NJAS - Wageningen Journal of Life Sciences 64–65 (2013) 95–103

ELSEVIER

NJAS - Wageningen Journal of Life Sciences

journal homepage: www.elsevier.com/locate/njas

Review

Designing the emerging EU pesticide policy: A literature review

T. Skevas, A.G.J.M. Oude Lansink*, S.E. Stefanou

Wageningen University, P.O. Box 8130, NL-6700 EW Wageningen, The Netherlands

ARTICLE INFO

Article history:
Received 11 April 2012
Accepted 18 September 2012
Available online 22 October 2012

Keywords:
Pesticides
Elasticities
Policy design
Production function

ABSTRACT

A European Union (EU) wide pesticide tax scheme is among the future plans of EU policy makers. This study examines the information needs for applying an optimal pesticide policy framework at the EU level. Damage control specification studies, empirical results from pesticide demand elasticity, issues on pesticide risk valuation and uncertainty, and knowledge on the indirect effects of pesticides in relation to current pesticide policies are analysed. Knowledge gaps based on reviewing this information are identified and an illustration is provided of the direction future pesticide policies should take.

Contents

1. Introduction

The past decades have witnessed a considerable increase in the global production of agricultural goods and services. Plant protection products have played a major role in driving this growth, as have other technological innovations. However, the excessive use of inputs like plant protection products has a concomitant impact on the environment.

Plant protection products are active substances that enable farmers to control different pests including weeds, and thus constitute one of the most important inputs in agricultural production [1]. There is a large range of positive outcomes from the use of different pesticides related to improving crop yields and the quality of production resulting in increased farm and agribusiness profits. With weeds being the major yield-reducing factor for many crops, herbicides are the most widely used type of pesticides. Cooper and Dobson [2] refer to a number of benefits from pesticide use, among which are (1) the improved shelf life of produce, (2) the reduced drudgery of weeding, which frees labour for other tasks, (3) reduced fuel use for weeding, (4) invasive species control, (5) increased livestock yields and quality, and (6) garden plant protection.

The publication of Rachel Carson's *Silent Spring* [3], which highlighted the risks of pesticide use, stimulated the steady progress in documenting the negative spillovers arising from the continuous use of chemical inputs [4–8]. Pesticides are not restricted to use in agriculture: they are used frequently for landscaping, maintaining sporting fields, for road and railway side weed control, and public building maintenance. These substances can be dangerous for human health when the degree of exposure exceeds the safety levels. Exposure can be direct, for example when farm workers apply pesticides to various crops, and indirect when consumers ingest agricultural products that contain traces of the

* Corresponding author. Tel.: +317 485194.
E-mail address: alfons.oudelansink@wur.nl (A.G.J.M. Oude Lansink).

1573-5214/$ – see front matter © 2012 Royal Netherlands Society for Agricultural Sciences. Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.njas.2012.09.001

chemical, or even when bystanders happen to be nearby application areas.

Additionally, the excessive and uncontrolled use of pesticides can pose serious and irreversible environmental risks and costs. The decline in the number of beneficial pest predators has led to the proliferation of various pests and diseases with adverse impacts on fauna and flora [5]. Certain pesticides applied to crops eventually end up in ground and surface water. Sharpley et al. [6] note that pesticides play an important role in the pollution of surface water. Pesticides have toxic effects on humans, livestock and wildlife [7] while among the risks they pose are pesticide residues in food, water, and soil, harm to agro-ecosystems, adverse effects on target biota, and pest resistance [8]. Pesticide-resistant weeds and pests can trigger increased pesticide applications to reduce the damage, resulting in higher economic costs that farmers must shoulder.

The individual EU member countries and the European Commission (EC) have a long history of controlling pesticide use through a myriad of country-specific programmes. Pesticide policies were first introduced at EU level in 1979. The directives 91/414/EC and 98/8/EC on the placing of plant protection products and biocidal products on the market were the first ones dealing with the authorization of pesticides. The waste framework directive (2006/12/EC) and the directive on hazardous waste (91/689/EEC) constitute regulations impacting pesticide use in many ways, as they establish provisions for the safe collection/disposal of empty pesticide packages and unused or expired pesticides. The water framework directive (2000/609/EC) and the regulation on MRLs (396/2005) address pesticide residuals, where the first identifies substances that are hazardous for water (including active substances in plant protection products) and the second sets maximum residue levels of active substances in food and feed. The Thematic Strategy on the Sustainable Use of Pesticides completes the overview of the existing pesticide regulations, as it aims to regulate pesticide use. Regulation No. 1107/2009 concerning the placing of plant protection products on the market and directive No. 2009/128/EC on the sustainable use of pesticides are due to replace directive 91/414/EC. Among the future goals are the establishment of quantitative reduction targets and the introduction of tax schemes.

Many EU member states show an increase in the sales of pesticides over the period 2002–2008 (e.g., the Netherlands 33%, Germany 17% and Denmark 39%) [9]. The increase in pesticide use and the continuous presence of pesticides in aquatic environments in conjunction with the fact that the current pesticide regulatory framework does not sufficiently address the actual use-phase of pesticides has led the EU to consider an overhaul of the pesticide regulations [10]. The upgrade of existing pesticide regulations includes the introduction of an EU-wide regulatory framework on pesticides, grounded upon economic incentives. The foundation of future EU policy schemes aims at the sustainable use of pesticides in European agriculture. This effort involves reducing the risks and impacts of pesticide use on human health and the environment, while still being consistent with crop protection. The design of optimal pesticide policies requires insight into the relationships between production decisions on crop yields and their quality, the environmental and health spillover impacts of pesticide use, and how policies and regulations influence production decision-making. A key policy consideration is balancing the incentives for economic growth against the adverse impact on the environment, which is broadly defined to include the management of land, water and air, as well as the overall stability and biodiversity of the ecological system.

The objective of this paper is to explore the potential for introducing an optimal pesticide policy at EU level from an economic point of view. The paper contributes to the literature by reviewing the information needed for the introduction of such a policy framework and by identifying knowledge gaps to be addressed in support of an optimal pesticide policy design. The remainder of the paper is organized as follows. The next section presents an optimal pesticide policy framework. This is followed by a review of the existing literature on pesticides that indicate the extent to which the current literature provides information needed for the implementation of optimal pesticide policies. The final section discusses knowledge gaps based on the literature review.

2. An optimal pesticide policy framework

Under the Pigouvian tradition, the optimal pesticide policy grounded on economic incentives should include taxes (or subsidies) to control pesticide externalities, where the tax (or subsidy) reflects the marginal net damage (benefit) of pesticide use. The problem with such a policy framework is that obtaining an accurate estimate of the monetary value of pesticide damage (or benefit) is not an easy task, mainly because of prohibitive information requirements. Alternatively, Baumol and Oates [11] proposed the establishment of a set of standards or targets for environmental quality followed by the design of a regulatory system that could employ taxes (or subsidies) to attain these standards. The authors add that although this will not result in an optimal allocation of resources (such as pesticides) it represents the most cost effective way in attaining the specified standards. A pesticide policy framework that combines market-based instruments with standards for acceptable environmental and health quality will enable policy makers to base the charge rates or prices on the acceptability standards rather than on the unknown value of marginal net damages [12–14].

The design and application of a pesticide policy framework grounded on market-based instruments and environmental and/or health standards, requires rigorous information on different dimensions and aspects of pesticide use. The elements needed by policy makers to apply such a policy framework may be summarized by information on (1) the production structure (i.e., production function, pesticide demand elasticities), (2) attitudes towards risk and uncertainty related to pesticides application, (3) the value of pesticides to consumers (e.g., the willingness to pay (WTP) for lower pesticide use), and (4) the indirect effects of pesticide use. Information on the production structure of pesticide use includes trends in pesticide use (overuse or underuse), and the direction and extent farmers' behaviour will change following the introduction of a pesticide tax. In particular, will a pesticide price increase lead to significantly decreased pesticide use? Information on the riskiness of pesticides in relation to output realization may enhance the effectiveness of pesticide policy tools while evidence on the consumers' WTP for reducing pesticide-adverse effects can reveal if there is a demand for more environmental friendly products. So policy makers may use this information by providing an incentive to farmers to switch to more environmental friendly forms of production (e.g., organic or Integrated Pest Management[1] (IPM)). Finally, detailed data on the indirect effects of pesticides can assist policy makers in setting proper environmental and health standards that can increase the effectiveness of the different economic instruments.

It is important to note that optimal pesticide use may be attained not only through the use of market-based instruments, such as taxes and subsidies, but also of alternative instruments. For instance, command-and-control regulations may be among the means to reach a policy goal. Unlike market-based instruments that encourage firms' behaviour through market signals,

[1] The Food and Agriculture Organisation [94] defines IPM as "an ecosystem approach to crop production and protection that combines different management strategies and practices to grow healthy crops and minimize the use of pesticides."

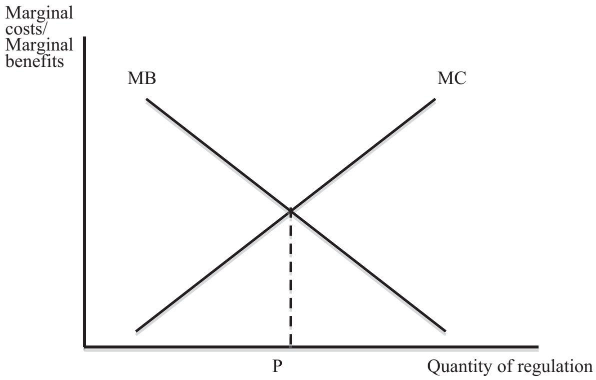

Fig. 1. Cost-benefit analysis of a regulation.

command-and-control regulations set uniform standards for firms. An example of a command-and-control measure in relation to pesticide policy is a ban on the use of specific pesticides. Stavins [15] argues that despite the proven success of market-based instruments in reducing environmental pollution at a low cost, they did not come close to replacing command-and-control measures. Given that market-based instruments have a limited impact on farmers' behaviour in the short term, command-and-control measures (e.g., bans on pesticides) can more likely provide the desired reductions in pesticide use to policy makers in the short term. As research on pesticide externalities advances, pesticide bans may always have a place in pesticide policy frameworks.[2] Baumol and Oates [11] add that a mixed system of regulations, composed of both fiscal and non-fiscal measures, constitutes an optimal regulatory strategy to reduce firms' externalities. A complement to public or market intervention instrument can be agricultural production on certified farms (organic or IPM) or self-regulation. Farmers can form groups with common production rules (e.g., IPM), facing the opportunity to gain from their collective capacity to establish a reputation for their products. In this way farmers can experience higher revenues and society can benefit from reduced pesticide externalities. The formation of producer organizations can be promoted by governments through providing financial facilities (e.g., lower firm taxation).

An essential part of the design of an optimal pesticide policy is a rigorous comparison of the environmental benefits with the abatement costs for pesticide users and the administrative costs of implementing the policy [16]. For instance, environmental benefits could be quantified in terms of species richness [17] or quality of nearby surface water bodies and aquifers. Abatement costs are an important component of farmers' expenses and an assessment of the impacts of the potential policies in terms of the economic viability of adoption of different abatement strategies (e.g., purchasing more environmental friendly pesticides, mechanical weeding) is essential. Administrative costs of implementing a policy could include costs of monitoring and keeping accounts of farmers' abatement strategies, collecting tax revenues in case of an economic incentive-based policy and developing and updating a hazard ranking system for pesticides. As governments' capacity to spend on regulation may be limited, cost-benefit analysis could be a valuable guide for assessing the economic viability and effectiveness of different pesticide policy frameworks. Cost-benefit analysis can also help identify the optimal intensity of regulation needed as shown by Fig. 1, where MC reflects the marginal costs and MB the marginal benefits of pesticide regulation. At the intersection point P, the incremental benefits from additional regulation are just offset by the incremental costs (e.g., additional abatement costs and administrative costs). Concerns about environmental benefits revolve whether we are above or below the intersection point P and whether the benefits from environmental improvement will exceed the costs of attaining this improvement. Balancing regulatory costs and benefits is complicated by uncertainties and stochastic events related to pesticide use and their spillovers, such as extreme climatic conditions (e.g., high precipitation levels can increase pesticide leaching) and occurrence of new pest infestations (that can trigger higher pesticide applications and increase environmental spillovers).

[2] Many active ingredients have been recently banned, based on their adverse effect on human health.

3. Production structure

Determining the impacts of a pesticide policy and the design of an optimal pesticide policy requires information on the role of pesticides in the production process and the relation between pesticide use and pesticide prices. Section 3.1 discusses the available literature on estimating the production function in the presence of pesticides, whereas Section 3.2 presents empirical studies on pesticide price elasticities.

3.1. Production function

In economics, a production function is a relation expressing the amount of output attained by a firm for all combinations of inputs [18]. Traditional specifications of the production function in agricultural production are characterized by the symmetric treatment of the inputs involved in the production process. Damage abatement specifications treat inputs asymmetrically, i.e., inputs are separated into those that increase output (productive inputs) and those that reduce damage (damage abatement inputs) [19]. The concept of a damage abatement input was introduced by Hall and Norgaard [20] and Talpaz and Borosh [21] and suggests that pesticides have an indirect effect on output in future years caused by pesticide resistance rather than a direct yield-increasing effect. Lichtenberg and Zilberman [22] were the first to specify production functions that are consistent with the concept of damage abatement input. Apart from pesticides, damage control inputs could include windbreaks, buffer zones and antibiotics. The Lichtenberg and Zilberman (LZ) [22] damage control framework enables economists to observe that the Cobb-Douglas formulations used in this study resulted in an upward bias in the optimal pesticide use estimations, whereas recent evidence suggests an overuse [23,24]. The LZ damage control specification was applied by Oude Lansink and Carpentier [19], Babcock et al. [23], Guan et al. [24], Carrasco-Tauber and Moffit [25], Chambers and Lichtenberg [26], Oude Lansink and Silva [27], and Lin et al. [28]. Table 1 reviews these studies using a set of the following common criteria: (1) setting, (2) modelling framework, (3) data and application, and (4) results and policy implications. The results are mixed with some studies that indicate the overuse of pesticides, and other ones that indicate underuse.

Although the LZ specification constitutes a useful and widely acceptable tool in the economics of pesticide use, the various critiques [19,27] and mixed results developed by some authors perpetuate the debate regarding this specification. The majority of findings show that pesticides are underused, which is contrary to the conventional view. Some interesting insights emerge from studies implementing the LZ specification predicting the overuse of pesticides. The choice of specification for the damage abatement function significantly impacts pesticide productivity estimates. Studies permitting specifications allowing a decreasing marginal product of pesticides are more likely to predict pesticide

Table 1
Studies that have successfully applied the LZ specification.

Study	Modelling framework	Data/Application	Trend in pesticide use
Oude Lansink and Carpentier [19]	Generalized Maximum Entropy estimation	Secondary; Arable farms, The Netherlands	Underused
Babcock et al. [23]	Damage control dynamic model	Secondary; Apple production; North Carolina, USA	Overused
Carrasco-Tauber and Moffit [25]	Damage control dynamic model	Secondary; USA agriculture	Underused
Oude Lansink and Silva [27]	Data envelopment analysis	Secondary; Arable farms, The Netherlands.	Underused
Chambers and Lichtenberg [26]	Dual representation of generalized LZ model	Secondary; USA. Agriculture	Underused
Guan et al. [24]	Damage control model	Secondary; Potato production, The Netherlands	Overused
Lin et al. [28]	Cobb-Douglas vs exponential, logistic and Weibul damage-control specification	Secondary; Potato production, Pacific Northwest, USA	Trend depends on model selection

overuse. Furthermore, the examined product/crop can influence the final result regarding the overuse or underuse of pesticides. Babcock et al. [23] applied the LZ specification to apple production data in North Carolina and found that pesticides are overused. However, apple production requires a considerable number of preventive pesticide applications in order to obtain high quality output. Therefore, this preventive application can justify the overuse of pesticides.

3.2. Pesticide demand elasticity

The pesticide demand elasticity is a parameter that shows the responsiveness of the pesticide quantity demanded by a change in the pesticide price. The design of regulatory frameworks for levies on pesticides requires estimates of pesticide demand elasticities. Table 2 presents a review of the pesticide demand elasticity estimates of European countries and the USA. A general conclusion based on this table is that the price elasticity of pesticide demand is low (in most cases), indicating that pesticide use is indifferent to pesticide price increases. Inelastic demand can indicate a lack of knowledge among farmers regarding alternative production practices, a strong intention towards risk aversion, or can be due to behavioural factors like professional pride derived from weed-free fields. Inelastic pesticide demand is also reported by Hoevenagel et al. [13] in their study of an EU wide scheme for levies on pesticides. Therefore, a tax on pesticides is expected to create considerable revenues but will have a small contribution to reducing pesticide externalities. Another important conclusion from Table 2 is that a lower elasticity of pesticide demand is found in studies that maintain a lower level of aggregation of the pesticide input (e.g., modelling specific pesticides such as herbicides and fungicides separately, versus aggregating over all types of pesticides). This suggests that there are few substitutes for these specific products, with the result that the producers face difficulties in adjusting their agricultural practices. The difficulty of finding lower-risk alternatives or applying alternative crop protection practices is also mentioned by Wilson and Tisdel [29].

4. Risk and uncertainty for the pesticides user and regulator in relation to pesticide use

Both the regulator and the pesticide user face risks and different sources of uncertainties that affect the social optimum. Production uncertainty related to variability in climatic conditions can affect farmers' pesticide use decisions. For instance, high levels of precipitation can increase weed growth, leading to increased herbicide applications. Skevas et al. [30] show that ignoring the effects of variability in production conditions when measuring farmers' performance may lead to an overestimation of farmers' pesticide environmental inefficiency. The pesticide user also faces uncertainty about pest arrival that can lead to the overuse of pesticides relative to the private or social optimum. Norgaard [31] notes that the major motivation for pesticide application is the provision of some “insurance” against damage. Feder [32] shows that an increase in the degree of uncertainty due to pest damage will cause an increase in the amount of pesticide used. As uncertainty in the pest–pesticide system leads to a higher and more frequent use of pesticides, there is also uncertainty regarding the effectiveness of pesticides. Farmers lack full knowledge of the relation between pesticides and pest mortality [32] and the effectiveness of pesticides can be influenced by fluctuations in temperature, wind and air humidity conditions. So the pest population can vary with changes in climatic conditions, though these changes can also alter the effect of pesticides, as every chemical product has different durability.

The Just and Pope [33] approach to modelling production processes in the face of production risk has been a popular addition to the literature, and is widely used in applied analyses related to pesticide use. In the Just and Pope model, the variation in production is influenced by the input levels: some inputs may be variation-increasing, whereas other inputs are variation-decreasing, where risk is defined as the variance of output. Saha et al. [34] and Griffiths and Anderson [35] also support the conventional view that pesticides are risk-reducing inputs.

On the other hand, Horowitz and Lichtenberg [36] show that limited knowledge of the production process, captured by assuming that pest damage is independent of other factors affecting output, leads to the conventional view that pesticides are risk-reducing inputs. Pesticides may increase risk when pest populations are positively correlated with growth conditions. When pest populations are large and growth conditions are favourable, pesticides will be risk-increasing as they increase the variability of harvests (increase output under good growth conditions). Gotsch and Regev's [37] study of Swiss wheat producers shows that fungicides have a risk-increasing effect on farm revenues when rain levels are low. Similar results are reported by Saha et al. [38] when the production process takes into account the interaction between pesticides and fertilizers, and by Pannell [39] where herbicides have a risk-increasing effect on wheat farmers in Kansas. Horowitz and Lichtenberg [40] have shown that pesticides may be risk-increasing inputs and farmers who purchase federal government crop insurance use more chemicals *ceteris paribus*. This view on pesticides is contradicted by Smith and Goodwin [41].

Saha et al. [38] report the importance of considering the stochastic nature of both the damage control and the production function to avoid overestimating the marginal productivity of damage control inputs. With pesticide productivity affected by the level of the developed resistance, the more resistant the pest population, the higher the use of the damage control agents (pesticides) until resistance is sufficiently pervasive and alternative damage control measures are more cost effective.

Uncertainty of the regulator of pesticides arises from incomplete knowledge about the side effects of pesticides. Postponing

Table 2
Pesticide Demand Elasticity Estimates.

Study	Country/region	Elasticity
Aaltink [65]	The Netherlands	−0.13 to −0.39
Antle [66]	USA	−0.19
Bauer et al. [67]	German regions	−0.02
Brown and Christensen [68]	USA	−0.18
Carpentier [69]	France	−0.3
DHV and LUW [70]	The Netherlands	−0.2 to −0.3
Dubgaard [71]	Denmark	−0.3 (threshold approach)
Dubgaard [72]	Denmark	−0.7 (herbicides), −0.8 (fung. + insect.)
Ecotec [73]	UK	−0.5 to −0.7 (herbicides)
Elhorst [74]	The Netherlands	−0.3
Falconer [62]	UK (East Anglia)	−0.1 to −0.3
Gren [75]	Sweden	−0.4 (fung.), −0.5 (insect.), −0.9 (fung.)
Johnsson [76]	Sweden	−0.3 to −0.4 (pesticides)
Komen et al. [77]	The Netherlands	−0.14 to −0.25
Lichtenberg et al. [78]	USA	−0.33 to −0.66
McIntosh and Williams [79]	Georgia (USA)	−0.11
Oskam et al. [80]	The Netherlands	−0.1 to −0.5 (pesticides)
Oskam et al. [14]	EU	−0.2 to −0.5 (pesticides)
Oude Lansink [81]	The Netherlands	−0.12
Oude Lansink and Peerlings [82]	The Netherlands	−0.48 (pesticides)
Papanagiotou [83]	Greece	−0.28
Petterson et al. [84]	Sweden	−0.2
Rude [85]	Sweden	−0.22 to −0.32
Russell et al. [86]	UK (Northwest)	−1.1 (pesticides in cereals)
SEPA [87]	Sweden	−0.2 to −0.4
Schulte [88]	Three German regions	−0.23 to −0.65
Villezca and Shumway [89]	Texas and Florida (USA)	−0.16 to −0.21

Source: Hoevenagel et al. [13]; Falconer and Hodge [90]; Fernandez-Cornejo et al. [91].

pesticide regulation to wait for better scientific knowledge can lead to irreversible environmental and health costs. The precautionary principle, first defined in the 1992 Rio Declaration, addresses this issue by maintaining that uncertainty regarding the environmental or health effects of pesticide use should not act as an obstacle to the timely introduction of pesticide policies. The precautionary principle is theoretically grounded in the theory of the quasi-option value and, in this context, implying that greater uncertainty about the future impacts of an externality increases the costs of current use of pesticides [42].

The following hypothetical example illustrates how the precautionary principle applies to pesticide application in agriculture. Consider the introduction of a tax scheme to internalize pesticide externalities in a two-time period setting. In the current period there is uncertainty about the future state of the world. The negative external effects of pesticides have not been documented fully, nor have the costs of introduction been quantified precisely. However, introducing a pesticide tax in the current period can be more costly than waiting for better information, as the intensity of regulation introduced may be excessive. Acting in the future period can be devastating in terms of biodiversity loss, as there are often difficulties with enhancing biodiversity levels after long periods of intensive agrochemical use [43], Therefore, uncertainty about the benefits, or avoiding negative external effects, may induce the regulator to introduce a greater intensity of regulation in the current period.

Risk and uncertainty have implications not only for the time of introduction and the intensity of regulation per se but also for the choice of policy instrument; i.e., taxation versus quantity control that may involve bans or quota. Weitzman [44] finds that when there is uncertainty about the marginal costs of supplying a good, a price instrument is more (less) efficient than a quantity instrument if the marginal benefits of that good are relatively flat (steep) compared with the marginal costs. Hepburn [45] provides a graphical representation of Weitzman's finding by illustrating the choice of a tax versus a quantity control relative to the marginal costs and benefits followed by practical examples. In the case of pesticides, let's hypothesize that the relevant good is the reduction of pesticide environmental spillovers (i.e., providing a cleaner/safer environment). Suppose the marginal cost of reducing the environmental spillovers of pesticides is uncertain and increases quickly due to irreversibility involved in enhancing for example biodiversity levels [43]. The marginal benefit from a decrease in the environmental spillovers of pesticides is relatively flat (i.e., the environmental damages from pesticide use may still be high but do not change rapidly as a function of additional pesticide applications). In this case, a pesticide tax is the appropriate instrument to use. On the other hand, if damages rise above a regulatory limit then the use of a quantity-based instrument (e.g., a ban on pesticides) is encouraged.

5. Pesticide risk valuation

During the last two decades, many attempts have been made to value pesticide risks. Economists have focused primarily on the evaluation of health benefits for farmers and consumers due to the historically human-driven interest in pesticide risk management. The food safety literature focuses primarily on the evaluation of human health risks related to the presence of pesticide residues in fresh food whereas the valuation literature focuses on consumers' WTP for residue-free products [46]. In recent years, WTP studies have been extended to pesticide health risks for farmers [47], whereas some studies estimate WTP for both human health and the environment (e.g., [48]). The meta-analyses of Florax et al. [46] and Travisi et al. [49] provide an overview of the literature on pesticide risk valuation. These analyses find that the literature is diverse, providing WTP estimates largely for various human health risks, with fewer studies addressing environmental risks. The studies addressing the negative externalities on human health find great variation in the WTP estimates, with some studies finding higher WTP for human safety than for environmental quality [48], whereas others present higher WTP for environmental quality than for food safety and human health [50]. This mixed evidence is attributed to the use of different valuation techniques, and to differences among the available biomedical and ecotoxicological data. Foster and Mourato [48] provide a conjoint analysis of pesticide risks by estimating the marginal value of risk reduction for human health and bird biodiversity. Additionally, Schou et al. [51] and Travisi and Nijkamp [52] used a choice experiment approach to estimate the economic value of reduced risks from pesticide use. The latter approach was also used by Chalak et al. [53], who found high WTP for reduced pesticide use for both environmental quality and consumer health. Moreover, their study indicates the presence of heterogeneous preferences for pesticide reduction in relation to environmental quality and food safety.

The review of WTP studies has shown that consumers, in general, are willing to pay for a reduction in human health and environmental risks resulting from the application of pesticides. This fact favours farmers' switch to IPM or organic agriculture. In this way, reductions in pesticide use could be attained with gains in farm income through conversion to less pesticide-intensive cropping systems. Advice, training and extension in reduced pesticide use practices can encourage farmers' conversion to less pesticide-intensive farming. Subsidizing production on certified farms (e.g., IPM or organic) or promoting self-regulation for pesticide-free products may further stimulate farmers to alter their crop protection practices.

The many WTP studies available enable the calculation of a mean WTP for a lower exposure to different risks. As the income elasticity of WTP for risk reduction is not significantly different from zero and geographical differences in valuation are minor [46], WTP estimates from other countries can be used in EU pesticide policy design to assist, in the case of an economic incentive-based policy, in determining the pesticide tax level and in quantifying the benefits from pesticide risk reduction, more generally.

6. Indirect effects of pesticides

Data on the indirect effects of pesticides can enable the development of environmental and health standards, thus favouring the introduction of regulatory schemes that will use economic incentives to attain these standards. Research on pesticide spillovers on human health seems to be more advanced considering the banning of many active ingredients on human health grounds. Sexton et al. [54] underline the need for and difficulty in incorporating and translating pesticide externalities into policy. They also confirm the low level of knowledge on the environmental effects of pesticides compared with human health effects. The use of environmental and health standards in pesticide policies in different EU countries are listed in Table 3. Only a few European countries (i.e., Sweden, Norway, France, and Belgium) use environmental and/or health standards to base their pesticide policy tools on. Sweden was one of the first countries to introduce a simple tax scheme based on an environmental tax, whereas Norway uses a tax system where the taxation level is banded by health and environmental properties. In France there are taxes on seven categories of pesticides as non-point sources of pollution, which reflects the differing environmental load of each plant protection product. Belgium has recently introduced a pesticide tax on five active substances that is based on health and environmental risk criteria [55]. According to OECD [55] the use of plant protection products in the abovementioned countries has declined, but it is difficult to separate the impact of taxation on pesticide use from other factors influencing farmers' use decisions. Moreover, in Norway, the high reductions in pesticide risks should be treated with caution due to the stockpiling of pesticides prior to the expected increases in pesticide taxation [55].

The changes in environmental and health risks can be quantified through a number of indices providing a measure of the hazard inherent to a substance. The Environmental Impact Quotient (EIQ) is such an index that calculates pesticides' toxicity by taking into account the potential hazard to field workers, consumers and the environment [56]. Cross and Edwards-Jones [57] use the EIQ and a simple extension of it to assess changes in pesticide hazard in the UK for arable farming between 1992 and 2008. Labite et al. [58] review 19 pesticide hazard indices, stating that indices differ in terms of methods used and functionality. In conclusion, the current literature offers approaches to quantify pesticide spillovers with the selection of the appropriate approach depending on the specific requirements and available data [58].

7. Discussion

The review of the information needed for the introduction of an optimal pesticide policy framework in the EU has revealed several knowledge gaps, thus providing useful insights to policy makers. The evidence from studies using the LZ specification is mixed. Overuse or underuse of pesticides may depend on the specification itself but also on the application to different crops. More research needs to be done across EU countries for different crops to obtain a clear view of pesticide use trends. Overuse of pesticides implies that policy efforts should focus on decreasing applied quantities whereas underuse shows that the policy target should not be to reduce the pesticide application volume but to stimulate substitution of hazardous products with low-toxicity alternatives.

Pesticide productivity varies amongst other things with changes in climatic conditions, indicating that taxes on pesticides should be country or region specific. A considerable number of pesticide risk studies oppose the conventional view of pesticides being risk reducing. If pesticides are risk increasing then a pesticide tax (leading to reduced pesticide use) will render agricultural production less risky. Greater dissemination of such scientific findings may increase the effectiveness of pesticide tax schemes. With pesticide demand in general being inelastic, only large pesticide price changes can alter farmers' practices. Considering that high pesticide tax rates may be politically problematic, pesticide taxation might not be considered an effective policy instrument. However, taking into account producers' heterogeneity, economic incentives may still play a role in pesticide policies by encouraging efficiency improvements in pesticide applications or movement to less pesticide intensive forms of cropping (e.g., IPM).

As pesticides are not homogeneous goods, pesticide taxation needs classification according to toxic contents [59]; i.e., higher taxes to be imposed on pesticides that are more harmful to the environment and human health. Hazard ranking approaches are available but their use depends amongst other things on data availability [58]. Oskam et al. [14] strongly encourage the European Commission to adopt a uniform or, if possible, a differentiated tax within the EU. A uniform tax would be a second-best choice in cases where there is lack of data on the external effects of pesticides, rendering the pesticide differentiation process a difficult task. In this case a uniform tax can lead to increased tax revenues (due to inelastic pesticide demand, as shown in Section 3.2) that can be used to fund research on pesticide externalities and stimulate the development of a system of pesticide hazard ranking that will enable policy makers to develop differentiated taxes. Effective pesticide policies should differentiate pesticides according to their health and environmental externalities as current EU pesticide policy [1] highlights the importance of reducing risks to both human health and the environment.

More than a decade ago, Hoevenagel et al. [13] noted the difficulties in discriminating pesticides according to their environmental externalities. Since then, no action has been taken by the EU in stimulating an EU-wide or country specific data collection of pesticide impacts. Labite et al. [58] confirm the absence of a standard

Table 3
Pesticide policies in different European countries.

Country	Description of pesticide policy	Values for pesticide taxes/fees/levies
Sweden	Environmental tax per kg of active substance	30 SEK per kg active substance (ac) (€3.25 per kg ac)
Norway	Banded tax system	Basic tax: 20 NOK per ha (€2.6 per ha), LT products: €2.6 per ha, MT: €10.4 per ha, HT: €20.8 per ha[a]
Denmark	- Differentiated pesticide tax - Overall tax on all pesticides.	Insecticides: 54% of retail price (rp), Herbicides/fungicides/growth regulators: 34% of rp; wood preservatives: 3% of gross value
Italy	Sales control, pesticide tax	0.5% and 1% over the final price of domestic and imported pesticides, respectively
UK	- Target fee for registration - General fee for industry.	Target fee: €5000, General fee: €5719
Switzerland	- Direct payments, Extra subsidies. - Minimum ecological standards.	
Finland	Registration charge	€ 840 + 3.5% of final price (excluding VAT)
Netherlands	Integrated crop protection on certified farms	
France	Pesticide tax	Category[a] 1: € per ton, 2: € 381 per ton, 3: €610 per ton, 4: €838 per ton, 5: €1067 per ton, 6: €1372 per ton, 7: €1677 per ton
Germany	Pesticide reduction programme	
Belgium	Tax on five active substances[b]	€0.395 per kg

Source: OECD [55]; Hoevenagel et al. [13]; PAN Europe [92]; Parkkinen [93].
[a] LT, MT and HT denote low medium and high toxicity products, respectively. Pesticides taxes also exist for seed treatment pesticides (€1.3 per ha), concentrated hobby products (€130 per ha), and ready to use hobby products (€390 per ha).
[b] Categories reflect the different environmental load of each plant protection product with 1 and 7 being the lowest and highest toxicity category, respectively. [c] Based on health and environmental criteria.

methodology for selecting input data for tools that rank pesticide risks. Zilberman and Millock [60] argue that the construction of an effective pesticide tax scheme requires rigorous data collection on pesticide use at farm level. As pesticide application levels and their externalities are very diverse across different regions and under different climatic conditions [61], country-specific research is of utmost importance. Pesticide classification through the development of environmental impact-based indicators for each country or region would be important for improving the effectiveness of pesticide policies. The tax systems based on environmental standards and used in some countries encompass compelling lessons for an EU-wide regulatory framework on ways to charge, collect, differentiate and reimburse the tax. The limited use of the environmental or health standards in national pesticide policies and the small reductions in pesticide use in the countries that use these standards may be attributed to the multidimensionality and lack of data on indirect effects of pesticides. This has made it impossible for policy makers to introduce optimal economic incentive-based policies that will not only aim to finance national action plans but will also affect farmers' behaviour.

Falconer [62] argues that an effective environmental banding could be based on groups of pesticides with similar hazard scores instead of developing environmental indicators (based on environmental impacts) for each pesticide. A starting point for such a classification could be the development of hazard scores for the labelling of pesticides, including precautions for environmental and human health safety and its mandatory in all EU member states. Pesticide clusters with higher hazard scores could be prioritized for reductions.

The optimal regulatory strategy does not have to be composed of single policy tools but can involve a mixture of measures and actions such as tax schemes, direct controls, farm certification and self-regulation. In this way the different measures may compensate each one's deficiencies. Taxes may have little effect on total pesticide use, but may help in creating awareness among farmers; direct controls can be an effective tool for reducing pesticide use, but often have little support among farmers; certification and self-regulation are facing relatively high transaction and monitoring costs, but are appealing tools for affecting farmer behaviour in the long run. Skevas et al. [95] examined the impact of different economic instruments on pesticide use and environmental spillovers in Dutch arable farming and concluded that a pesticide policy composed of different instruments may better address the desired policy targets. Pesticide policies can be co-ordinated by the EU with taxes or direct controls that are country or region specific, as pesticide use and externalities vary regionally due to differences in agronomic characteristics [63]. Action taken at EU level implies strong competitive effects between national regulatory systems [64]. Integrating economic incentives (defined at EU level) in existing national regulatory structures may induce strong political pressures on national policy makers to reform these structures. Knill and Lenschow [64] state that the use of economic instruments at EU level has been relatively weak compared with the national level, pointing to the required member states' unanimity needed in tax-related decisions as a limiting factor. However, the authors add that such problems may be bypassed by enhanced co-operation among groups of member states. Finally, a cost-benefit analysis assessing environmental benefits, farmers' abatement costs and administrative costs of implementing a pesticide policy should be an essential step in designing and evaluating an optimal regulatory strategy.

8. Concluding remarks

In an era where existing EU pesticide policies are streamlined and new policies are planned, this study sheds light on the optimal pesticide policy framework and examines the elements needed for applying such a framework. An optimal pesticide policy should include tax schemes that are based on standards for environmental and health quality but may not rely necessarily on a specific measure. As the introduction of market-based policy instruments is among the future plans of EU policy makers, this study offers some important insights. Inelastic pesticide demand suggests that tax rates should be high while the development of health and environmental standards, where differentiated tax rates can be based on, needs further attention due to inadequate information on pesticide externalities. Evidence from pesticide use trends (overuse or underuse) among different crops and countries and its relation to risk is mixed, implying that further investigation is needed possibly at individual country level. The availability and robustness of WTP estimates concerning their income elasticity and geographical distribution enables policy makers to use WTP estimates from other countries in the design of pesticide regulations. The great variety of pesticide risks suggests that more primary research is needed. Pesticides affect human beings and other organisms differently and have various environmental effects across countries due to differences in climatic conditions and species richness. Therefore pesticide policy tools like taxes need classification according to toxic contents. Approaches developing ranking systems of pesticide hazards do exist but their use depends on data availability. Country-specific research on the effects of existing active ingredients on the environment and a comparison of their effects on human health may enable researchers to introduce differentiated fiscal measures, and trigger the chemical industry to develop effective alternatives. As agrochemical innovation in general is complex, costly and time consuming, the development of economic incentive-based policies grounded in the reality of agriculture can foster the innovation of crop pest agents.

Acknowledgments

The authors acknowledge the support by the EU-funded project, TEAMPEST, a collaborative project in the Seventh Framework Programme Theme 2: Food, Agriculture and Fisheries, and Biotechnology (http://www.eng.auth.gr/ mattas/teampest/).

References

[1] Commission of the European Communities, A thematic strategy on the sustainable use of pesticides. Communication for the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, COM (2006) 372 Final, Brussels, 2006.
[2] J. Cooper, H. Dobson, The benefits of pesticides to mankind and the environment, Crop Protection 26 (2007) 1337–1348.
[3] R.L. Carson, Silent Spring, Houghton Mifflin Company, Boston, 1962.
[4] D. Pimentel, H. Acquay, M. Biltonen, P. Rice, M. Silva, J. Nelson, V. Lipner, S. Giordano, A. Horowitz, M. D'Amore, Environmental and economic costs of pesticide use, BioScience 42 (1992) 750–760.
[5] D. Pimentel, A. Greiner, Environmental and socio-economic costs of pesticide use, in: D. Pimentel (Ed.), Techniques for Reducing Pesticide Use: Economic and Environmental Benefits, John Wiley & Sons, Chichester, 1997, pp. 51–78.
[6] A.N. Sharpley, R.W. McDowell, P.J.A. Kleinman, Phosphorus loss from land to water: integrating agricultural and environmental management, Plant and Soil 237 (2001) 287–307.
[7] R. Schulz, G. Thiere, J.A. Dabrowski, A combined microcosm and field approach to evaluate the aquatic toxicity of azinphos-methyl to stream communities, Environmental Toxicology and Chemistry 21 (2002) 2172–2178.
[8] L. Levitan, How "to" and "why": assessing the enviro-social impacts of pesticides, Crop Protection 19 (2000) 629–636.
[9] Eurostat, 2012, Retrieved: 2 September 2012, Available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database
[10] Anon, The state of food insecurity in the world: 2004, FAO/Economic and Social Department, Food and Agriculture Organization, Rome, 2004.
[11] W.J. Baumol, W.E. Oates, The Theory of Environmental Policy, Cambridge University Press, Cambridge, 1988.
[12] J. Pretty, C. Brett, D. Gee, R. Hine, C. Mason, J. Morison, M. Rayment, G. Van der Bijl, T. Dobbs, Policy challenges and priorities for internalizing the externalities of modern agriculture, Journal of Environmental Planning and Management 44 (2001) 263–283.
[13] R. Hoevenagel, E. van Noort, R. De Kok, Study on a European Union wide regulatory framework for levies on pesticides, Commissioned by: European Commission/DG XI, EIM/Haskoning, Zoetermeer, 1999.
[14] A.J. Oskam, R. Vijftigschild, C. Graveland, Additional EU Policy Instruments for Plant Protection Products, Wageningen Agricultural University (Mansholt Institute), Wageningen, 1997.
[15] R.N. Stavins, Experience with market-based environmental policy instruments, in: K.G. Mäler, J.R. Vincent (Eds.), Handbook of Environmental Economics Environmental Degradation and Institutional Responses, vol., Elsevier Science, North-Holland,Amsterdam, 2003, pp. 355–435.
[16] C. Brethour, A. Weersink, An economic evaluation of the environmental benefits from pesticide reduction, Agricultural Economics 25 (2001) 219–226.
[17] C.A. Brittain, M. Vighi, R. Bommarco, J. Settele, S.G. Potts, Impacts of a pesticide on pollinator species richness at different spatial scales, Basic and Applied Ecology 11 (2010) 106–115.
[18] D. Aigner, C.A. Knox Lovel, P. Schmidt, Formulation and estimation of stochastic frontier production function models, Journal of Econometrics 6 (1977) 21–37.
[19] A. Oude Lansink, A. Carpentier, Damage control productivity: an input damage abatement approach, Journal of Agricultural Economics 52 (2001) 1–12.
[20] D.C. Hall, R.B. Norgaard, On the timing and application of pesticides: rejoinder, American Journal of Agricultural Economics 55 (1973) 198–201.
[21] H. Talpaz, I. Borosh, Strategy for pesticide use: frequency and application, American Journal of Agricultural Economics 56 (1974) 769–775.
[22] E. Lichtenberg, D. Zilberman, The econometrics of damage control: why specification matters, American Journal of Agricultural Economics 68 (1986) 261–273.
[23] B.A. Babcock, E. Lichtenberg, D. Zilberman, Impact of damage control and quality of output: estimating pest control effectiveness, American Journal of Agricultural Economics 74 (1992) 165–172.
[24] Z. Guan, A. Oude Lansink, M. van Ittersum, A. Wossink, Integrating agronomic principles into production function specification: a dichotomy of growth inputs and facilitating inputs, American Journal of Agricultural Economics 88 (2006) 203–214.
[25] C. Carrasco-Tauber, L.J. Moffit, Damage control econometrics: functional specification and pesticide productivity, American Journal of Agricultural Economics 74 (1992) 158–162.
[26] R.G. Chambers, E. Lichtenberg, Simple econometrics of pesticide productivity, American Journal of Agricultural Economics 76 (1994) 407–417.
[27] A. Oude Lansink, E. Silva, Non-parametric production analysis of pesticides use in the Netherlands, Journal of Productivity Analysis 21 (2004) 49–65.
[28] B.H. Lin, S. Jans, K. Ingram, L. Hansen, Pesticide Productivity in Pacific Northwest Potato Production. Agricultural Resources: Inputs, US Department of Agriculture, 1993 (ERS publication AR-29).
[29] C. Wilson, C. Tisdell, Why farmers continue to use pesticides despite environmental, health and sustainability costs, Ecological Economics 39 (2001) 449–462.
[30] T. Skevas, A. Oude Lansink, S. Stefanou, Measuring technical efficiency in the presence of pesticide spillovers and production uncertainty: the case of Dutch arable farms, European Journal of Operational Research 223 (2012) 550–559.
[31] R.B. Norgaard, The economics of improving pesticide use, Annual Review of Entomology 21 (1976) 45–60.
[32] G. Feder, Pesticides, information, and pest management under uncertainty, American Journal of Agricultural Economics 61 (1979) 97–103.
[33] R.E. Just, R.D. Pope, Stochastic specification of production functions and economic implications, Journal of Econometrics 7 (1978) 67–86.
[34] A. Saha, C.R. Shumway, H. Talpaz, Joint estimation of risk preference structure and technology using expo-power utility, American Journal of Agricultural Economics 76 (1994) 173–184.
[35] W.E. Griffiths, J.R. Anderson, Using time-series and cross-section data to estimate a production function with positive and negative marginal risks, Journal of the American Statistical Association 77 (1982) 529–536.
[36] J.K. Horowitz, E. Lichtenberg, Risk-reducing and risk-increasing effects of pesticides, Journal of Agricultural Economics 45 (1994) 82–89.
[37] N. Gotsch, U. Regev, Fungicide use under risk in Swiss wheat production, Agricultural Economics 14 (1996) 1–9.
[38] A. Saha, C.R. Shumway, A. Havenner, The economics and econometrics of damage control, American Journal of Agricultural Economics 79 (1997) 773–785.
[39] D.J. Pannell, Optimal herbicide strategies for weed control under risk aversion, Review of Agricultural Economics 17 (1995) 337–350.
[40] J.K. Horowitz, E. Lichtenberg, Insurance, moral hazard, and chemical use in agriculture, American Journal of Agricultural Economics 75 (1993) 926–935.
[41] V.H. Smith, B.K. Goodwin, Crop insurance, moral hazard, and agricultural chemical use, American Journal of Agricultural Economics 78 (1996) 428–438.
[42] K.J. Arrow, A.C. Fisher, Environmental Preservation, Uncertainty, and Irreversibility, The Quarterly Journal of Economics 88 (1974) 312–319.
[43] F. Berendse, M.J.M. Oomes, H.J. Altena, W. Elberse, Experiments on the restoration of species-rich meadows in The Netherlands, Biological Conservation 62 (1992) 59–65.
[44] M. Weitzman, Prices vs quantities, Review of Economic Studies 41 (1974) 477–491.
[45] C. Hepburn, Regulation by prices, quantities, or both: a review of instrument choice, Oxford Review of Economic Policy 22 (2006) 226–247.
[46] R.J. Florax, C.M. Travisi, P. Nijkamp, A meta-analysis of the willingness to pay for reductions in pesticide risk exposure, European Review of Agricultural Economics 32 (2005) 441–467.
[47] C. Wilson, Pesticide avoidance: a result from a Sri-Lankan study with health policy implications, in: D.C. Hall, L.J. Moffitt (Eds.), Economics of Pesticides, Sustainable Food Production, and Organic Food Markets., Elsevier Science, Amsterdam, 2002.
[48] V. Foster, S. Mourato, Valuing the multiple impacts of pesticides use in the UK: a contingent ranking approach, Journal of Agricultural Economics 51 (2000) 1–21.
[49] C.M. Travisi, P. Nijkamp, G. Vindigni, Pesticide risk valuation in empirical economics: a comparative analysis, Ecological Economics 56 (2006) 455–474.
[50] K. Balcombe, A. Bailey, A. Chalak, I.M. Fraser, Bayesian estimation of willingness-to-pay where respondents mis-report their preferences, Oxford Bulletin of Economics and Statistics 69 (2007) 413–438.
[51] J.S. Schou, B. Hasler, B. Nahrsted, Valuation of biodiversity effects from reduced pesticide use, Integrated Environmental Assessment and Management 2 (2006) 174–181.
[52] C.M. Travisi, P. Nijkamp, Valuing environmental and health risk in agriculture: a choice experiment approach to pesticides in Italy, Ecological Economics 67 (2008) 598–607.
[53] A. Chalak, K. Balcombe, A. Bailey, I. Fraser, Pesticides, preference heterogeneity and environmental taxes, Journal of Agricultural Economics 59 (2008) 537–554.

[54] S.E. Sexton, Z. Lei, D. Zilberman, The economics of pesticides and pest control, International Review of Environmental and Resource Economics 1 (2007) 271–326.
[55] OECD, Environmental Performance of Agriculture in OECD Countries since 1990, Paris, 2008.
[56] J. Kovach, C. Petzoldt, J. Tette, A method to measure the environmental impact of pesticides, New York's Food and Life Science Bulletin (1992).
[57] P. Cross, G. Edwards-Jones, Variation in pesticide hazard from arable crop production in Great Britain from 1992 to 2008: an extended time-series analysis, Crop Protection 30 (2011) 1579–1585.
[58] H. Labite, F. Butler, E. Cummins, A review and evaluation of plant protection product ranking tools used in agriculture, Human and Ecological Risk Assessment 17 (2011) 300–327.
[59] C.W. Nam, R. Parsche, D.M. Radulescu, M. Schöpe, Taxation of fertilizers, pesticides and energy use for agricultural production in selected EU countries, European Environment 17 (2007) 267–284.
[60] D. Zilberman, K. Millock, Financial incentives and pesticide use, Food Policy 22 (1997) 133–144.
[61] G.A.A. Wossink, T.A. Feitshans, Pesticide policies in the European Union, Drake Journal of Agricultural Law 5 (2000) 223–249.
[62] K.E. Falconer, Environmental policy and the use of agricultural pesticides, PhD Thesis, University of Cambridge, Cambridge, 1997.
[63] J.S. Schou, Indirect regulation of externalities: the case of Danish agriculture, European Environment 6 (1996) 162–167.
[64] C. Knill, A. Lenschow, Compliance, communication and competition: patterns of EU environmental policy making and their impact on policy convergence, European Environment 15 (2005) 114–128.
[65] A.J. Aaltink, Economische Gevolgen van de Beperking van het Bestrijdingsmiddelengebruik in de Akkerbouw, PhD Thesis, Wageningen University, Wageningen, 1992.
[66] J.M. Antle, The structure of US agricultural technology, 1910–1978, American Journal of Agricultural Economics 66 (1984) 414–421.
[67] S. Bauer, U. Hoppe, S. Hummelsheim, Decision support system for controlling pesticide use in Hessen, in: A.J. Oskam, R. Vijftigschild (Eds.), Proceedings, Workshop on Pesticides, 24–27 August 1995, Wageningen, 1995.
[68] R.S. Brown, L.R. Christensen, Estimating elasticities in a model of partial static equilibrium: an application to U.S. agriculture, in: E.R. Berndt, B.C. Field (Eds.), Modeling and Measuring Natural Resource Substitution, MIT Press, Cambridge MA, 1981.
[69] A. Carpentier, A pesticide ban in the context of intensive cropping technology. The case of the French crop sector, in: J. Michalek, C.H. Hanf (Eds.), The Economic Consequences of a Drastic Reduction in Pesticide Use in the EU, Wissenschaftsverlag Vauk Kiel KG, Christian Albrechts University, Kiel, 1994, pp. 281–303.
[70] DHV and LUW, The possibility of a regulatory framework for agricultural pesticides, Final Report, Wageningen, 1991.
[71] A. Dubgaard, Anvendelse of afgifter til regulering af pesticidforbruget, Statens Jordbrugokonomiske Institut, Rapport 35, Copenhagen, 1987.
[72] A. Dubgaard, Pesticide regulation in Denmark, in: N. Hanley (Ed.), Farming and the Countryside: An Analysis of External Costs and Benefits, CAB International, Wallingford, 1991, pp. 48–58.
[73] Ecotec, Economic Instruments for Pesticide Minimization, Ecotec, Birmingham, 1997.
[74] J.P. Elhorst, De Inkomensvorming en Inkomensverdeling in de Nederlandse Landbouw Verklaard vanuit de Huishoudproduktietheorie, vol. 72, LEI-onderzoeksverslag, The Hague, 1990.
[75] I.M. Gren, Regulating the farmers' use of pesticides in Sweden, in: H. Opschoor, K. Turner (Eds.), Economic Incentives and Environmental Policies: Principles and Practice, North-Holland, Dordrecht, 1994.
[76] B. Johnsson, Kostnader for Begransad Anvandning av Kemiska Bekampningsmedel, Research Paper, Department of Economics Swidissh University of Agricultural Sciences, Uppsala, 1991.
[77] M.H.C. Komen, A.J. Oskam, J. Peerlings, Effects of reduced pesticide application for the Dutch economy, in: A.J. Oskam, R. Vijftigschild (Eds.), Proceedings, Workshop on Pesticides, Wageningen, 24–27 August 1995, Wageningen, 1995.
[78] E. Lichtenberg, D.D. Parker, D. Zilberman, Marginal analysis of welfare costs of environmental policies: the case of pesticide regulation, American Journal of Agricultural Economics 70 (1988) 867–874.
[79] C.S. McIntosh, A.A. Williams, Multiproduct production choices and pesticide regulation in Georgia, Southern Journal of Agricultural Economics 24 (1992) 135–144.
[80] A.J. Oskam, H. van Zeijts, G.J. Thijssen, G.A.A. Wossink, R. Vijftigschild, Pesticide use and pesticide policy in The Netherlands, Wageningen Economic Studies 26, Wageningen, 1992.
[81] A. Oude Lansink, Effects of input quota in dutch arable farming, Tijdschrift voor Sociaal Wetenschappelijk Onderzoek van de Landbouw 9 (1994) 197–217.
[82] A. Oude Lansink, J. Peerlings, Farm specific impacts of policy changes on pesticide use in Dutch arable farming, in: A.J. Oskam, R. Vijftigschild (Eds.), Proceedings, Workshop on Pesticides, Wageningen, 24–27 August 1995, Wageningen, 1995.
[83] E. Papanagiotou, The potential for a substantial reduction of pesticide application in Greek Agriculture, in: A.J. Oskam, R. Vijftigschild (Eds.), Proceedings, Workshop on Pesticides, Wageningen, 24–27 August 1995, Wageningen, 1995.
[84] O. Petterson, J. Petterson, V. Johansson, H. Fogelfors, R. Sigvald, B. Johnsson, Minskad Bekampning I Jordbruket; Mogligheter och Kronsekvenser, K. Skogs-och Lantbruksakademisk Tidskrift 128 (1989) 379–396.
[85] S. Rude, Pesticideforbrugets Udvikling Landbrugs og Miljopolitiske Scenarier (Report No.68), Statens Jordbrugsokonomiske Institut, Copenhagen (English Summary), 1992.
[86] N.P. Russell, V.H. Smith, B.K. Goodwin, The effects of common agricultural policy reform demand for crop protection in the UK, in: A.J. Oskam, R. Vijftigschild (Eds.), Proceedings, Workshop on Pesticides, Wageningen, 24–27 August 1995, Wageningen, 1995.
[87] SEPA, Environmental taxes in Sweden, Swedish Environmental Protection Agency, Stockholm, 1997.
[88] J. Schulte, Der Einfluss eines begrentzen Handelsduenger und Pflanzenbehandlungs-Mitteleinsatzes auf Betriebsorganisation und Einkommen verschiedner Betriebssyteme. Dissertation Rheinischen Friedrich-Wilhelms Universität, Bonn, 1983.
[89] P. Villezca-Becerra, C.R. Shumway, State-level output supply and input demand elasticities for agricultural commodities, Journal of Agricultural Economics Research 44 (1992) 22–34.
[90] K. Falconer, I. Hodge, Using economic incentives for pesticide usage reductions: responsiveness to input taxation and agricultural systems, Agricultural Systems 63 (2000) 175–194.
[91] J. Fernandez-Cornejo, S. Jans, M. Smith, Issues in the economics of pesticide use in agriculture: a review of the empirical evidence, Review of Agricultural Economics 20 (1998) 462–488.
[92] PAN Europe, Pesticide taxes- national examples and key ingredients, Briefing no. 6, 2005, Retrieved: 10 September 2008, Available at: http://www.pan-europe.info/publications/index.shtm
[93] T. Parkkinen, Detailed information on environment-related taxes and charges in Finland. Finland's Environmental Administration, 2008, Retrieved: 12 May 2009, Available at: http://www.environment.fi/download.asp?contentid=85625&lan=en
[94] FAO, AGP-Integrated Pest Management, 2012, Retrieved: 31 August 2012, Available at: http://www.fao.org/agriculture/crops/core-themes/theme/pests/ipm/en/
[95] T. Skevas, S. Stefanou, A. Oude Lansink, Can economic incentives encourage actual reductions in pesticide use and environmental spillovers? Agricultural Economics 43 (2012) 267–276.