, time and skills. Application of this framework can enhance the policy and decision making by governments and international bodies on managing plant health risks.

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Summary

According to the International Plant Protection Convention (IPPC) and the Agreement on the Application of Sanitary and Phytosanitary measures (SPS Agreement) of the World Trade Organization (WTO), phytosanitary measures should be economically justifiable. The economic impact assessments within a pest risk analysis are currently based on a framework with qualitative questions and not on an explicit quantification of costs (Sansford, 2002; Brunel et al., 2009). Available quantitative methodologies to assess plant health risks, and in particular economic impacts, are currently hardly applied in the assessment of plant health risks for the EU, restricting the economic justification of plant health policies.

This research aimed to develop a bio-economic framework at the EU level to quantify the economic impacts of pest invasions, by the integration of relevant knowledge on fundamental niche, spread, and direct and indirect economic effects, while accounting for differences in spatial resolution. The framework is applied to pests that differ in terms of the scope of economic impacts, available information, and assessment objective, to attest its feasibility.

Chapter 2 evaluates the main available techniques for quantitative economic impact assessment: partial budgeting, partial equilibrium analysis, input output analysis, and computable general equilibrium analysis. These techniques differ in width of scope with respect to market mechanisms (relationships between supply, demand, and prices), and linkages between agriculture and other sectors of the economy. As a consequence, techniques differ in their ability to assess direct and indirect (e.g. economy-wide) effects of pest introduction. An overview of traits of the available methods is provided to support the selection of the most appropriate technique for conducting a PRA. It was concluded that partial budgeting and partial equilibrium modelling are the most suitable techniques. Partial budgeting is the default method when conducting economic impact assessment. Its required data can often be obtained at a reasonable level of accuracy, and the human resources needed to apply the method are modest. Furthermore, results of partial budgeting evaluations provide necessary input for the more sophisticated techniques, like partial equilibrium modelling. The use of partial equilibrium modelling within a pest risk assessment is appropriate when the pest impacts are expected to change prices or social welfare significantly, while not affecting other non-agricultural markets nor generating measurable macroeconomic changes. Partial equilibrium modelling requires some advanced skills comparing to partial budgeting. The

technique is more complex and involves modelling producer and consumer reactions to price changes, which may resulted in more uncertain results, compared to partial budgeting. Partial equilibrium modelling provides policy makers insight in the distribution of the costs of a pest invasion across producers and consumers. It also shows whether the indirect market impacts will increase or decrease the initial direct impact of pest invasion. These additional insights are relevant to support policy responses, e.g. compensation policies.

Chapter 3 assesses the economic impacts posed by Potato Spindle Tuber Viroid (PSTVd) in the EU. These estimated impacts are compared with the costs of the current phytosanitary measures in order to verify if the measures are economically justified. The bio-economic framework integrates a potential pest spread model elicited from experts and an economic model to quantify the resulting impacts. The assessment of direct costs of a PSTVd outbreak, with current knowledge and uncertainty, suggests that the costs of the measures and their benefit (€5.6 M/year) are of the same order of magnitude. Therefore, an assessment of direct economic consequences does not result in a convincing justification of measures. The total economic impact, considering price changes and higher costs for consumers, was estimated at 4.4 M€ for potatoes and 5.7 M€ for tomatoes. Consumers bore 92% of the total costs of invasion in the case of potato and 77% in the case of tomato. If the presence of PSTVd would imply export restrictions, resulting in an annual loss of more than 1% of the total EU export value of potatoes and tomatoes, the cost of current phytosanitary measures would also be justified. The potential economic impacts of PSTVd into the European Union are therefore demonstrably of importance when considering market effects or export losses but questionable if only accounting for the direct losses. The large degree of uncertainty in the prevalence of disease contributes to the justifiability of measures based on the precautionary principle.

Chapter 4 estimates the dynamics of economic impacts over time due to the expected spread of Pine Wood Nematode (PWN) in the EU. The bio-economic framework integrates a biological invasion spread and economic models. The results of this economic assessment demonstrate that an uncontrolled PWN invasion will lead to large economic consequences for the conifer forestry industry in the EU. A PWN invasion from the current point of entry in Portugal is expected to affect 10.6% of the studied EU area by 2030 leading to cumulated wood loss of €22 billion, representing 3.2% of the total value of PWN susceptible coniferous trees in the EU. The economic impact assessment identifies Portugal, Spain, North West Italy and France (i.e. Languedoc-Roussillon, Bourgogne, Poitou-Charentes, Aquitaine, Midi-

Pyrenees, Limousin, Rhone-Alpes, Provence-Alpes Cote d'Azur and the Auvergne) as endangered area. Of these French regions, Aquitaine is predicted to have the highest impacts because of the presence of dense coniferous forests. Expected future intensification of control measures are economically justified.

Chapter 5 assesses the economic impacts posed by *Candidatus* Liberibacter Solanacearum (CLS) in the EU in order to economically justify a decision on the pest quarantine status. The bio-economic framework is based on potential pest spread model elicited from experts and a quantitative economic model. Economic impact assessment showed that at the most likely infestation level CLS may have a significant direct impact on potato and tomato producers of 222 M€ per annum. Uncertainty analysis showed wide boundaries of 192 - 512 M€ (5-95 percentile). The expected negative impact on societal welfare at the most likely infestation level is less than the estimated direct impacts, viz. 114 million euros per year. The potential economic impacts of CLS into the European Union are demonstrably of major importance. Therefore, a decision to categorize CLS as a quarantine pest is supported..

Chapter 6 clarifies the essential data and models needed to conduct a quantitative economic impact assessment and compares the strengths and weaknesses of the qualitative and quantitative approach and presents the implications for PRA-practitioners. Whilst the qualitative approach may be adequate in many instances, it may lack transparency and demonstrable objectivity. A quantitative approach for economic impact assessment may improve transparency and strengthen the justification for measures, if taken, but requires additional work, and it requires specific data and models. It is concluded that a quantitative approach is preferable if the expected economic impact is ambiguous when using a qualitative approach, and when there are sufficient resources to conduct the analysis.

Samenvatting (Summary in Dutch)

Volgens de richtlijnen van de International Plant Protection Convention (IPPC) en de Agreement on the Application of Sanitary and Phytosanitary measures (SPS-overeenkomst) van de World Trade Organization (WTO), dienen fytosanitaire maatregelen enkel toegepast te worden indien ze economisch verantwoord zijn. Binnen de huidige pest risico analyses is de evaluatie van de economische gevolgen voornamelijk gebaseerd op een kader met kwalitatieve vragen en niet op een expliciete kwantificering ervan (Sansford, 2002; Brunel et al., 2009). Beschikbare kwantitatieve methodieken ter beoordeling van plantenziekterisico's, en met name de economische gevolgen, worden momenteel nauwelijks toegepast bij de beoordeling van de fytosanitaire risico's voor de EU, hetgeen de economische rechtvaardiging van het toegepaste plantgezondheidsbeleid beperkt.

Dit onderzoek is gericht op de ontwikkeling van een bio-economisch kader om op EU-niveau de economische gevolgen van pest invasies te kwantificeren. Een dergelijk kader vereist een integratie op ruimtelijk niveau van relevante kennis omtrent de pest op het gebied van de fundamentele niche, de verspreiding en de economische effecten. Om de haalbaarheid van een dergelijk kwantitatieve integratie te bepalen, is het kader toegepast in een drietal risicoanalyses die onderling verschillen in termen van de beschikbaarheid van relevante invoergegevens, de gestelde doelfunctie en dekking van economische impacts.

In hoofdstuk 2 zijn de beschikbare kwantitatieve analyse technieken nader geëvalueerd om te komen tot de selectie van de meest geschikte techniek ter bepaling van de economische gevolgen van een pest-invasie. De geëvalueerde technieken bestaan uit de partial budgeting techniek, de partial equilibrium analyse, de input-output analyse en de computable general equilibrium analyse. Deze technieken verschillen in de mate waarin rekening kan worden gehouden met veranderingen in de marktmechanismen (relaties tussen aanbod, vraag en marktprijzen), en eventuele verbanden tussen landbouw en andere sectoren van de economie. Dientengevolge verschillen de technieken in hun vermogen om de directe (o.a. productieverliezen) en indirecte (o.a. prijswijzigingen) effecten van een pestintroductie te evalueren. Geconcludeerd wordt dat de partial budgeting methode en de partial equilibrium analyse de meest geschikte technieken zijn. Partial budgeting is daarbij de basale techniek die standaard bij elke economische analyse toegepast kan worden om de directe kosten van een invasie te berekenen. De toepassing vereist invoergegevens die vaak op een redelijk niveau van nauwkeurigheid te verkregen zijn, terwijl de benodigde personele middelen beperkt zijn.

Daarnaast leveren de resultaten van de partial budgeting evaluaties, de benodigde input op voor de meer geavanceerde technieken, zoals de partial equilibrium modellering.

Het gebruik van de partial equilibrium modellering binnen een pest risico assessment is geschikt wanneer verwacht wordt dat de pestinvasie resulteert in aanzienlijke wijzigingen in marktprijzen of economische welvaart, zonder daarbij een invloed te hebben op andere niet-agrarische markten of te resulteren in meetbare macro-economische veranderingen. De partial equilibrium techniek omvat de modellering van de reacties van producenten en consumenten op prijswijzigingen, hetgeen - vergelijken met partial budgetting – kan resulteren in meer onzekere resultaten (= grotere spreiding in de resultaten). Partial equilibrium modellering biedt beleidsmakers inzicht in de verdeling van de kosten van een pestinvasie over de betrokken producenten en consumenten. Het toont ook of de indirecte markteffecten de directe kosten van de pest invasie zullen vergroten of verkleinen. Deze aanvullende inzichten zijn relevant voor beleidsvorming, zoals bijvoorbeeld bij de ontwikkeling van een compensatie beleid.

Hoofdstuk 3 beoordeelt de economische gevolgen van een niet-gereguleerde Potato Spindle Tuber viroid (PSTVd) uitbraak in de EU. De geschatte economische impact wordt vergeleken met de kosten van de huidige fytosanitaire maatregelen, om na te gaan of deze maatregelen economisch gerechtvaardigd zijn. Door het ontbreken van relevante verspreidingsgegevens, is de verspreiding binnen de EU gebaseerd op de verwachtingen van experts. Gegeven de onzekerheid omtrent de verwachte verspreiding, lijken de directe kosten van een PSTVd-uitbraak van dezelfde orde van grootte te zijn als de kosten van de huidige maatregelen (€5,6 miljoen/jaar). De evaluatie van de directe economische gevolgen leidt zodoende niet tot een overtuigende rechtvaardiging van de huidige maatregelen. De totale directe en indirecte kosten worden geschat op 4.4 M€ in de aardappelketen en 5.7 M€ in de tomatenketen, hetgeen de huidige fytosanitaire kosten wel overtreft. Consumenten dragen 92% van deze totale kosten in het geval van aardappelen en 77% in het geval van tomaten. Daarnaast zijn de kosten van de maatregelen economisch gerechtvaardigd indien de aanwezigheid van PSTVd, onafhankelijk van het niveau van de directe effecten, resulteert in exportverliezen van meer dan 1% van de totale waarde van de uitvoer uit de EU. De potentiële, economische impact van PSTVd in de Europese Unie is daarom van aantoonbaar belang indien rekening gehouden wordt met de marktgevolgen of mogelijke exportverliezen, maar van twijfelachtig belang indien deze gevolgen niet in ogenschouw worden genomen. Op basis van het voorzorgsbeginsel, concluderen we dat de huidige fytosanitaire maatregelen tegen PSTVd economisch gerechtvaardigd zijn.

Hoofdstuk 4 schat de dynamiek van de economische effecten gerelateerd aan de verwachte verspreiding van het Pine Wood Nematode (PWN) dennenaaltje in de EU. In deze analyse wordt op ruimtelijk niveau de output van een stochastisch verspreidingsmodel geïntegreerd met de partial budgeting en partial equilibrium modellen, ter berekening van de directe en indirecte gevolgen. De resultaten tonen aan dat een ongecontroleerde PWN invasie zal leiden tot grote economische gevolgen voor de conifeer houtverwerkende industrie in de EU. Zonder regulering zal het aaltje vanuit de huidig geïnfecteerde locaties in Portugal naar verwachting in 2030 zodanig verspreid zijn dat het de houtopbrengst in 10,6% van het EU gebied zal beïnvloeden. T.a.v. het geanalyseerde tijdsbestek komt dit overeen met een gecumuleerd houtverlies van €22 miljard, hetgeen 3,2% van de totale waarde van PWN gevoelige coniferen in de EU vertegenwoordigt. De economische assessment identificeert Portugal, Spanje, Noord West Italië en Frankrijk (d.w.z. Bourgogne, Languedoc-Roussillon, Poitou-Charentes, Aquitaine, Midi-Pyrenees, Limousin, Rhone-Alpes, Provence-Alpes-Cote d'Azur en de Auvergne) als het bedreigde gebied. Van alle Franse regio's, zijn de economische gevolgen het grootst voor Aquitanië vanwege de aanwezige, hoge dichtheid aan naaldbossen. Op basis van de uitgevoerde analyse wordt geconcludeerd dat de verwachte, toekomstige intensivering van controle maatregelen gericht tegen PWN economisch gerechtvaardigd zijn.

Hoofdstuk 5 beoordeelt de economische effecten van de pest *Candidatus* Liberibacter Solanacearum (CLS) in de EU, om een eventueel besluit omtrent zijn quarantainestatus economisch te rechtvaardigen. Inschattingen voor de verspreiding van de pest binnen de EU zijn verkregen van experts. Uitgaande van het meest waarschijnlijke besmettingsniveau, resulteert een introductie en verspreiding van CLS in de EU, in aanzienlijke directe economische gevolgen voor de aardappel- en tomatenproducenten van zo'n € 222 miljoen per jaar. Gevoeligheidsanalyses tonen een grote spreiding in de directe kosten, variërend van zo'n €192 tot €512 miljoen per jaar (5-95-percentiel). De totale economische impact ofwel de verwachte negatieve impact op de maatschappelijke welvaart van €114 miljoen euro per jaar ligt uiteindelijk lager dan de geschatte directe impact. De potentiële economische impact van CLS in de Europese Unie is aantoonbaar van groot belang, hetgeen een besluit om CLS te categoriseren als een quarantaine pest ondersteunt.

Hoofdstuk 6 verduidelijkt de benodigde gegevens en modellen voor het uitvoeren van een kwantitatieve economische assessment, vergelijkt de sterke en zwakke punten van de kwalitatieve en kwantitatieve benadering en presenteert de implicaties voor PRA-analisten. Hoewel de kwalitatieve benadering van de economische gevolgen in veel gevallen voldoende kan zijn kan, mist het transparantie en aantoonbare objectiviteit. Een kwantitatieve benadering van de economische gevolgen op basis van het ontwikkelde kader kan de transparantie verbeteren en de rechtvaardiging van genomen maatregelen versterken, maar vereist meer vaardigheden en specifieke gegevens en modellen. Een kwantitatieve benadering is zodoende met name wenselijk in situaties waarin de verwachte economische impact op basis van een kwalitatieve analyse niet eenduidig is (o.a. bij de evaluatie van controle alternatieven) en er voldoende middelen aanwezig zijn.

Publications

Peer-reviewed publications

Soliman T., Mourits M.C.M., Oude Lansink A.G.J.M., van der Werf W., 2012. Quantitative economic impact assessment of an invasive plant disease under uncertainty – a case study for PSTVd invasion into the European Union, Crop Protection 40, 28-35.

Soliman T., Mourits M.C.M., Oude Lansink A.G.J.M., van der Werf W., 2010. Economic impact assessment in pest risk analysis, Crop Protection 29, 517–524.

Other Scientific publications

Baker RHA, Benninga J, Bremmer J, Brunel S, Dupin M, Eyre D, Ilieva Z, Jarošík, Kehlenbeck H, Kriticos DJ, Makowski D, Pergl J, Reynaud P, Robinet C, **Soliman T**, van der Werf W, Worner S., 2012. A decision support scheme for mapping endangered areas in pest risk analysis. EPPO Bulletin/Bulletin OEPP 42, 65–73.

About the author

Tarek Soliman was born on December 21st 1979 in Cairo, Egypt. He accomplished his high school in the scientific specialization in 1997. In the same year, he started his bachelor degree at Cairo University with a specialization in ‘Economics’. He graduated from Cairo University in 2001. After graduation, he worked at the Egyptian-American Bank till 2004. In 2004, he was granted a scholarship by the International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM) to study a Master of Science program in Agricultural Economics at the Mediterranean Agronomic Institute of Chania (MAICh) in Crete, Greece. The M.Sc. thesis has been elaborated within the framework of the EU-funded project “*Market and Trade Policies for Mediterranean Agriculture: The case of fruit, vegetable and olive oil (MEDFROL)*”. In 2006, he obtained his Master of Science degree with distinction. From September 2006 till June 2007, Tarek was working at Credit Agricole Bank in Egypt. In 2007, Tarek was awarded a scholarship for the Ph.D. program in economics at CERGE-EI, Charles University of Prague in Czech Republic, where he attended the course work of the American style Ph.D. program. In May 2008, he was accepted for an (AIO) Ph.D. position at Wageningen University. From May 2008 until May 2012, he was working on his Ph.D. thesis entitled “*Economic impact assessment of invasive plant pests in the European Union*”. The Ph.D. thesis has been elaborated within the framework of the EU-funded project “*Enhancement of Pest Risk Analysis Techniques (PRATIQUE)*”. During his Ph.D. program, Tarek provided an ad-hoc consultancy and advisory work to the European and Mediterranean Plant Protection Organization (EPPO) in Paris, France. In addition, he was awarded a scholarship to attend an intensive entrepreneurship course at University of Wisconsin in USA.

eMail: *Tariq.Soliman@yahoo.com*

Tarek Soliman
PhD candidate, Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Wageningen School
of Social Sciences

Name of the activity	Department/Institute	Year	ECTS*
Project related competences			
Agri-food Industrial Organisation	BEC, WUR	2008	4
Advanced Industrial Organization (Empirical)	The Netherlands network of Economics (NAKE)	2011	3
Advanced Econometrics AEP 50806	WUR	2009	6
Nonparametric Static Approaches	WASS	2008	4
Dynamic Efficiency Approaches	WASS	2008	1.5
The Bayesian Approach in theory & practice	WASS	2008	1.5
Plant pathogens, Insects and Weeds I	PE&RC	2009	3
Pest Risk Analysis	European and Mediterranean plant protection organization (EPPO), Cyprus	2008	1.5
Integrated Assessment of Agriculture and Sustainable Development (SEAMLESS)	Wageningen Centre for Agroecology and Systems Analysis (WaCASA)	2008	1.5
General research related competences			
Introduction course	WASS	2009	1
Academic writing II	Wageningen University	2010	1.5
PhD discussion Group	BEC, WUR	2008-2012	4
Using voice in presentations	WUR	2011	1
Economic impact assessment of pine wood nematode in the EU	EAAE congress, Switzerland	2011	1
Quantitative economic impact assessment model of pest invasion	PRATIQUE conference on pest risk analysis (PRA), UK	2011	1
Economic impact assessment of PSTVd in the EU	19th Meeting of the Expert Panel on PRA Development, France	2010	1
Career related competences/personal development			
Entrepreneurship Boot camp	University of Wisconsin, USA	2009	3
Total (minimum 30 ECTS)			**39.5**

*One ECTS on average is equivalent to 28 hours of course work

Colophon

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