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LEVIES FOR SUSTAINABLE AGRICULTURE? A META-ANALYTIC EXPLORATION OF DIFFERENT PESTICIDE PRICE ELASTICITIES IN AGRICULTURE

PETER NIJKAMP

GERARD PEPPING

Free University, The Netherlands

ABSTRACT

This article addresses the analytical potential of meta-analysis. Meta-analysis originated as a statistical procedure for combining and comparing research findings from different studies focusing on similar phenomena. For the social sciences, meta-analysis is particularly suitable in cases where research outcomes on similar phenomena are to be judged or even transferred to other situations. However, social science research is characterized by a low level of controllability. Moreover, in many cases the sample size of case studies of applied research on a given phenomenon is rather small. The main aim of the present article is to demonstrate that a new methodology based on a recently developed multidimensional classification method, coined rough set analysis, may be very suitable, as this method is able to deal with pattern recognition in categorical variables and to derive logical binary statements from a given data set. This method will be illustrated empirically in this article by exploring the potential impact of pesticide price regulation in agriculture on the basis of a comparative analysis of price elasticities collected from a limited set of studies. First, we carry out a conventional meta-analytic literary search, and collect and compare data on price elasticities by searching through the existing literature. Second, we apply rough set analysis in order to investigate the determinants of the price elasticity of the demand for pesticides, and end with some conclusions.

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1. INTRODUCTION

The rising popularity of the notion of *sustainable development* has increasingly provoked the need for operational (i.e., practical, measurable and policy-relevant) insight into the background of this concept. The standard, widely-cited World Commission on Environment and Development (WCED) definition of sustainable development as "a development that fulfills the needs of the present generation without endangering the future needs of future generations" is a meaningful starting point, but fails to offer manageable guidelines for sustainability strategies of local, regional, national, or international decision-making bodies or other actors. The complementary description of sustainable development by the International Union on Conservation of Nature/United Nations Environment Programme/World Wildlife Fund (IUCN/UNEP/WWF) emphasizes, from a more ecological angle, the need for "improving the quality of human life while living within the carrying capacity of supporting ecosystems." Since the beginning of the worldwide debate on sustainable development, a massive volume of literature has been published on this notion. Although no uniformly accepted definition has emerged, the basic intentions of the sustainability concept are clear: it aims at directing decisions of policy bodies and private actors toward a joint state of the economy (or society at large) and the ecology, such that the needs of current and future generations are fulfilled without eroding the ecological basis for a proper welfare and activity level of these generations [1].

In this framework, also Food and Agriculture Organization of the United Nations (FAO) has developed its own definition by encapsulating the interest of agricultural activities. Sustainable development is in the FAO description "environmentally non-degrading, technically appropriate, economic viable, and socially acceptable." This broad notion was put in a more precise context by specifying the features of a sustainable development as follows: "Resource use and environmental management are combined with increased and sustained production, secure livelihoods, food security, equity, social stability, and people's participation in the development process" [2]. This means clearly that in the FAO view this notion refers to a balance between environmental, social, and economic objectives to obtain maximum welfare, broadly defined, while taking account of external factors such as technology. In this context, agriculture is certainly a sector of preponderant importance. It plays a pivotal economic role in many developing and developed countries and is crucial to any development policy.

The strategic position of agriculture rests on the fact that this sector serves to satisfy basic human needs, while especially in developing countries a large share of employment is offered by this sector. At the same time, agriculture is concerned with the use of natural resources whose functioning is critical to ecological systems quality. Overexploitation of such resources erodes not only the ecological base, but also the economic prerequisites of our life support systems. This means that agriculture plays an absolutely critical role in a co-evolutionary development strategy of each country [3, 4].

Clearly, new technologies may help to improve the efficiency of agricultural production, but may at the same time be harmful because of overexploitation of resources and less environmental-benign production modes. Thus a fine tuning between economic progress, technology use, and environmental management is necessary for a balanced development of agriculture in all countries.

A clear example of a potentially unsustainable development path in agriculture is the wide-spread adoption of pesticides of a varied nature. The intensive use of pesticides in large parts of agricultural production in the world has been one of the key factors contributing to high production levels and efficiency rises. However, there is a rising concern about the impact of pesticides on human health and the environment. As a result, several national and international initiatives have been taken to reduce the use of pesticides and their emission into the environment. For example, the Commission of the European Communities has declared in its Fifth Environmental Action Programme (1992) that a significant reduction of pesticide use per unit of land should be achieved by the year 2000. Levies are often seen as a proper tool for a more sustainable use of pesticides (cf. [5]).

Farmers play a crucial role in the reduction of pesticide use and consequently in a reduction of the impact of pesticides on the environment. Therefore, the major challenge for an environmental-benign pesticide policy is, in addition to the formulation of legislative compulsory measures, to find ways for stimulating farmers to adapt their current farming practices. Various policy options exist for such a strategy. We mention here financial compensation for costs of additional protective measures taken by farmers, creation of a new market incentive by environmental quality labels, and direct regulation by licenses and competence certificates for pesticide retailers and farmers [6-9].

In this article we will explore in more detail the opportunities offered by the policy option of pesticide price regulation. We will do so by identifying common lessons from a set of pesticide price elasticity studies on the basis of a comparative analysis. The main emphasis will be on the use of recently developed meta-analytic techniques in order to draw general or transferable conclusions out of a limited set of existing case studies. Meta-analysis has become a popular and powerful tool in comparative case study research in the past decade. It comprises a variety of methods and techniques; a concise introduction and survey will be given in Section 2. In the framework of the present article two steps will be taken. First, we will use elasticities by searching through the existing literature. Various results on this subject taken from simulation exercises and survey data work undertaken by others will be examined and evaluated (Section 3). And second, we will undertake a more sophisticated meta-analysis using modern rough set analysis in order to investigate the determinants of pesticide price elasticity (Section 4). Finally, the article will offer some conclusions.

2. THE USE OF META-ANALYSIS IN COMPARATIVE CASE STUDY RESEARCH

As mentioned, our comparative analysis of pesticide price elasticities will be based on a meta-analytic approach. Meta-analysis began as a statistical procedure for combining and comparing research findings from different studies focusing on similar phenomena (see [10-12]). Meta-analysis is particularly suitable in cases where research outcomes are to be judged or compared (or even transferred to other situations) when there are no controlled conditions. In the past decade, a variety of meta-analytical methods have been developed [13, 14]. Most meta-analytical techniques are designed for sufficiently large numbers of case studies, so that statistical probability statements can be inferred. And in this respect, meta-analysis has shown its usefulness as a methodological tool for comparative study in the social sciences. Examples can be found in psychology, labor economics, environmental science, and transportation science [15-19].

In general terms, the meta-analytical approach provides a series of techniques that allow the cumulative results of a set of individual studies. In this way it does not only provide more accurate evaluations of quantitative parameters, but it may also offer new insights into phenomena for which as yet no specific study exists. It may also help to pinpoint judgment bias and to provide more clearly defined inferences on the economic costs and benefits from the plethora of data that exists. It may act as a supplement to more common literary type of analytical approaches when reviewing the usefulness of parameters derived from prior studies and help direct new research to areas where there is a clear need for generalization and transferability.

A good description of the potential of meta-analysis can be found in [20]. "Meta-analysis offers a set of quantitative techniques that permit synthesizing results of many types of research, including opinion surveys, correlational studies, experimental and quasi-experimental studies and regression analysis probing causal models. In meta-analysis the investigator gathers together all the studies relevant to an issue and then constructs at least one indicator of the relationship under investigation from each of the studies. These study-level indicators are then used (much as observations from individual respondents are used in individual surveys, correlational studies, or experiments) to compute means, standard deviations and more complex statistics" [20]. In conclusion, meta-analysis seeks to gain additional scientific insights in a variety of ways from previous investigations. These ways are:

- combining and averaging, possibly using weights, estimated values or basic relationships, performance indicators, or achievements;
- comparing, evaluating, and ranking different studies on the basis of well-defined scientific criteria or performance measures;
- aggregating studies, by considering complementary results or explanations;

- apprehending common elements in different studies of a similar phenomenon;
- evaluating different methods applied to similar questions or research issues; and
- tracing key factors that are responsible for differing results across similar studies or research endeavors undertaken elsewhere.

In conclusion, meta-analysis is largely a mode of thinking and may comprise a multiplicity of different methods and techniques, which are often statistical in nature. Especially in cases of quasi-controlled or non-controlled comparative experimentation, the level of information is often not cardinal, but imprecise (e.g., categorical, qualitative, fuzzy). In recent years, rough set theory has emerged as a powerful analytical tool for dealing with "soft" data. Rough set theory aims to offer a classification of data measured on any information level by manipulating data in such a way that a range of consistent and feasible cause-effect relationships can be identified, while it is also able to eliminate redundant information. Therefore, we will give a concise introduction to rough set theory [21-22].

Rough set analysis is a non-parametric statistical method that is able to handle a rather diverse and less immediately tangible set of factors. Rough set analysis, proposed in the early 1980s by Pawlak [21, 24] provides a formal tool for transforming a data set, such as a collection of past examples or a record of experience, into structured knowledge, in the sense of ability to classify objects in distinct classes of attributes [25]. In such an approach it is not always possible to distinguish objects on the basis of given information (descriptors) about them. This imperfect information causes indiscernibility of objects through the values of the attributes describing them and prevents them from being unambiguously assigned to a given single set. In this case the only sets which can be precisely characterized in terms of values of ranges of such attributes are lower and upper approximations of the set of objects. Rough set theory has proven to be a useful tool for a large class of qualitative or fuzzy multiple-attribute decision problems. It can effectively deal with problems of explanation and prescription of a decision situation where knowledge is imperfect. It is helpful in evaluating the importance of particular attributes and eliminating redundant ones from a decision table, and it may generate sorting and choice rules using only the remaining attributes so as to identify new choice options in policy problems and next to rank them.

Decision rules, which constitute the most relevant aspects of rough set analysis, may be applied immediately in order to supply recommendations and advice in problems of *multi-attribute sorting*, that is in the assignment of each potential action to an appropriate pre-defined category according to particular aims. In this case, the classification of a new object may be usefully undertaken by a comparison between its description (values of the condition attributes) and the values contained in the decision rules. These are more general than the information contained in the original decision table and permit a classification of new or additional objects in larger numbers and more easily than would be possible using a direct comparison between these and the original examples. From the comparison with the decision rules one of the following cases may take place:

- the new object matches an exact rule;
- the new object matches more than one exact rule, indicating the same decision class;
- the new object matches an approximate rule or more than one rule, indicating different decision classes; or
- the new object does not match any decision rule.

In this way, rough set analysis can also be used as a tool for conditional transferability of results from some case study to a new situation. The mathematics of rough set is rather complicated, but has been properly described in the literature and will not be repeated here. We will now illustrate the relevance of rough set analysis by applying it to our comparative analysis of pesticide price elasticities.

The decisive principle in our comparative analysis is to address the effects of pesticide price policies on the *use* of pesticides. This aim guarantees a clear economic focus of investigating the possible impact of pesticide policies. This leads in turn also to a clear difference with meta-analytic applications carried out in the field of the *natural sciences* such as biology, physics, or chemistry.

With reference to various methodological issues set out in this section, a few additional remarks are in order here. The use of pesticides will most likely vary largely between different countries, between different sectors, and between different time periods—caused, e.g., by technological progress and market changes. Therefore, it will be necessary to incorporate moderator variables accounting for the above mentioned variations. Clearly, the outcome to be explained is unambiguous in the sense that there is only one single indicator, i.e., the price elasticity of farmers' demand for pesticides, although there may be variations in definition across different elasticity studies. Furthermore, it ought to be mentioned that the number of existing studies on pesticide price elasticities is low. This means a severe limitation to our comparative analysis, as the criteria for the selection of studies in our meta-analytic approach are primarily limited to the existing elasticity studies. And finally, concerning the meta-analysis itself, all variables included in our meta-case study are of a discrete nature, and hence rough set analysis is—next to a traditional comparative literary approach—particularly suited for quantitative analysis of such variables.

3. A LITERATURE SEARCH ON PESTICIDE PRICE ELASTICITIES

The research on the impacts of changing pesticide prices on its use consists mainly of studies using damage-threshold models, econometric models, and linear programming models. In most of these studies pesticides are included as one of the production factors. Sensitivity analyses regarding the specific impacts of changing pesticide price on pesticide use are, therefore, partial analyses of broader models.

Damage-threshold models indicate the level of crop disease at which it becomes cost-effective to apply a treatment by pesticides. To be able to specify the damage threshold, the product prices and the cost of pesticides must be known. These models can be used to assist farm management.

Econometric approaches use models composed of quantified relationships between the key variables of interest (the price of pesticides, demand for pesticides, demand for other variable inputs like energy, seed, etc., supply of output, and demand for capital, etc.). Production behavior of farm households is often modeled starting from neoclassical theory. Therefore, all relationships within these models have a causal interpretation. The models are in most cases quantified by applying statistical techniques to historical data [26]. Their advantage is thus that they represent observed behavior. Their disadvantage is that new biotechnology techniques cannot be incorporated in a straightforward way.

Linear programming models are frequently employed to simulate the economic decision-making process at the micro or farm level. Environmental aspects of agricultural production can in most cases also be incorporated in this method in two respects. First, linear programming provides an explicit and efficient optimum-seeking procedure (maximizing the gross farm result). Second, once the program has been formulated, the results obtained by changing the variables of interest can be rapidly calculated. For the investigation of pesticide price regulation effects, the individual farm is a good starting point, because it is at this level that the actual decisions are made about cropping patterns, production intensities, use of input factors, etc. The major advantage of using linear programming models for environmental economic research is that several activities producing the same product can be considered at the same time, expressed by various cropping variants in the models concerned. The environmental impacts are represented in the technical coefficients of the production process in the linear programming matrix. The objective function includes usually financial results reflected in gross margin figures. With a range of cropping variants, it is then possible to investigate the effects of levy systems on pesticide use.

In this context, a major source of reference was offered by a study of Oskam et al. [26] in which a review has taken place of several recent economic and econometric analyses of possible pesticide price policies in four EC countries, along with some other separate studies. In total thirteen studies were found which yielded empirical evidence on the price elasticity of the demand for pesticides. This may mean a bias toward North-European studies, but since pesticides are a major concern in the intensive North-European agriculture, the comparative meta-analytic investigation is still warranted as it may pinpoint key factors which might be further tested in a broader set of more representative studies (by consulting e.g., World Agricultural Economics or Rural Sociology Abstracts). Some studies which provided information on the relation between levies on pesticides and the use of pesticides, did unfortunately not express these relationships in terms of price elasticities (in particular, the studies of Jong [27] and Wossink [28]). We will first give concise relevant details on each of these investigations classified on a country basis.

1. Sweden

Damage-threshold models were used by the Kungliga Skogs- och Lantbruksakademien [29] to identify damage thresholds for various crops, fungus diseases, and insect infestations. Calculations were made on the basis of data gathered from a large number of experimental fields at different locations in Sweden where crop protection experiments were undertaken and data were available on a large number of diseases, infestations, and crops. Using damage-threshold models it was examined whether or not pest control for a certain crop/disease combination was economically feasible for these areas. To this aim quantitative scenarios were constructed with different quotas on pesticides. It was assumed that producers would receive compensatory payments for income losses incurred from the imposition of pesticide quotas. The compensation would take place by adjusting product prices, so that the result would be an increase in domestic prices for farm products. An interregional, spatial linear programming model of Swedish food production was next used to assess the aggregated economic effects of reduced pesticide use. Finally, from this analysis the sensitivity of pesticide use to price change was derived by assuming that imposing a levy, which is equivalent to the value of the additional revenue obtained by additional treatment, would lead to the targeted reductions in pesticide use.

2. Denmark

In a study of Dubgaard [30] also an ad-hoc damage-threshold model was used to run simulations, while the results were interpreted on an aggregated level. Data were collected from experimental fields throughout Denmark, similar to the above described research done by Kungliga Skogs- och Lantbruksakademien [29]. To determine induced technological change in the model, estimates made by experts in crop protection were used.

3. Denmark

The same study as described under (2) used also econometric methods in order to investigate the observed behavior of farmers for obtaining reference material for empirical findings [30]. For that purpose, a regression analysis was carried out based on annual Danish data on prices and pesticide use for the period 1971-1985. In the regression equations the average number of treatments per hectare were reflected as a function of index prices of pesticides and a trend variable.

4. Germany

In a micro-oriented study of Schulte, the effects of a reduced application of fertilizers and pesticides on farmers' incomes were investigated [31]. Among the instruments taken into consideration was a tax on fungicides. Linear programming models were used for five farms, differentiating between factors such as farm size, region, etc. The farms investigated were three arable farms, an intensive livestock farm, and a mixed farm.

5. The Netherlands

In a study of Elhorst an econometric approach was used, viz. an agricultural household production model, in which the neoclassical theory of producer and consumer behavior was incorporated [32]. Price sensitivities to fertilizers, pesticides, and other variable inputs were investigated in Dutch arable farming. These inputs were combined under the heading of "non-factor inputs." Data were used for the period 1980-1987.

6. The Netherlands

The study by Oskam contains results on the use of fertilizers and pesticides in Dutch arable farming, using data from a stratified sample of arable farms for the period 1970-1987 [33]. A distinction was made between specialized farms, where more than 80 percent of the land is reserved for arable crops including feed crops, and farms where 50 to 80 percent is reserved for arable farming. This interesting study revealed various explanatory factors of the use of pesticides. Among these were the cropping plan of the farms and the quantity and quality of crops. Price sensitivities of the different crops to the price of pesticides were first determined by estimating the volume of pesticide use per crop per year. By means of regression analysis, these estimates were then used to determine to what extent pesticide use is increasing. In addition, the degree to which pesticide use is influenced by the prices of crops and pesticides was investigated. The resulting price elasticities are to be regarded as medium-term results, since the specified relationship between pesticide use and pesticide price incorporates short-term as well as long-term effects.

7. The Netherlands

In another Dutch study, by Houwen, the aim was to assess the effects of the developments in the EC agricultural policy and the strengthening of the environmental policy on arable farms on a regional basis in the Netherlands [34]. The study used a linear programming model on a micro level, based on environmental-economic modeling. In this study no explicit values were assessed for pesticide price elasticities, but it is possible to infer an approximate value of the price elasticity of the farmers' use of pesticides out of scenarios of various price changes.

8. The United States

In a study of Chambers and Lichtenberg, an econometric model was used to estimate pest damage [35]. The basis was an econometric framework for estimating pesticide technologies that recognizes the peculiar role pesticides play as damage-control agents. A multi-output version of such a basic model was developed and the generalized model's dual representation was derived, which was conditionally additive in the prices of abatement activities and other prices. The econometric procedure for estimating the dual technology (including the estimation of the price elasticity of pesticide demand) was applied to an aggregate time-series data set for the entire U.S. agricultural production sector for the period 1949-1990. Three separate econometric estimation procedures were used: an exponential model, a logistic model, and a generalized Leontief model, providing three different estimates of pesticide price elasticity.

9. The Netherlands

De Jong used an environmental-economic linear programming model on a micro level in order to investigate the necessary level of levies of pesticides to achieve the reduction goals of the Dutch multi-year crop protection plan [27]. The impacts of pesticide levies on the environment and the income of farmers were investigated. Representative models of large farms were formulated for four specific Dutch agricultural regions, while two representative models of small farms were selected, resulting in a total of six different models of agricultural farms. To obtain data on a national level, the totals of the six types of linear programming models were aggregated, representing altogether arable farming in the Netherlands. Unfortunately, the study did not give explicit values for pesticide use elasticities, although a quantitive assessment of farmers' change in pesticide use can be derived from the data. However, initial prices are not known, so that this lack of information makes the results hardly usable for our analysis.

10. The Netherlands

The study of Oskam et al. assessed the influence of pesticide prices on the demand for pesticides in Dutch arable farming and in Dutch horticulture by using econometric models for these two sectors [26]. The models assumed short-term profit-maximizing behavior with respect to variable input factors. Both models were aggregate models, covering respectively the Dutch arable and horticultural sector as a whole. They were quantified by using data on these sectors for the period 1970-1988. Short-term elasticities (1 year) were assessed as well as medium-term (3 years) and long-term (10 years) elasticities. It was assumed that in the medium term the amounts of capital goods will also partially adjust to a change in the pesticide price, influencing in turn pesticide demand. In the long run, it was assumed that the amounts of capital goods would fully adapt to changes in pesticide prices.

11. The Netherlands

An econometric approach to investigate pesticides' price elasticities was also used by Aaltink [36]. He based his model on a profit function as well as a cost function (the latter assumes that the amount of production is fixed in the short term). The same data set was used for quantifying both models, but prices and profits were normalized by the price of the other variable input for the case of the model using the profit function. Both approaches were used to assess short-term as well as long-term elasticities; both elasticity values appeared to be more or less equal.

12. The Netherlands

The study of Wossink used a micro-level linear programming model for the evaluation of various scenario developments regarding changing price and policy conditions for the arable farming sector [28]. The computations performed with the model enabled to assess the changes in farm organization resulting from six scenarios. These scenarios represented combinations of technical developments, environmental regulations, and different forms of price and market policies. The relevant scenario for the assessment of the impact of pesticide levies was calculated for the year 2000, implying long-term elasticities. The model was quantified by applying it to a series of eight representative farm types in a specific region in the Netherlands. These were selected by means of a cluster analysis of specialized arable farms in this region. Like in the studies of Houwen [34] and de Jong [27], no explicit values were assessed for pesticide price elasticities, but it is possible to infer approximate quantitative results about the farmers' change of use of pesticides in the case of different levy scenarios, by taking the average relative changes in pesticide use in order to approximate the elasticity concerned.

13. The Philippines

Finally, a study by Antle and Pingali consisted of an econometric approach to investigate the impacts of pesticide use on farmer health by means of a health model and, subsequently, the impacts of farmer health on farm productivity by means of a production model [37]. These models were then combined in a simulation analysis to investigate the health and productivity tradeoffs implied by a policy to restrict the use of pesticides, including the option of a price regulation for insecticides and herbicides. This simulation analysis provided estimates of the effect of a tax on these pesticides on their use. A distinction was made between the direct regulating effect of pesticide price policy on farm productivity and an indirect effect, through the impact on health. Regarding this indirect effect, this study thus differs from the other econometric studies, which do not account for health effects. However, these health effects are expected to be less important in developed countries because of more advanced spraying materials and stronger legal health prescriptions regarding the handling of pesticides. The study concentrated on the rice producing sector in two regions of the Philippines. The empirical base for the estimation of the production model contained data from a farm-level survey in both regions, with a total of 126 observations. The empirical base for the estimation of the health model included data on pesticide handling and the health of 113 farmers out of a subset of the above sample, which were monitored in the two regions respectively during the period 1987-1990 and 1988-1991.

The results of the various case studies are summarized in a tabular form in Table 1. Features of these thirteen cases are included. The publication of research findings shows also much variation across various channels ranging from informal (grey) to the formal refereed publication channels. As shown in a recent study, different publication channels may show different results [38]. There is also much variation in terms of the package of pesticides considered and of the levies envisaged. Also the models used show quite some diversity. This makes it once more difficult to come up with an unambiguous comparative research finding, an observation which justifies the use of meta-analytic methods.

Finally, the estimated values of the price elasticities show also some variation, although they seem to cluster around the values –0.2 to –0.4. There are clearly a few outliers, within a minimum of almost 0 and a maximum of –1.5. But most other values offer a reasonable similarity, despite the enormous variety in background variables and moderator variables.

Having drawn now our first indicative conclusions, we will in the next section apply rough set analysis in order to identify more precisely the successive conditions under which ranges of values of price elasticities of pesticide use are realized.

4. APPLICATION OF ROUGH SET ANALYSIS TO PESTICIDE PRICE POLICY STUDIES

At first glance, the results of the above review of pesticide price elasticities seem to exhibit quite some diversity. The estimations of elasticity values range from practically 0 (–0.05) to a level of –1.53. What we are interested in now, are the factors that cause these variations in the estimations. The number of studies (13) is, however, not sufficient to use any conventional statistical method to investigate the importance of different factors. From this perspective, a non-probabilistic qualitative method like rough set analysis seems to be well suited for dealing with this problem. Therefore, we will now apply this method to the data presented in Table 1. The following set of hypotheses will be used for the selection of the potentially explanatory factors.

1. Country

It may be hypothesized that elasticities may vary between different countries. In fact, this might be the strongest determinant of a given pesticide price elasticity. Various reasons can be thought of for explaining this. First, looking at the natural situation, the type and quality of agricultural soils differ between various countries. Similar crops in different countries may have different growing characteristics. This would mean that the marginal impacts of using pesticides may differ, resulting in different levels of use. Second, agricultural policies may differ between countries, e.g., in the area of legal quality requirements to agricultural crops. Such requirements are not only dependent on the country's own policy but also on policies of countries to which products are exported. Such policies place different levels of restrictions on agricultural production, through which demand of pesticides may not have a monotone relationship with pesticide costs, but may have a jump-wise relationship, specific for each country. Third, the influence of farmers' income should be taken into consideration. It is expected that pesticide use may be lower as the average income of farmers is lower. It would be important here to make a distinction between developed countries and Third World countries.

2. Data Collection Period

A second important factor may be the time period over which the data for the different studies have been collected. The length of these time periods can be regarded as a proxy for the quantity (and thus, the representativeness) of the data set used (if data are collected on a yearly basis). Secondly, the initial point in time is also relevant, since price elasticities will vary over time. Facing the first (1949) and last year (1991) of data collection in our data set, there may be of course large fluctuations between the different studies caused by socioeconomic and technical developments in the years after the Second World War.

3. Year of Publication

A factor which should also be taken into consideration is the year of publication on the result, which may be a good indicator for the year in which the research was carried out. This aspect may be important in the sense that developments in data analysis techniques and improvements of the quality of econometric models over time may reduce the level of errors in the research results due to uncertainty on the level of modeling [25]. For a discussion of such uncertainty aspects we refer to [25].

Table 1. Overview of Case Studies on Price Elasticities of Pesticide Use

Country, Author, and Year	Publication Channel	Type of Agriculture	Type of Pesticide	Levy/Effect	Price Elasticity	Model Used
1. Sweden Kungliga Skogs- och Lantbruksakademien 1989	Research report	Arable farming Livestock	All	1000 Kroner/ha leads to reduction of 33% in area sprayed	*Approx. −0.2*	LP model of agricultural sector at macro level (interregional and spatial)
2. Denmark Dubgaard 1991	Journal (C)	Mixed	All	100 Danish Kroner/standard dose*ha (or 60% average price increase of pesticides) leads to reduction in use of 20-25%; 200 Danish Kroner/ standard dose*ha (or 120% average price increase of pesticides) leads to reduction in use of 40-45%	*−0.2/−0.3*	Damage-threshold model combined with crop protection expert opinion
3. Denmark Dubgaard 1991	Research report	Mixed	Herbicides (A) Fungicides/ insecticides (B)		*−0.69* (A) *−0.81* (B)	Econometric model
4. Germany Schulte 1983	Ph.D. Dissertation	Mixed (5 farms)	Fungicides		*−0.5*	LP model
5. Netherlands Elhorst 1990	Research report	Arable farming	All (including fertilizers)		*−0.29* (probably under-estimation; see [26])	Agricultural household production model with distinction between factor inputs and non-factor inputs (the latter comprising pesticides)

6. Netherlands Oskam 1992	Research report	Arable farming (stratified sample: distinction between farms with arable crops on > 80% and 50-80% of land use, respectively)	All (including fertilizers)		*−0.4/−0.5*	Regression analysis
7. Netherlands Houwen 1993	Research report	Arable farming	All	Price increases of Dfl 10, 25, and 100 per kg of active ingredients (a.i.) lead respectively to no change in average use (remains 7.76 kg a.i./ha), a reduction to 5.24 kg a.i./ha and to 3.25 kg a.i./ha	*Approx. −0.22*	LP model (micro-level)
8. U.S.A. Chambers and Lichtenberg 1994	Journal (B)	U.S. agricultural production sector (Mixed)	All		*−1.53104* (A) *−1.50587* (B) *−0.04966* (C)	Econometric macro models: Exponential model (A) Logistic model (B) Generalized Leontief model (C)
9. Netherlands Jong 1991	M.A. Thesis	Arable farming	All		Unknown	LP model (micro-level)

Table 1. (Cont'd.)

Country, Author, and Year	Publication Channel	Type of Agriculture	Type of Pesticide	Levy/Effect	Price Elasticity	Model Used
10. Netherlands Oskam et al. 1992	Research report	Arable farming (A) Horticulture (B)	All		*For A and B respectively:* • *short term −0.21/−0.25* • *medium term −0.22/−0.26* • *long term −0.22/−0.29*	Econometric model
11. Netherlands Aaltink 1992	M.A. Thesis	Arable farming	All		• *short/long term −0.39* (A) • *short/long term −0.13* (B)	Econometric model: Profit function approach (A) Cost function approach (B)
12. Netherlands Wossink 1993	Ph.D. Dissertation	Arable farming	All		*For herbicides/ insecticides respectively −0.76/−0.52*	LP model (micro level) Long-term elasticities (year 2000)
13. Philippines Antle and Pingali 1994	Journal (B)	Arable farming (rice production)	Herbicides/ insecticides	Uniform levy on herbicides/insecticides	*−0.27 in case of both herbicides and insecticides*	Econometric analysis: simulation analysis with production model and health model

4. Publication Channel

It may be hypothesized that the quality of research is related to the channel of publishing it. In this sense, it is useful to distinguish between publications on different scientific levels, e.g., M.A. thesis, Ph.D. dissertation, contribution to a book or journal article. Furthermore, there may be a difference between "independent" (non-commercial) research and "dependent" (commercial) research. Clearly, in principle, such differences should of course not influence the results, but practice may be different [38]. It is an interesting property of meta-analysis, however, that it is also able to take into account such interesting issues which go beyond the characteristics of the research itself.

5. Type of Agriculture

Pesticide price elasticities differ considerably between different types of agriculture. Each type of agriculture has its specific crop species, by which available alternatives for crop protection are specific to each type of agriculture. It is to be expected that the fewer alternatives there are, the smaller the price elasticity will be. Furthermore, each type of cropping activity has its specific share of pesticide costs in total costs. If this ratio is high, a rise in pesticide costs will have a relatively large impact on total costs, probably resulting in a relatively high price elasticity.

6. Pesticide Type

It is to be expected that cost elasticities differ among different types of pesticides. This is explained by the different natures of plagues occurring in agricultural activities. The demand of pesticides against plagues which would cause a total destruction of harvest is probably totally price-inelastic. However, specific plagues may ravage a variety of crops in different manners. Therefore, it is difficult to assign to each type of pesticide a certain level that indicates its potential to prevent or reduce crop damage. Nevertheless, we may use pesticide type as an explanatory factor for price elasticity.

7. Levy

We expect that, in conformity with micro-economic theory, the price elasticity varies along with the level of the respective price. This means that at forehand in empirical studies using real-world data, a uniformly measured elasticity does not exist across countries which have different pesticide price levels. Furthermore, in this context we may expect variations in results between modeling studies on the one hand and stated and revealed behavior studies on the other hand. For example, most modeling studies do not account for the above non-uniformity, while revealed behavior studies focus on a specific (real) initial price level.

8. Model

A clear factor of difference between various studies is the type of model used to estimate cost elasticities. This factor is common to all case studies of meta-analysis. In this case we may make a distinction between linear programming techniques and econometric methods to model farm activity. It might also be possible to make a further distinction into threshold models. In almost all studies in our sample, pesticides are included as one of the production factors, while the aims of the studies are broader than just predicting the impacts of changes in factor prices on farmer productivity or profit.

For the application of rough set analysis, we have coded the above list of relevant variables as presented in Table 2. The flexibility in choosing classes of variables provided a way of interactive experimenting with the data. In Table 2 four alternative codifications are presented, as these are used in four respective rounds of a rough set analysis.

The application of the above sets of classifications of data in a rough set context resulted in a set of nine "reducts" (or minimal sets), shown in Table 3. A reduct is a reduced set of attributes, which provides the same quality of classification of the explained variable as the original set of attributes. This means that if there are only few possibilities for such a set of attributes, then the information has relatively much predictive power [21]. This relatively large number of nine reducts in our case was not very satisfactory. However, the core set of attributes (i.e., the intersection of all reducts) consisted of the single variable of the type of agriculture, which is revealing in terms of the relative explanatory power of one variable in relation to the other ones.

The unsatisfactory high number of reducts in the first round of analysis made us decide to make some changes in our classification. This has led to a sensitivity analysis on the classification; this has led to three additional rounds of sensitivity analysis on the various codes. Therefore, in a second round, we changed the classification of the country variable into only two classes: on the one hand developed countries, and on the other hand developing countries. This latter distinction is meaningful with regard to the influence (or restriction) of the farmers' income on the use of pesticides. Running next again a rough set analysis on the adjusted data matrix led to a smaller set of reducts (5; see Table 3), while the core set consisted this time of two variables: type of agriculture and type of pesticides.

After this more satisfactory execution of the analysis, an important conclusion is that across the studies from the literature search, there are two key variables that have a relatively strong impact on the use of pesticides (type of agriculture and type of pesticides). They are both very plausible factors, since both are directly related to farm operation, while the other variables considered are more general in nature, as they focus on research characteristics.

In a third round of our analysis, we omitted next the following variables: year of publication, publication channel, and the levy variable. The classifications of

Table 2. Coding of Attributes in Four Rounds of Analysis (R1-R4)

	R1	R2	R3	R4
A1. Country				
Sweden	1	1	1	1
Denmark	2	1	1	2
Germany	3	1	1	3
Netherlands	4	1	1	4
USA	5	1	1	5
Philippines	6	2	2	6
A2. Data period				
1971-1989	1	1	1	1
1970-1987	1	1	1	1
1970-1988	1	1	1	1
1980-1987	2	2	2	2
1949-1990	4	4	4	4
1987-1991	3	3	3	3
Unknown	5	5	5	5
A3. Year of publication				
Until 1990	1	1	—	—
After 1990	2	2		
A4. Publication channel				
Research report	1	1	—	—
Journal	2	2		
Ph.D. Dissertation	3	3		
M.A. Thesis	4	4		
A5. Type of agriculture				
Arable	1	1	1	1
Mixed	2	2	2	2
A6. Pesticide type				
All	1	1	1	1
All incl. fertilizers	1	1	1	1
Fungicides	2	2	2	2
Herbi/insecticides	3	3	3	3
Fungi/insecticides	3	3	3	3
Herbicides	4	4	4	4
Insecticides	5	5	5	5
A7. Levy				
Given levy	1	1	—	—
No given levy	2	2		
A8. Model				
Linear programming	1	1	1	1
Econometric	2	2	2	2
Price Elasticity				
0 to −1.9	1	1	1	1
−1.9 to −0.3	2	2	2	2
−0.3 to −0.6	3	3	3	3
−0.6 to −1	4	4	4	4
−1 to −infinity	5	5	5	5

Notes: Ri denotes round i, i = 1, 2, 3, 4. "—" means that the respective variable is not included.

Table 3. Reducts and Cores

	R1	R2	R3	R4
Reducts (or minimal sets)	1. {4,5,6,8} 2. {2,5,6,8} 3. {1,4,5,8} 4. {1,2,5,7,8} 5. {3,4,5,6,7} 6. {2,5,6,7} 7. {1,3,4,5,7} 8. {1,2,4,5} 9. {2,4,5,6}	1. {4,5,6,8} 2. {2,5,6,8} 3. {3,4,5,6,7} 4. {2,5,6,7} 5. {2,4,5,6}	1. {2,5,6,8}	1. {2,5,6,8}
Core set	A5	A5, A6	A2, A5, A6, A8	A2, A5, A6, A8
Accuracy of classification	0.7778	0.7778	0.7778	0.7778
Quality of classification	0.8750	0.8750	0.8750	0.8750

the other variables were retained from the second round of analysis. The results of this round were rather satisfactory: it led to only one reduct of four variables (see Table 3) which were in this case equal to the core set. In addition to the type of agriculture and the type of pesticide, the core set consisted now also of the data period variable and the model type variable. Apparently, the two attributes of the set at hand which are related to the basic methodological and empirical differences across the studies, have (in conjunction with variables defining the type of agricultural operation) the strongest explanatory power for the variance in research outcomes. With regard to the data period variable, it is however not clear which of its dimensions (the length of the data collection period or the date of this period) cause this variation.

Finally, in a last round of analysis we tested the robustness of the above results. We did so by taking into consideration the same variables as in the third round of analysis. However, we changed the classification of the country variable to its original coding (each country separately coded) to investigate whether this variable would consistently fall out of the core set. This round of analysis led to exactly the same reduct as in the third round. We may therefore draw the conclusion that—in comparison with other possible explanatory factors—price elasticities of pesticide demand do not show large variations that can be explained by geographical factors. This is in contrast with the intuitive consideration that factors like farmers' income and soil types play relatively important roles.

In addition to the investigation of the explanatory power of the various variables, it is also interesting to look at the direction in which the investigated variables impact on research outcomes on price elasticities of pesticide demand. Therefore, we should look at the set of "decision rules." These can be expressed as logical "if . . . , then . . ." statements which can be derived from the information table used. They can be used for predictions by matching the descriptions of cases to be predicted with the decision rules.

This set of rules, based on the attributes of the core set of the four attributes which have appeared to be powerful, turn out to be the same in each of the four classification rounds. These rules are shown in Table 4.

We can now draw some quite interesting conclusions from this result. First, it appears that when the period of data collection is longer, the study leads to a relatively higher price elasticity. A data period of ten years leads to a significantly lower elasticity than a data collection period of forty years. This is a plausible result since, in the long run, price elasticity of pesticide demand is larger than in the short run because of the long-term adaptive behavior and flexibility of farmers (the Le Chatelier principle; see [39]). It should be noted, however, that this statement would need some further research, as there might be a difference between a long period of observation and the time span used in the model specification. Second, it seems that when a farm uses the full range of pesticides (herbicides, fungicides, insecticides), it is less price-elastic than when it uses a lower number of pesticide types. This risk dispersion result may be explained by a partial substitutability between different pesticide options, but also this result calls for some caution, as it is not always clear from the studies that

Table 4. Set of Decision Rules, Based on the Core Set of Attributes A2, A5, A6, and A8, Generated for All Rounds of Analysis

Number	Rule (Attributes)	Class (Price Elasticities)
1	A2 = 5 and A5 = 1 and A6 = 1 and A8 = 2	1 or 3 (non-deterministic rule)
2	A2 = 2 and A6 = 1	2
3	A2 = 3 and A6 = 3	2
4	A2 = 5 and A5 = 2 and A6 = 1	2
5	A2 = 1 and A5 = 2 and A6 = 1	2
6	A2 = 5 and A5 = 1 and A6 = 1 and A8 = 1	2
7	A6 = 2	3
8	A2 = 1 and A5 = 1 and A6 = 1	3
9	A6 = 4	4
10	A6 = 5	4
11	A2 = 1 and A6 = 3	4
12	A2 = 4	5

farmers are only using one type of pesticide, when the research focuses on that pesticide [40].

In the cases of the other two variables (type of agriculture and type of research model), no unambiguous inferences can be drawn on their influence on the level of price elasticities from the set of decision rules in our rough set analysis.

5. CONCLUSIONS

Existing scientific evidence on the order of magnitude of farmers' price elasticities of pesticide demand is fragmented. In this study we have collected several studies which have tried to assess this elasticity. The results of the various studies appear to fluctuate between an elasticity of almost 0 and –1.5. From a policy perspective, it is very important to have more profound insight into the factors which cause the differences in price sensitivity in order to be able to identify optimal pest control policies. By using meta-analysis, we have tried to detect the most important factors that cause the variance between the research outcomes. In this way, relevant policy information could be extracted on differences in sensitivity between various farming segments (in terms of type of agriculture, type of pesticides used, etc.), as well as usable information for further research in this area. Some intuitive expectations were more or less confirmed by the findings of our analysis. It appeared that in conjunction with variables defining the type of agricultural operation (i.e., type of agriculture and type of pesticides used), variables that define the basic methodological and empirical differences across the different studies have the strongest explanatory power for the variance in research outcomes.

Furthermore, the results confirmed also our prior expectation that in the long run the price elasticity of pesticide demand is higher than in the short run, because of the likely long-term adaptive behavior of farmers. Besides, our findings suggest that when a farm uses the full range of pesticides (herbicides, fungicides, insecticides), it is less price-elastic than when it uses a lower number of pesticide types. This suggests that the level of sustainability or "packaging" between different pesticide options may be a critical factor.

Our meta-analytic exploration of a sample of price elasticity studies suggests that—with some variation—levies may be a fairly effective tool to reduce the use of pesticides in a sustainable agricultural policy. The above empirical results have also clearly demonstrated the usefulness of meta-analysis in exploratory economic research on policy effectiveness in the agricultural sector. Clearly, the set of studies could have been broader, and hence more representative, but the first results point at interesting results which might be tested by further in-depth case study work.

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Direct reprint requests to:

Peter Nijkamp
Department of Economics
Free University
De Boelelaan 1105
1081 HV Amsterdam
The Netherlands